

ACTION HISTORY OF RTI REQUEST No.WLIOI/R/E/22/00007

Applicant Name Tarika Jain

Text of Application Please provide me with the following information/documents: Any guidelines for prioritization of Invasive Alien Plants in India for their better management The impact study of invasive alien plant species in aquatic ecosystem (marine and inland) Copies of research outputs, reports of program/projects, schemes related to management of invasive plant species produced in the last 5 years Details of funds received and utilized by the WII for research and management of invasive plant species in the last 10 financial years.

Reply of Application Kindly see the attached letter. It is to inform you that Annexure-I was shared through email, bounced back may be an issue with the big size of Annexure-I. Hence same is uploaded in Google Drive and the link has been shared through email with a request to kindly download the data within 15 days of receipt of this email.

SN.	Action Taken	Date of Action	Action Taken By	Remarks
1	RTI REQUEST RECEIVED	24/02/2022	Nodal Officer	
2	REQUEST FORWARDED TO CPIO	25/02/2022	Nodal Officer	Forwarded to CPIO(s) : (1) Monali Sen
3	REQUEST DISPOSED OF	14/03/2022	Monali Sen-(CPIO)	

[Print](#)



No. WII/RTI/CPIO/2021-22 (Qtr-IV)/91

Date: 11th March, 2022

To,

Ms. Tarika Jain
D-359, Lower Ground Floor,
Defence Colony,
New Delhi, Pin:110024
Email: tarika.jain@vidhilegalpolicy.in

Sub.: Information under RTI Act, 2005-reg.

Ref.: Your Online RTI No. WLIOI/R/E/22/00007 dated 24/02/2022

Madam,

Please refer to your application cited above under RTI Act, 2005. In this context, point-wise response to your queries is given below:

Information Sought under RTI	Reply
Please provide me with the following information/documents: Any guidelines for prioritization of Invasive Alien Plants in India for their better management. The impact study of invasive alien plant species in aquatic ecosystem (marine and inland). Copies of research outputs, reports of program/projects, schemes related to management of invasive plant species produced in the last 5 years. Details of funds received and utilized by the WII for research and management of invasive plant species in the last 10 financial years.	See the attached Annexure-I.

If you are not satisfied with the aforesaid reply, you may appeal to the Dr. Dhananjai Mohan, Director & Appellate Authority, Wildlife Institute of India, Post Box 18, Chandrabani, Dehradun – 248 001, Ph. 0135-2640910.

Thanking you,

Yours faithfully,

(Dr. Monali Sen, IFS)
N.O. & CPIO (RTI)

Details of project/funds received by WII

Title of the Project: Ecological impacts of major invasive alien plants (IAPs) on native flora in Rajaji Tiger Reserve, Uttarakhand

Total Budget : 25,80,324 INR

Funding agency: DST-SERB (Science and Engineering Research Board)

Project No : CRG/2019/001077

Institute Name : Wildlife Institute of India (WII)

Project Start Date : 14-Jul-20

Duration : 36 months

Project Completion Date : 13-Jul-23

Status : Ongoing

Prerati Sen
INFORMATION PROVIDED
UNDER RTI

PhD Thesis from WII

1. Mungi, N.A. (2021). Modeling plant invasions in tropical forests of India. PhD Thesis submitted to Forest Research Institute, (Deemed to be) University, Dehradun.

2. Chaudhary A., (2022). Distribution of major Alien Invasive Plants and Impact Assessment of *Ageratina adenophora* (Spreng.) K. & R. in Kailash Sacred Landscape, Uttarakhand. PhD Thesis submitted to Forest Research Institute, (Deemed to be) University, Dehradun.

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*Identifying knowledge gaps in the research
and management of invasive species in
India*

**Ninad Avinash Mungi, Monica Kaushik,
Nitya Prakash Mohanty, Rajat Rastogi,
J. Antony Johnson & Qamar Qureshi**

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Identifying knowledge gaps in the research and management of invasive species in India

Ninad Avinash Mungi¹ · Monica Kaushik¹ · Nitya Prakash Mohanty² · Rajat Rastogi¹ · J. Antony Johnson¹ · Qamar Qureshi¹

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Abstract

India, a megadiverse tropical country is grappling with the issue of biological invasions. As a signatory to the Convention on Biological Diversity, India is committed for managing its major biological invasions by 2020. Lack of prioritization of invasive species for control and management is the biggest hurdle for achieving this commitment. We reviewed 21 High Concern Invasive Species (HiCIS) across four major ecosystems (terrestrial mainland, island, freshwater, and marine) in India, utilizing the prioritization framework for understanding the existing knowledge and gaps. We reviewed the existing peer-reviewed and grey literature on HiCIS for information on their ecology, impacts, and management. Prioritization framework provided “priority scores” and “confidence scores” to each HiCIS, where priority score comprised of the species’ ecology and its management lacunae. Confidence score represented the reliability of the priority score. We found that invasions on terrestrial mainland ecosystem in India are the most studied invasions followed by freshwater, island, and marine ecosystem. Priority score of a given HiCIS was positively correlated with its impacts on biodiversity ($R = 0.63$), physical environment ($R = 0.70$), and ecosystem services ($R = 0.60$). This correlation supports scientific focus on deleterious species. The study also indicates policies and guidelines in place for management of invasions as a part of a larger scheme or Legal Act, resulting in their obscurity to the managers, and hindering management of HiCIS. This quantitative synthesis provides a model framework for countries struggling with channelizing management efforts to an overwhelmingly large number of invasive species.

Keywords Conservation policy · India · Invasive species · Prioritization

Introduction

Human-induced biological invasions have homogenized the global biota and irreversibly modified many native ecosystems (Ellis 2011; Simberloff et al. 2013). It has threatened the ecological integrity of landscapes by affecting key processes,

leading to local extinction of native species in some instances (Sax et al. 2002; Clavero and Garcia-Berthou 2006). Economic sectors like agriculture, timber industry, irrigation, and human healthcare are also affected due to biological invasions worldwide (Pimentel et al. 2001). Such impacts on varied sectors have severe consequences for the livelihood, ecological

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security, and economic growth of developing or underdeveloped countries (Early et al. 2016), where the knowledge on this subject is often fragmented (McGeoch et al. 2010). Managers dealing with invasive species in such countries often have limited resources to deal with multiple invasion events. Such challenges demand a logical and evidence-based framework for management of concerned species.

India is one such developing country, where invasive species pose a severe ecological threat but their management and control is limited due to lack and unequal research across diverse ecosystems. Native ecosystems in India are under a gamut of anthropogenic influences, which might facilitate invasive species (e.g. Mungi et al. 2018) and affect already threatened native species (Theoharides and Dukes 2007). The total cost of environmental and agricultural losses caused by the invasive species in India is speculated to be around 116 billion USD per year (Pimentel et al. 2001). As a result, of increasing concern on biological invasions, India included identifying and managing invasive species and their pathways as its fourth national biodiversity target (Pande and Arora 2015), in alignment with the ninth Aichi target. Non-native species in India are represented by approximately 18,000 plants, 30 mammals, 4 birds, 300 freshwater fishes, 1100 arthropods, and 18 marine species that could be potentially invasive (Ali and Pelkey 2013). However, managing all non-native species by 2020 is not practically possible. Successful invasive species management elsewhere has demonstrated the importance of species prioritization, leading to the effective allocation of resources (Lowe et al. 2000; Koehn 2004; Nel et al. 2004). Hence, selected few High Concern Invasive Species (HiCIS) with known negative impacts were focused for management through an expert panel comprising of stakeholders involved in research and management of invasive species in India (Kaushik and Mungi 2015; Mathur et al. 2015).

Prioritization based on experience or solely on expert knowledge could be biased and demands for scientific validity. This in-turn demands for systematic prioritization using available information on the ecology of invasive species and their management aspects. Prioritization is usually conducted using two frameworks 1) Evidence-Based Analytical Protocols (Morse et al. 2004; Randall et al. 2008; Brunel et al. 2010): an induction-based identification of a high concern invasive species, based on long-term observations and experiments. The major drawback of this approach is its time and resource exhaustive nature and 2) Expert-Based Evaluation Protocol (Robertson et al. 2003; Liu et al. 2010; Forsyth et al. 2012): a knowledge-based review of existing information by interviewing the experts involved in studying and managing invasive species. The major limitation of this approach is its value-driven nature and subjectivity regarding the ranking system. However, both approaches can be used in combination to overcome the limitations and improve the timely decisions and its effective outreach. Moreover, in case

of India, few invasive species have been studied and managed in almost all the landscapes and the major ecosystems (Bhagwat et al. 2012); but their results are not published or are restricted to the regional reports and practice guidelines (e.g. forest management plans). Hence, it is essential to consider this experience and grey literature in addition to peer-reviewed publications for filling the knowledge gap for robust prioritization. This process also helps to bridge the gap between managers and scientists by bringing them on the common platform for the assessment (Kumschick et al. 2012; Lach et al. 2003; Marris 2006; Mungi and Qureshi 2018). Present study relies on this combination of above-mentioned two methods. We prepared a list of HiCIS through consultation with experts and later reviewed existing knowledge (ecology, impacts, and management) on the HiCIS in India by using a prioritization framework to identify the knowledge gaps.

Method

Expert-based selection of species and criteria

We reviewed information for 21 HiCIS species shortlisted by the expert panel (Mathur et al. 2015). These species belonged to one of the four major ecosystems viz. terrestrial, freshwater, marine, and island. For each species, we reviewed published information under three modules - ecology, impacts, and management, for assigning the priority scores using the Delphi method (Robertson et al. 2003). These modules were selected to understand the invasive potential of species, magnitude of its impacts and type of management intervention used for either control or containment. Each module had multiple criteria developed by the experts involved in studying and managing invasive plants (Kaushik and Mungi 2015), which can be scored quantitatively. The ecology module had criteria evaluating species distribution, density, dispersal, dispersal agents, invasiveness, and recolonization potential. The impact module had criteria regarding species' impact on biodiversity, physical parameters, ecosystem services, and economics. The management module had criteria for controlling techniques, restoration, legislation, stakeholders, and conflict involved. In total, 21 species were evaluated for 17 criteria under three modules (Table S1).

Evidence-based review and scoring

To score the criteria, we conducted a literature search using ISI Web of Knowledge database and Google Scholar. The publication period, journal categories, and languages were not restricted. We used species name and generic synonyms (e.g., *Cassia tora* OR *Senna tora*) as the search string for finding relevant information on every species. Our study focused on

Table 1 Priority scores of High Concern Invasive Species (HiCIS) under different priority models based on their ecology, impacts, and management. Priority is depicted from red to blue (higher priority to

lower priority). Confidence score represent the quality of existing scientific knowledge for every species

Species name	Neutral model	Management model	Impact model	Ecology model	Confidence score
<i>Prosopis juliflora</i>	15.0	9.8	10.2	10.1	2.7
<i>Chromolaena odoratum</i>	12.7	8.5	8.4	8.8	2.8
<i>Mikania micrantha</i>	12.1	7.8	8.3	8.5	2.7
<i>Parthenium hysteroporus</i>	12.1	8.0	8.0	8.6	2.9
<i>Mimosa diplotricha</i>	12.1	8.1	7.9	8.5	2.8
<i>Lantana camara</i>	11.7	7.4	7.7	8.5	2.7
<i>Eichhornia crassipes</i>	11.0	7.0	7.4	7.8	2.7
<i>Clarias gariepinus</i>	10.4	7.3	6.7	7.1	2.2
<i>Kappaphycus alvarezii</i>	10.1	7.6	6.2	6.9	2.4
<i>Salmo trutta fario</i>	9.8	6.8	6.0	6.8	2.0
<i>Senna tora</i>	9.5	6.4	5.6	7.1	2.4
<i>Oreochromis mossambicus</i>	9.2	6.5	5.7	6.4	2.1
<i>Ageratina adenophora</i>	9.0	6.2	5.7	6.5	2.4
<i>Ipomoea carnea</i>	8.6	6.2	5.5	5.9	2.1
<i>Cyprinus carpio</i>	8.2	5.7	5.2	5.7	1.7
<i>Hyptis suaveolens</i>	8.2	5.8	5.0	5.9	2.2
<i>Axis axis</i>	7.5	6.0	4.9	5.0	2.0
<i>Achatina fulica</i>	6.9	6.3	4.4	4.5	2.4
<i>Ageratum conyzoides</i>	6.7	5.4	4.1	4.6	2.1
<i>Xanthium strumarium</i>	6.5	5.6	3.7	4.6	2.2
<i>Hoplobatrachus tigerinus</i>	4.7	3.9	3.0	3.1	1.5

the criteria provided in Table S1, and hence, we avoided any literature regarding phytochemical analysis, behavior, animal husbandry, disease pathology, and any study outside the political boundary of India. The criteria under the ecology and impact modules of species are usually published. However, except for a few popular invasive species, we had limited number of studies regarding their management. Hence, we collected information from managers and other practitioners in the workshop (mentioned in the acknowledgments) regarding different management techniques used across the country and the associated economics, legislation, and stakeholders involved in the process. Scoring for each criterion was either binary or ordinal (Table S1). Each criterion was scored (henceforth, 'priority score') using the degree of precise scientific knowledge or replicable and logic-based expert opinion. As a result, the priority score was higher for species with established impacts, higher distributional magnitude, inadequate information on management and policies; and vice-versa. To scale the confidence of information obtained from varying sources, we included an associated 'confidence score'. If the priority score was based on published evidence, the confidence score was 1; if based on unpublished data (i.e. grey literature) or experience, it was 0.5; and if based on extrapolative interpretation of studies, it was 0.25. Confidence scores not only represent the precision of criterion scores but also indicate the state of knowledge about each species on every aspect.

Priority models

To make all the criteria comparable after evaluating priority and confidence scores for each species, we standardized the summed priority score for each criterion by dividing it with the maximum possible score for each criterion. Based on the three modules of the criteria we developed four 'priority models' viz. neutral, management, impact, and invasiveness potential by assigning different weights to every module. Neutral model: assigning equal weight to all module; whereas, in other models, higher weight was given to the module of interest while assigning equal weight to rest of the modules. We calculated the model confidence score by summing the confidence score and dividing it by the total number of criteria in a model. The final priority score of a model was obtained by summing the weighed priority scores and its confidence for each species. This weighing scheme provides flexibility and control to the decision maker to choose priority based invasive species as per their focus and demand. In case, the stakeholders are interested in managing the invasive species with existing guidelines on management techniques and policies, management model can be used to identify such HiCIS. In another case, if decision-makers are concerned about the high impact on native species due to an invasive species, they can use the impact model.

Evaluating ecosystem priority and reasons

To identify an ecosystem that has relatively higher priority, we compared different ecosystems for the difference in priority and confidence score using Mann–Whitney U test. For this, we used the average priority and confidence scores for all the species selected under each ecosystem. Subsequently, for understanding the reasons for high priority perception, we investigated the correlation in the priority of a species and its economic and ecological aspects. For this, we correlated the overall priority score generated by the neutral model with a standardized score of all criteria (e.g. the effect on biodiversity, availability of policy for management or control, etc.) for every species using Pearson correlation and assessed its statistical significance.

Result

Out of 14 HiCIS plants, one was algae, and 13 belonged to the dicotyledonous class of angiosperm. Of the seven HiCIS animals, one was mollusc, four were fishes, one was amphibian, and one mammal. Overall, the priority score of the freshwater ecosystem was insignificantly higher ($p < 0.50$) compared to the terrestrial ecosystem (Fig. 1). However, confidence scores for the terrestrial ecosystem were significantly higher ($p < 0.004$) to the freshwater ecosystem. When assessed between terrestrial and island ecosystems, the terrestrial ecosystem had insignificantly higher priority ($p < 0.11$) and

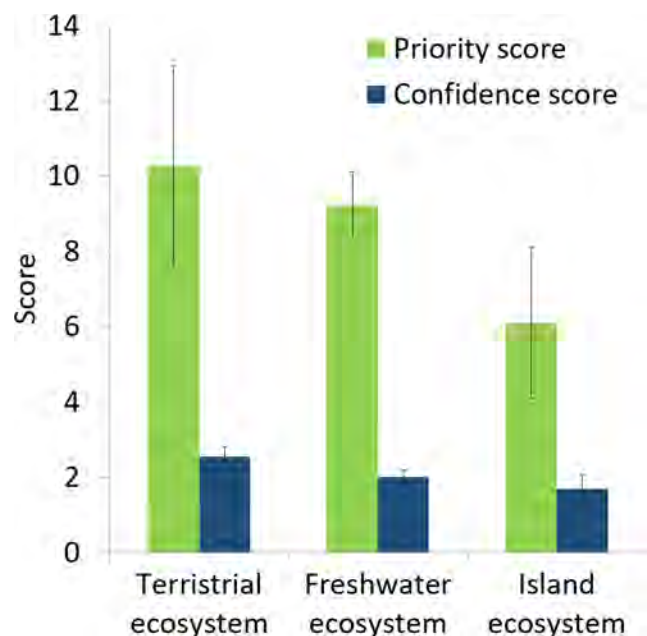


Fig. 1 Average priority and confidence scores (mean $\pm$ SE) for High Concern Invasive Species across different ecosystems (Marine ecosystem was excluded as it had only one High Concern Invasive Species, which cannot be compared using present statistics)

significantly higher confidence score ($p < 0.03$) (Fig. 1). Out of all the criteria, a significantly positive correlation with the neutral priority model was observed for criteria on impact on biodiversity ($R = 0.63$, $p < 0.005$), impact on physical environment ($R = 0.70$, $p < 0.005$), and impact on ecosystem services ($R = 0.60$, $p < 0.01$); while significantly negative relation ($R = -0.46$, $p < 0.05$) was observed with availability of legal instruments. A positive correlation was also observed in the neutral priority score and the criteria of spatial distribution ($R = 0.42$, $p < 0.08$).

Terrestrial mainland ecosystem

Terrestrial ecosystem had 11 plants and one animal identified as high concern by the experts during the workshop. Prioritization framework identified *Prosopis juliflora* as the top HiCIS priority followed by *Chromolaena odorata*; whereas, *Xanthium strumarium* and *Ageratum conyzoides* gained the least priority across all priority models (Table 1). *Parthenium hysterophorus* was the species with highest confidence score across the ecosystems; while, *Xanthium strumarium*, *Ageratum conyzoides*, and *Hyptis suaveolens* were the species with least confidence in the terrestrial ecosystem (Table 1) (Fig. 2). The Giant African land snail (*Achatina fulica*) received higher priority in management weighed model and had moderate confidence score (Table 1).

Island ecosystem

Populations of the Spotted deer (*Axis axis*) and the Indian bullfrog (*Hoplobatrachus tigerinus*), occurring on the

Andaman Islands, received high priority. The Spotted deer received a higher priority (Fig. 2) and confidence score than the Indian bullfrog (Table 1), and had a higher criterion and confidence score across all priority models (Table 1). Management model for the Spotted deer received a higher score as compared to ecology and impact models. The Indian bullfrog was ranked the lowest among all species.

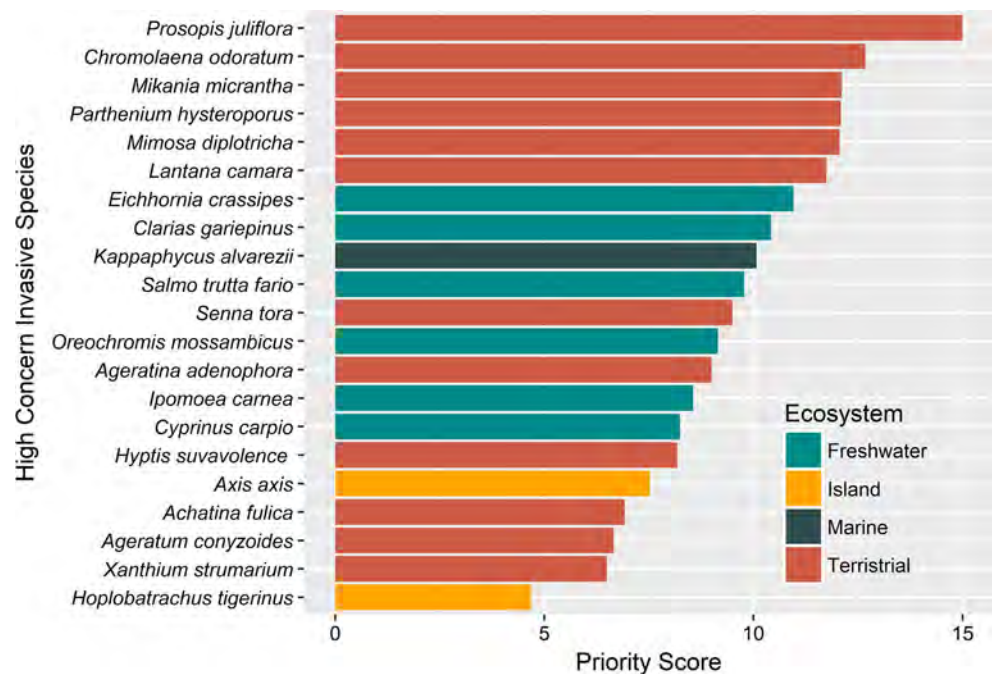
Freshwater ecosystem

This ecosystem had the second highest number of priority species after the terrestrial ecosystem. Four fishes and two plants were identified as HiCIS in the freshwater ecosystem. Prioritization framework assigned highest priority and confidence score to *Eichhornia crassipes* followed by *Clarias gariepinus* in this ecosystem. Interestingly, *Eichhornia crassipes* received lower priority in the management model, where *Clarias gariepinus* received the highest priority (Table 1). *Cyprinus carpio* had the least priority and confidence score across the models in the ecosystem followed by *Ipomoea carnea*, both with a moderate confidence score. *Oreochromis mossambicus* was a species with moderate priority and confidence score (Fig. 2).

Marine ecosystem

The sea algae *Kappaphycus alvarezii* was the sole nominated marine invasive species by the experts attending the workshop. The algae ranked seventh in the management model; else, it ranked at the ninth amongst all the HiCIS (Table 1) (Fig. 2).

Fig. 2 Priority score of High Concern Invasive Species (HiCIS) in terrestrial, freshwater, marine and island ecosystem of India



Discussion

Present study evaluated the research and management priorities for the 21 HiCIS within four major ecosystems of India. The significant relationship between priority scores and impacts of the HiCIS on native biodiversity, environment, and ecosystem services explains the importance of the impacts on biotic components for the designation of a species as HiCIS. Secondly, the negative relationship between priority scores and lacuna in legal instruments for management indicates a lack of legal policies and management guidelines for the less popular species with lower priority.

Across all the ecosystems in India, freshwater and island ecosystems received a lower confidence score reflecting the research and information gap for these ecosystems. This gap in information might be due to the limited research in these ecosystems, amidst the repeated invasion, particularly through aquaculture. Since only mechanical removal of these species is practiced in pockets of its invasion range, the priority score of these species in the management model was higher than other models. The mainland terrestrial ecosystem plant species had the highest priority scores representing significant ecological evidence, yet, paucity in their management. However, high confidence score point towards a higher degree of scientific consideration for the terrestrial ecosystem. This can also be suggestive of the bias in the conduct of research across ecosystems, since most of the conservation research is carried out for flagship species on terrestrial mainland. Island ecosystem had invasive species that are protected by the law in India. However, their presence on the islands, where they are non-native, imparts their adverse effects on the ecosystem. Although their management is perceived as a conflict with the existing law, our study revealed the presence of all amendments for managing these species, once their impacts are documented. Nomination of a single species in the marine ecosystem, although, reflects scantiness in research about marine ecosystem, but it might also be a product of underrepresentation of experts in the panel identifying the HiCIS (Mathur et al. 2015).

Similarly, previous studies have also expressed the paucity of information regarding the invasive status of fungi, bacteria, and other micro-organisms (Bebber and Gurr 2015; Mallon et al. 2015; Walsh et al. 2016). Though impacts of microscopic invasive species on the agricultural crops, pisciculture, and animal husbandry are established (Pimentel et al. 2001) but information about their status and control mechanism is either limited or unknown to many stakeholders. Due to the difference in the conservation priorities and ecological settings of these species and ecosystems, we discuss each ecosystem in detail in the supplementary information 1.

As India plans to manage the priority species by 2020, it is crucial to focus on management-based research, as invasiveness and impacts on the ecosystem are already documented. The spatial distribution of invasive species often represents invasiveness and provides an opportunity for prioritizing management. However, we observed that the information on spatial distribution for all HiCIS at optimal scale, which is important for management or understanding the spread of the species, is unavailable but crucial for prioritizing management effort. Notably, we found existing legal instruments through which a species could be declared as invasive for managing it inside/outside protected areas. However, these legal instruments and guidelines for invasive species management were part of larger legal schemes (e.g. National Forest Policy 1988, National Working Plan Code 2014, Marine Product Export Development Authority) and wildlife laws for protected area management (e.g. Wildlife (Protection) Act 1972). Given that, the lack of explicit legal scheme and guidelines for invasive species management might bring subjectivity due to differing interpretation of a given scheme by the park managers. It would be particularly true for managing invasions inside Protected Areas that are governed by strict national laws.

Nevertheless, our synthesis revealed that in certain cases, invasive species were managed under existing umbrella policies and Acts (e.g. forest policies by the state of Madhya Pradesh-2005, Maharashtra-2008, and Assam-2004). However, prior managing a species within protected area, it is mandatory to prove a species to be invasive and detrimental for the ecosystem, which in turn demands scientific research and experimentation. Hence, we disagree with the previous study (Kannan et al. 2013) that believed legal unawareness to be responsible for poor management of invasive species in India; but simultaneously, we voice our concerns regarding the lacuna of explicit schemes for declaring and managing invasive species. Amidst the limited information for evidence-based policies, present review of published records and expert knowledge can help prioritize and channelize the limited resources for imminent threats brought by the invasive species.

Acknowledgments Present study is based on the workshop on 'Management of Human – Wildlife negative interactions and Invasive species', funded by the Ministry of Environment, Forestry and Climate Change (MoEF&CC) and organized by the Wildlife Institute of India (WII). We thank Dr. V.B. Mathur (WII), Dr. G.S. Rawat (WII), Dr. B.C. Sinha (WII), Dr. Y.V. Jhala (WII), Dr. S. Sathyakumar (WII), Dr. K. Sankar, and Shri. S.S. Bist for facilitating the study and participants of the workshop for giving field inputs. We thank Dr. Hukum Singh (Forest Research Institute) and the anonymous reviewers for improving the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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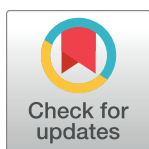
RESEARCH ARTICLE

Ageratina adenophora and *Lantana camara* in Kailash Sacred Landscape, India: Current distribution and future climatic scenarios through modeling

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Abstract

The Himalayan region is one of the global biodiversity hotspots. However, its biodiversity and ecosystems are threatened due to abiotic and biotic drivers. One of the major biotic threats to biodiversity in this region is the rapid spread of Invasive Alien Species (IAS). Natural forests and grasslands are increasingly getting infested by IAS affecting regeneration of native species and decline in availability of bio-resources. Assessing the current status of IAS and prediction of their future spread would be vital for evolving specific species management interventions. Keeping this in view, we conducted an in-depth study on two IASs, viz., *Ageratina adenophora* and *Lantana camara* in the Indian part of Kailash Sacred Landscape (KSL), Western Himalaya. Intensive field surveys were conducted to collect the presence of *A. adenophora* ($n = 567$) and *L. camara* ($n = 120$) along an altitudinal gradient between 300 and 3000 m a.s.l. We performed Principal Component Analysis to nullify the multi-collinearity effects of the environmental predictors following *MaxEnt* species distribution model in the current and future climatic scenarios for both the species. All current and future model precision (i.e., Area Under the Curve; AUC) for both species was higher than 0.81. It is predicted that under the current rate of climate change and higher emission (i.e., RCP 8.5 pathway), *A. adenophora* will spread 45.3% more than its current distribution and is likely to reach up to 3029 m a.s.l., whereas, *L. camara* will spread 29.8% more than its current distribution range and likely to reach up to 3018 m a.s.l. Our results will help in future conservation planning and participatory management of forests and grasslands in the Kailash Sacred Landscape—India.

Introduction

Invasive alien species (IAS) rank among the top three threats to global biodiversity, the other two being unsustainable harvest of various species from the wild and habitat degradation and

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loss [1]. Invasive species, coupled with unsustainable resource use and climate change have seriously affected the livelihoods of millions of people in south and south-east Asia [2]. The rapid spread of invasive alien species affects natural habitats, regeneration potential of native species and affects the productivity of forests and grassland habitats [3]. The spread of alien species is particularly challenging in terrestrial ecosystems across the world [4–6]. Changes in climatic conditions and land use practices favour the introduction and spread of IAS in most parts of the world [7–9]. Therefore, it is vital to assess the current extent and future scenarios of invasion for various IAS [10–12].

The Himalayan region, one of the global biodiversity hotspots, is quite vulnerable due to climate change and other abiotic and biotic drivers of change including the rapid spread of IAS. Some of the most obnoxious IAS in this region includes *Lantana camara*, *Ageratina adenophora*, *Parthenium hysterophorus*, and *Ageratum conyzoides* [13]. During the past few decades increasing anthropogenic pressures such as unabated linear infrastructure development, uncontrolled tourism, livestock grazing, agricultural expansion and extraction of non-timber forest products (NTFPs) have led to the degradation of wildlife habitats and the spread of a large number of invasive species [14]. It is estimated that total 297 IAS species belong to 65 families were reported in the IHR [13]. One of the major causes of the spread of IAS in the Himalayan region is climate change [15]. It has been observed that plant species of higher elevation are projected to shift higher, due to which a few IAS previously limited to the lower elevations are now shifting towards the higher altitudes in the Himalaya [15,16].

As a signatory to Convention on Biological Diversity, India has set its National Target in alignment with Aichi Biodiversity Targets. Accordingly, India's Biodiversity Strategy and Action Plan aim to identify the priority species of IAS as well as their invasion pathways so that appropriate management strategies could be formulated. It is realized that very few baseline studies have been conducted on the current extent and spread of even common species in the Himalayan region. Anthropogenic pressures coupled with climate change make complex the future prediction of species spread. Several authors [e.g., 15,17–21]; have opined that the IAS which were earlier limited to the lower areas are likely to shift towards the higher elevations in the Himalaya. This calls for the validation of earlier models as well as multi-location studies. In this paper, we present the findings of a case study on two IAS, viz., *A. adenophora* and *L. camara* at a landscape level within the Indian part of Kailash Sacred Landscape–India, hereafter referred as KSL–India. The major objectives of the study were to predict the potential current spread of these species in KSL–India and predict their invasion in future climate change scenarios.

Materials and methods

Study area

The study was carried out in KSL–India that is located between 29°26'35" to 30°35'13" N and 80°01'24" to 81°02'44" E. It is characterized by heterogeneous landscape, wide altitudinal range (ca. 800 to over 7000 m a.s.l.), diverse topography and rich biodiversity [17]. This area is contiguous with far-western Nepal and Tibet Autonomous Region (TAR) of China. The study area is spread over 7,120 km² (Fig 1).

KSL–India has the predominance of diverse natural ecosystems from grasslands to moist sub-tropical broadleaved to temperate oak forests, sub-alpine conifers, high altitude birch forests, while extensive alpine pastures occur in areas >3000 to 4000 m a.s.l. beside agro-ecosystems in lower reaches [22,23]. The diverse habitats cater to numerous indigenous flora and fauna. The forests in KSL–India falls into two categories—Protected Areas (PAs) and Non-Protected Areas. KSL–India includes only one legally designated PA (i.e. Askot Wildlife

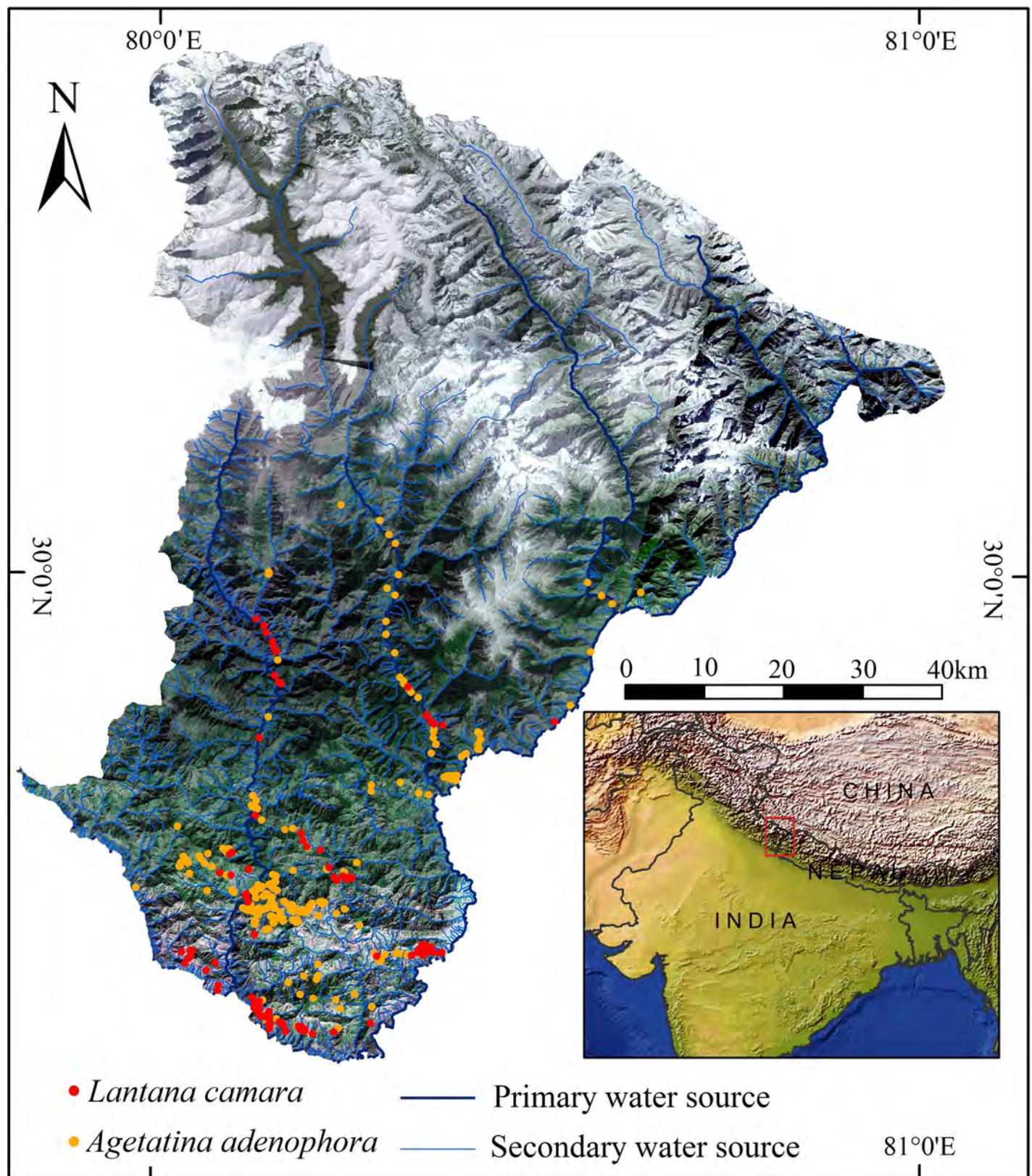


Fig 1. Geographical location of the study area with sampling locations of *Lantana camara* and *Ageratina adenophora*.

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Sanctuary) which provides important ecosystem services for the region. However, the non-PA category of forests includes reserve forests and protected forests under the control of the State Forest Department of Uttarakhand, managed for an extended period for the production of timber and non-timber forest products (NTFPs). KSL–India also includes highly interspersed small forest fragments falling under two broad categories, *i.e.*, civil/soyam forests and community forests are under the control of the Revenue Department of the State Government. The latter category of community forests, for nearly nine decades or so, has been managed by the local communities and is referred to as ‘Community Forests’ or ‘Van Panchayat Forests’. This community forest serves as the primary source of livelihood for locals. The KSL–India has experienced a considerable change during recent decades in terms of land use and land cover, along with the development of infrastructure and patterns of natural resources used by the local communities [23,24].

Species presence

After the extensive vegetation survey and consultation with experts, the two most widely spread IAS, *i.e.*, *Ageratina adenophora* (Asteraceae) and *Lantana camara* (Verbenaceae) were selected for the present study. *A. adenophora* is native of Central America [25] and distributed worldwide [26]. *L. camara*, native to Tropical America [27] is considered to be one of the most troublesome invasive species worldwide [28]. *A. Adenophora*, a perennial, herb produces a large number of tiny seeds which are dispersed by wind and human activities [29]. Its ubiquitous property to invade diverse habitats, such as roadsides, riverbanks, forest edges, crop fields, wastelands, and rubbish dump edges makes it fit to invade various ecosystems. *L. camara* is one of the most widely distributed IAS in India [30], resistant to fire and can regrow if burnt [31]. It reproduces primarily by seeds as well as through coppice and prefers to grow in degraded habitats.

Though, the species selected for the study are known to negatively affect the wildlife habitats and native vegetation, they are also known to have a few minor uses to local communities. Leaves of *A. adenophora* are used for cattle bed [32], or its leaf paste is applied to cuts and wounds and leaves are also have the properties of antimicrobial activity, antipyretic activity, wound healing, antioxidant activity, analgesic activity, anti-tumor activity, insecticidal activity, antiviral activity, anti-inflammatory activity, and larvicidal activity [33,34]. The wood of *L. camara* is used as fuel [35,36], a source of food for birds [37–39] and nectar for butterflies and moths [40,41] as flowering and fruiting happens throughout the year.

Presence record

We recorded *A. adenophora* and *L. camara* presence between 300 and 2500 m a.s.l. covering a wide range of habitats including agricultural lands, grasslands, fallow lands and forests, proximity to major road networks and naturally occurring drainages in different parts of the landscape during 2014 to 2017. A total of 567 and 120 presence locations for *A. adenophora* and *L. camara*, respectively were recorded using handheld Garmin N72 GPS (Supplementary Information). Of these, 80% locations were used for probability distribution modeling and the rest 20% were used to evaluate the model performance. The study was conducted outside the protected area and no Schedule-I or -II species were used in the study.

Selection of environmental and bioclimatic variables

We used two-time periods (“current” and “2050”) environmental data to model the *A. adenophora* and *L. camara* current and future distribution in KSL–India. A total of 22 environmental variables were used for probability distribution modeling in each period. We retrieved

standard 19 bioclimatic variables for WorldClim version 2 [42]. These are the average for the years 1970–2000 with a spatial resolution of 30 seconds ($\sim 1 \text{ km}^2$). These variables are considered as current bioclimatic variables. We also retrieved 19 bioclimatic variables with a spatial resolution of 30 seconds ($\sim 1 \text{ km}^2$) for the year 2050 (average for 2041–2060). These are the climate projections as per the Intergovernmental Panel on Climate Change (IPCC) 5th assessment report from Global Climate Models (GCMs) for one Representative Concentration Pathways (RCPs). However, we used RCP 8.5. Because, out of several IPCC climate change scenarios, RCP 8.5, generally taken as the basis for worst-case climate change scenario among all (viz., RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5.) [43–45]. The data were downscaled and calibrated using WorldClim 2 as baseline 'current' climate [42,46]. These bioclimatic data are also the most recent GCM climate projections that have already been considered in the IPCC fifth assessment report.

We also considered four major static topographic factors for both the “current” and “2050” time frame. These are elevation (ASTER, Digital elevation data from Advanced Space-borne Thermal Emission and Reflection Radiometer), slope, aspect, Euclidian distance from water channels and Euclidian distance from major roads. These variables were assumed to be constant across the entire study period. The details of all the variables used in this study are provided in Appendix 1 in [S1 Appendix](#).

Pair-wise Pearson correlations and principal component analysis

We checked for multi co-linearity with pair-wise correlations for both “current” and “2050” environmental data sets to avoid spurious model calibrations [47]. It is common practice to retain only predictors with pair-wise correlation $< |0.7|$ [48]. To nullify the correlation structure of the variables and inter-relationship among them, we implemented the Principal Component Analysis [PCA; 49,50]. The PCA reduces the number of orthogonal predictors each of which is the linear combination of 24 original environmental variables. All the exploratory variables were subjected to PCA to extract the factors of significant contribution using *prcomp* function and *predicting* the function of R version 3.3.3 [51]. Furthermore, we obtained 24 Principal Components (PCs) in raster format. For both “current” and “2050” data sets, the first six PCs accounted for 99% of the variability and were chosen for further multivariate species distribution modeling ([Table 1](#)).

MaxEnt species distribution modeling

Maximum Entropy (*MaxEnt*) distribution modeling was implied to identify the current and future invasion for both, *A. adenophora* and *L. camara* in KSL–India. *MaxEnt* is a machine learning algorithm that is widely used for species distribution modeling that uses presence-only data [52,53] to predict the potential distribution of a particular species in the current as well as future climatic scenarios [54,55].

The occurrence data from the field was collected for both *A. adenophora* ($n = 567$) and *L. camara* ($n = 120$). One thousand background points were drawn randomly across the KSL–India by considering the pseudo-absence of both species. We generated four main *MaxEnt* models (two for each species) using the six PCA derived explanatory variables for both the ‘current’ and ‘2050’ year.

We implemented k-fold cross-validation [56] to build each main *MaxEnt* model. Firstly, we used standard k-fold cross-validation in our randomly partitioned approach. In our k-fold cross-validation approach, the occurrence localities were divided randomly into 10 bins, where each bin constitutes an equal proportion of sample size [57,58]. Then, each model was developed iteratively, using $(k - 1)$ bins for model calibration in each iteration, with the

Table 1. Representation of the first seven principal components derived from all 24 original environmental variables along with the proportion of variance in environmental variables explained by each principal component and their cumulative proportion of variance.

Principal components	The “current” year		Year 2050	
	Proportion of Variance	Cumulative Proportion	Proportion of Variance	Cumulative Proportion
PC1	0.98890	0.98890	0.98880	0.98880
PC2	0.00810	0.99700	0.00810	0.99700
PC3	0.00276	0.99979	0.00277	0.99973
PC4	0.00013	0.99992	0.00015	0.99988
PC5	0.00007	0.99998	0.00008	0.99996
PC6	0.00001	0.99999	0.00003	0.99999
PC7	0.00000	1.00000	0.00000	1.00000

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remaining fold retained for evaluation. This is repeated until all the folds were utilized at least once for model evaluation. *MaxEnt* produces a model based on a series of ‘features’, such as linear, hinge, quadratic, product, threshold and discrete; we used all except for discrete, as all of our explanatory variables were continuous [59]. In the ‘feature’ functions, we set the beta multiplier as 0.5 (medium) that affects the smoothness of the model output. We have opted for the clamping function in each model as the use of the function is strongly suggested for projecting future species distributions [60,61].

As we set the models *via* k-fold cross-validation ($k = 10$), for each dataset, we used the respective evaluation localities to calculate Area Under the Curve (AUC) of the Receiver Operation Characteristic (ROC), which is a measure of the overall discriminatory ability of the model or to precisely evaluate model performance by plotting its model sensitivity graph [62]. We averaged those values from each sub-models of each main model and represented the averages for each of the four main *MaxEnt* models. The AUC score closer to 1 indicates that the model had accurately predicted the habitat, while a value ≤ 0.5 indicates the low accuracy of the model [63]. We also calculate other model evaluation matrices such as kappa max (kappa), true positive rate (TPR), true negative rate (TNR), and True skill statistics (TSS) using the ‘*dismo*’ package in R [64].

Binary habitat invasion maps for the ‘current’ and future ‘2050’ were prepared by using the threshold of maximum training sensitivity plus the specificity logistic threshold. The threshold approach of ‘*Maximum training sensitivity + specificity*’ is a more reliable, restrictive and conservative approach to understand the potential distribution of a species. This particular threshold approach is one of the popular methods either for presence/absence or presence-only data [65]. We used ‘*dismo*’ package in R [64] along with a source file developed to build all *MaxEnt* models [66] as well as to evaluate their performance.

Invasion across the elevation gradient

To check the future spread of *A. adenophora* and *L. camara*, we extracted all elevational range values from a 30 m resolution digital elevation model (ASTER) using the threshold polygons generated from *MaxEnt* main models. Elevation gradients that fall within the distribution ranges were re-classified into multiple classes considering 100 m a.s.l. intervals. Area invaded by both species in each elevation class was compared between current and 2050 year using paired sample t—test. The distributions of elevation class vs. invaded areas of both *A. adenophora* and *L. camara* were plotted separately for the current year and 2050 to visually assess their spread pattern across the elevation classes.

Results

The pair-wise Pearson correlations were generally higher ($r > |0.70|$) for most of the variables (Fig 2). We were not able to use these variables directly in *MaxEnt* as they showed high correlation, and this avoids the overprediction of suitability in *MaxEnt* models. However, PCA transformed the 24 environmental variables (each for ‘current’ and ‘2050’) into a composite set of 24 components that are orthogonal and un-correlated to each other. Six out of 24 components demonstrated the cumulative proportion of variance > 0.99 for both the ‘current’ and the year ‘2050’ (Table 1). The first six PCs each from the ‘current’ and ‘2050’ were represented in Appendices 2–3 in S1 Appendix.

Both training and test area under ROC curve (AUC) values were > 0.81 for both species under the ‘current’ and future ‘2050’ climatic conditions (Fig 3, Table 2). Other model evaluation statistics were provided in Appendix 4 in S1 Appendix. The current occurrence locations of *A. adenophora* and *L. camara* were 95.1% and 92.5%, respectively falls within their most climatically suitable current distribution ranges. The relative percent contribution of all PCs from both the ‘current’ and the year ‘2050’ are presented in Table 3, and all response curves associated with the above *MaxEnt* model predictions were given in Appendix 5 in S1 Appendix. The current and future distributions of the *A. adenophora* and *L. camara* along the elevation gradient of KSL–India are determined by the RCP 8.5 pathway projections for 2050 (Fig 4A and 4B).

The current distribution of *A. adenophora* ranges between 212–2616 m a.s.l., while *L. camara* distributed mostly below 2045 m a.s.l. The potential area that is currently vulnerable to invasion by *A. adenophora* and *L. camara* extends to 1403.7 km² and 1053.1 km², respectively. If the climate change continues to follow the higher emission RCP 8.5 pathway, by 2050, invasion of *A. adenophora* would reach up to 3029 m a.s.l., whereas, *L. camara* will invade up to 3018 m a.s.l. Both *A. adenophora* and *L. camara* will spread across the landscape occupying an area of 2039.7 km² and 1366.5 km², respectively. The area invasion by *A. adenophora* ($t =$

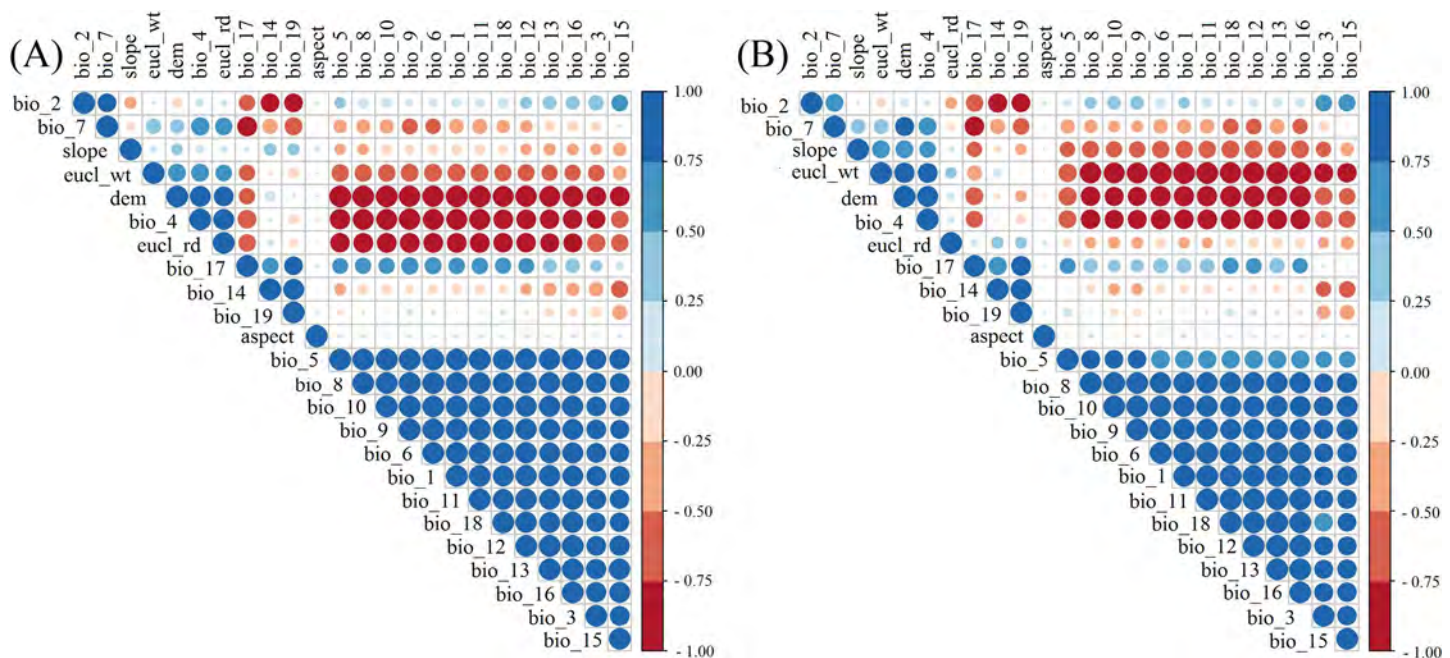


Fig 2. Representation of Pearson correlation matrix for environmental data of the “current” year (A) and year 2050 (B).

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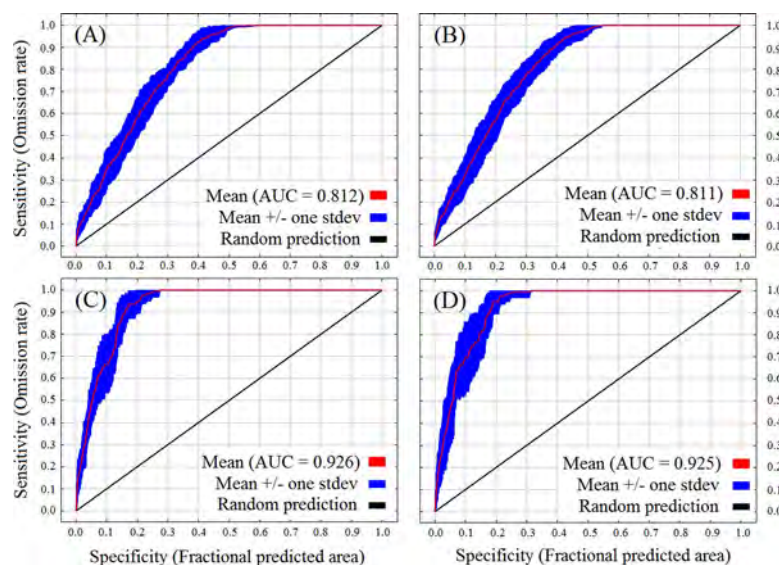


Fig 3. Receiver operating characteristic (ROC) curve for the predicted distribution *MaxEnt* models averaged over the ten replicate runs: *Ageratina adenophora* (the “current” year–A; year 2050 –B) and *Lantana camara* (the “current” year–C; year 2050 –D).

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–7.61, $df = 28$, $p \leq 0.05$) and *L. camara* ($t = -2.70$, $df = 28$, $p \leq 0.05$) will significantly increase by year 2050 across all designated elevation class (Fig 5).

Discussion

Plant invasion is the emerging area of science that impacts substantial economic and ecological imbalance by altering native plant community composition [67] and depleting native plant species diversity [68] thus affecting ecosystem processes [69–71]. The lower and mid ecosystems in the mountains are more vulnerable to invasion by exotic plant species due to the altering climate change and increasing anthropogenic pressure [72]. These plant species also exceeded their ranges and many of them have become abundant at higher elevations [73,74]. The increasing incidence of invasion in the high-altitude ecosystems [9] poses a significant threat to the native biological diversity of the region and it is expected to expand in the future [21]. Using principal components as input variables in *MaxEnt* enhances the prediction of good habitat suitability [50,75]. Alien species that seek to establish themselves in mountains easily proliferate and become difficult to sustain and manage due to the rugged and steppe mountain terrains [76]. It is important to detect potential invaders and take preventative action, since this is the most cost-effective way to restrict the spread of IAPS to new locations. This demonstrated an increasing (both vertical and horizontal) trend of plant invasion in KSL–India. Altering climatic condition and mostly increased temperature has been providing favourable conditions for the invasion and spread of these species in the KSL–India.

Table 2. The area under the receiver operating curve (AUC) score of *MaxEnt* models for both *Ageratina adenophora* and *Lantana camara*.

Species	The “current” year		Year 2050	
	Test AUC	Training AUC	Test AUC	Training AUC
<i>Ageratina adenophora</i>	0.81	0.82	0.81	0.82
<i>Lantana camara</i>	0.93	0.93	0.92	0.93

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Table 3. Relative contributions of each principal component (PC) are used in all the *MaxEnt* models.

PC	Contribution of <i>Ageratina adenophora</i> (%)		Contribution of <i>Lantana camara</i> (%)	
	The “current” year	Year 2050	The “current” year	Year 2050
PC1	83.00	86.10	62.8	65.2
PC2	00.00	00.10	0.1	0.2
PC3	01.10	02.40	9.1	15.6
PC4	04.60	04.60	2.1	1.1
PC5	07.30	05.40	16.7	15.8
PC6	04.00	01.50	9.1	2.2

<https://doi.org/10.1371/journal.pone.0239690.t003>

The presence of *L. camara* was recorded widely in forest and scrublands [77,78]. Looking forward, *L. camara* might also affect the regeneration of native biodiversity in the area. It appeared that in the future both of these IAS would colonize more vigorously in the landscape where currently they are not present. This invasion of both species is likely to happen if climate change continues to follow the higher emission RCP 8.5 pathway. Furthermore, *L. camara* will spread within a similar altitudinal range where it is currently absent. These species have already spread in mountains and along rivers and roadside [79]. *A. adenophora* presence between 2800 to 3000 m a.s.l. [13], which suggest that the spread of this species in higher regions of western Himalaya can cause a potential threat to the native biodiversity in the alpine and subalpine zone.

Our study also showed a similar trend, as this species will reach 968 m a.s.l. higher than its current distribution range. Our predictive models also depicted high infestation and expansion in the present climatic scenario by *A. adenophora* and *L. camara* in the lower parts of KSL–

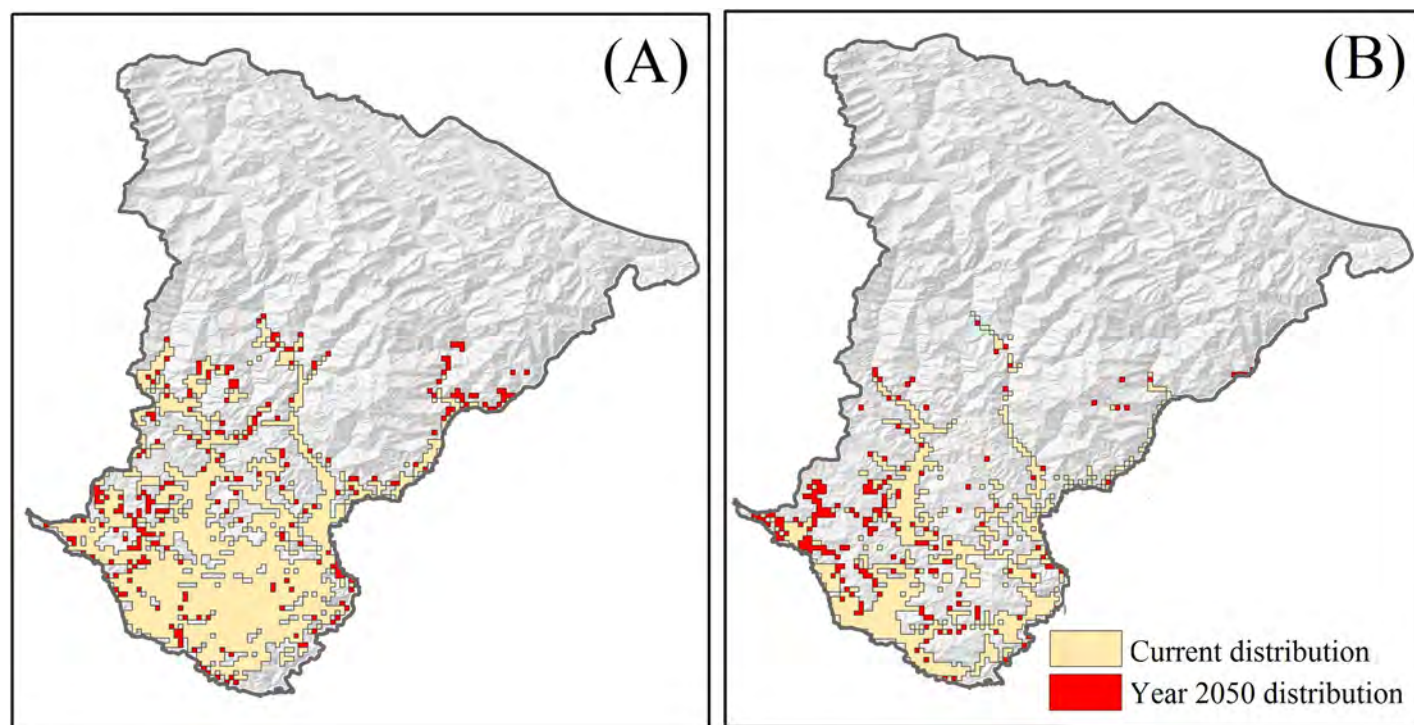


Fig 4. Predicted distribution *MaxEnt* models averaged over the ten replicate runs. Orange and Red polygons represent maximum training sensitivity + specificity logistic threshold for the distribution of (A) *Ageratina adenophora* and (B) *Lantana camara* in the “current” and year 2050.

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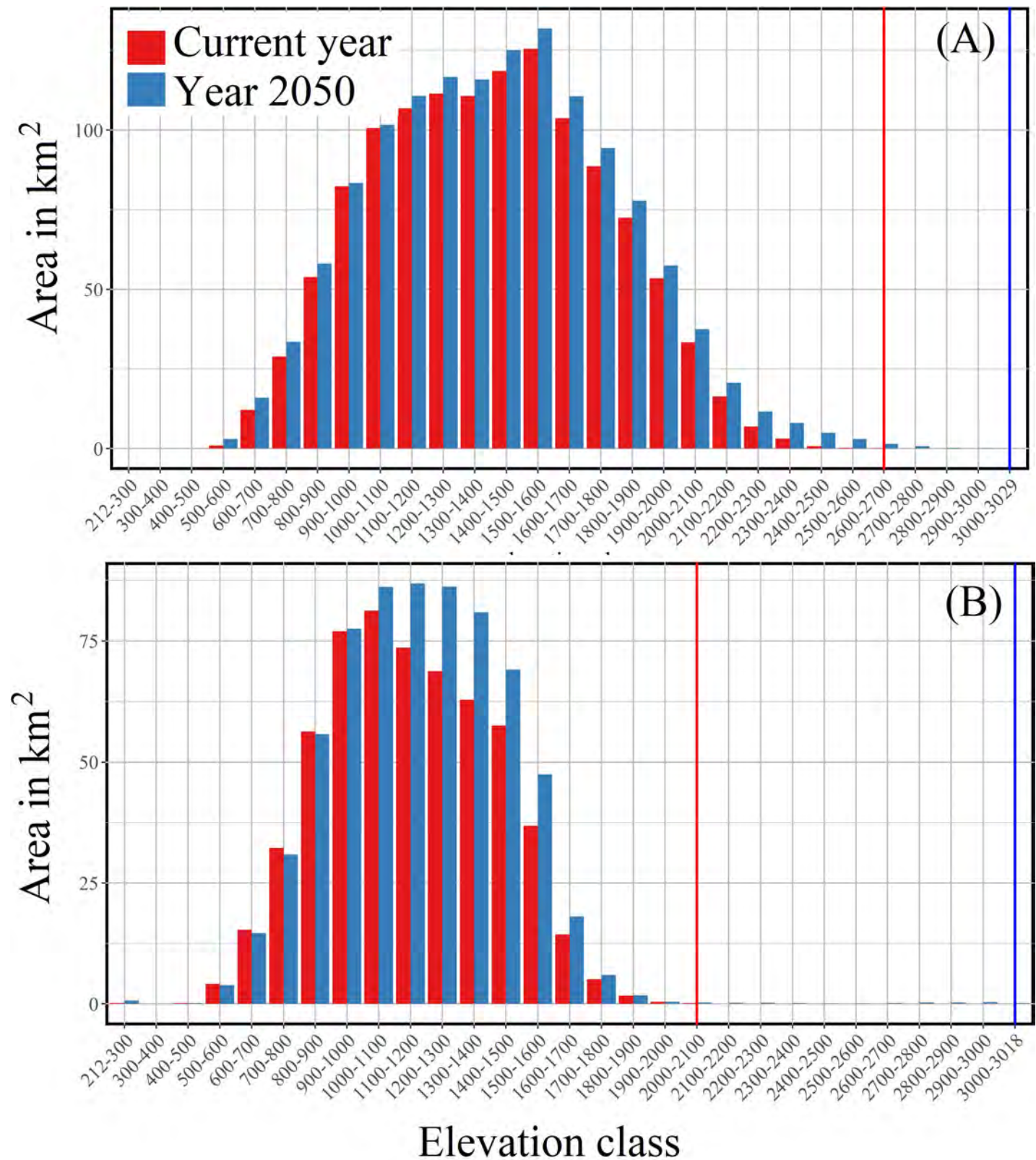


Fig 5. The predicted spread (in Km²) of *Ageratina adenophora* (A) and *Lantana camara* (B) in different elevation classes of KSL-India during the current year and the year 2050.

<https://doi.org/10.1371/journal.pone.0239690.g005>

India in western Himalaya. The *MaxEnt* model also predicted that the landscape provides more suitable conditions for the infestation of *A. adenophora* as compared to *L. camara* even at its current climatic condition. Both the species will expand their habitats with the increase in temperature and human activity in the landscape. Our study demonstrated similar results as compared to previous studies [80–82], but in a more robust and spatially explicit manner.

Our study has come up with a current pattern of distribution and established future scenarios of invasion by two highly obnoxious IAS within KSL–India. The distribution maps generated in this exercise would be of much help in further conservation planning and participatory management of forest/grassland management. The findings of our study can be used in the identification of vulnerable areas and important localities which are likely to be infested by these species. Habitat restoration and community-based monitoring at a local scale involving Biodiversity Management Committee (BMC) would be one of the logical steps forward.

Supporting information

S1 Appendix.
(DOCX)

S1 Data.
(RAR)

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Human–wildlife interactions and management of invasive alien species

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Human–wildlife interactions and management of invasive alien species*

Human–wildlife interactions turning into conflict and invasions of exotic flora and fauna are considered as the two biggest threats to wildlife conservation globally. In India, about 400 people are killed annually by elephants, many by carnivores, thousands of livestock are killed by big cats and hectares of agriculture areas are damaged by herbivores. Annually huge funds are allocated for preventing the entry of wild animals into the villages around protected areas (PA) and for compensation of conflicts. Simultaneously, biological invasions in the recent years have emerged as one of the major threats to the environment and has resulted in the loss of valuable ecosystem services. These problems are severe in developing countries such as India where most of the rural population depends on forests for their sustenance. Furthermore, increasing human population exerts pressure on the natural ecosystems, thereby increasing the frequency of these threats in future.

Frequently many studies have established invasive plants as one of the reasons for increasing negative human–wildlife interactions in India and adjoining countries. For example, decreased native food plants cover of Rhino¹ and reduced habitat use of elephant in Mudumalai Tiger Reserve have been attributed to invasive alien species².

The objective of this workshop was to bring together scientists, managers, field experts, policy makers, and representative of leading NGOs dealing with these issues for a better knowledge about the current state of the problems and to find a way forward. The workshop was conducted under the five major themes: (1) human–carnivore interactions, (2) human–herbivore interactions, (3) human–macaque interactions, (4) invasive alien species management and (5) law and

policy aspects for management of these problems. On the first day of the workshop, experts introduced the areas of concerns under different themes to all the participants followed by a focused discussions within working groups consisted of experts and researchers.

Ex-gratia, an important yet somewhat controversial tool of conflict management, was discussed exhaustively during the workshop. Group brainstormed on two important issues of (1) inequality in *ex-gratia* money across various states and (2) lack of quantification of ‘lost opportunity cost’ (opportunity to earn from the predated livestock in the years to come had it not been killed). According to the group, compensation can be strengthened by addressing these two limitations. Research findings of Y. V. Jhala and Kausik Banerjee (WII) also support the economic compensation that could minimize the negative attitude of local communities towards wildlife damage. For further strengthening the compensation, Ruchi Badola (WII) suggested on incorporating the social compensation in addition to economic one. S. S. Bist (WII) elaborated on the alternatives of economic compensation through subsidies for growing alternative crops, insurance for life and property, support for setting up wildlife-proof barriers, categorizing wildlife-depredation as ‘natural calamity’ and compensation by district administration.

Translocation of problem animal was also discussed in detail among the group members. Available standard operating procedures (SOP) recommend translocation of the rescued animal to a suitable habitat, however the assessment of the selected habitat is rarely done. Vidya Athreya (Wildlife Conservation Society) shared her findings wherein the translocation of leopard led to increased attack on humans in Maharashtra. Potential factors responsible for the increased conflict according to Athreya were the stress during the translocation process, homing instinct of the individual and loss of human fear during captivity. Qamar Qureshi (WII) also pointed out the drawbacks of translocation in terms of mortality of the concerned individual/population and/or transfer of the problem to other areas.

Experts also raised concern about the fate of wild animals in human-dominated landscapes. Population of mega carnivores and herbivores are connected through corridors which usually pass through a mosaic of anthropogenic land-uses. These corridors usually have low prey base and degraded habitats, thus making conflicts inevitable. With increasing landscape modification, chances of encountering these animals by humans as well as the negative interactions would increase. Hence, Dipankar Ghose (WWF) and Athreya highlighted the need to modify existing PA-centric approach of wildlife conservation to a landscape level conservation approach.

Overabundance of few species intensifies the negative interactions with humans. The reason for increase in population are species-specific. For example, changing land use pattern and increased resource availability post-green revolution period are considered as the causes for increasing population size of Nilgai, Wild Ass and Blackbuck. However, in the case of non-human primates conflict is increasing due to improper solid-waste management and religious attachments of human with the species. Population control of such species in high conflict areas is seen as a last resort for managing the negative human–wildlife interactions. However, experts cautioned to ascertain the population status of the species in question to avoid its local extirpation. Further, Bist added that population control of overabundant conflict animals become difficult if they belong to the Schedule I of Wildlife (Protection) Act, 1972.

A number of traditional and short-term mitigation measures to keep the animal away from the human habitations and crop lands were also discussed. It was realized that traditional preventive measures such as night vigil, noise (beating drums, fire crackers) and barriers (electric fencing, concrete walls, chili fencing and beehive near crop lands) could help in considerable reduction in damages due to wild animals.

Inventory and prioritization of invasive alien species (IAS) in various ecosystems based on research evidence was identified as the first step for their

*A report on two-day workshop on ‘Human–wildlife interactions and management of invasive alien species’. It was conducted by Wildlife Institute of India on 23 and 24 July 2014. The workshop was funded by the Ministry of Environment, Forests and Climate Change (MoEFCC) wherein a total of 110 participants discussed the topics over the two days.

management. It was deliberated that efforts should be invested to identify IAS in major ecosystems such as terrestrial, marine, island and fresh water. A tentative list of invasive alien species of national concern in major ecosystems was developed by the group. According to the working group, MoEFCC in the context of national bio-security should direct agencies and concerned ministries to brainstorm over the issue of biological invasions as it is one of the 20 Aichi Biodiversity targets. The group also suggested establishment of task force for managing invasion in every ecosystem. Qureshi expressed his concerns for using bio-control agents without controlled trials as it could result in additional introduction of alien species. He also suggested taking precautionary measures during restoration activities to prevent invasion of weedy and exotic species in PAs. Experts also agreed on completely stopping the fire treatment of invasive plants in PAs, as it could harm native species and add to the carbon emission. Further, everyone agreed upon revising Plant Quarantine (Regulation of Import into India) Order, 2003 to incorporate restriction on transfer of biological agents from foreign as well as distinct biogeographic landscape of the country. A

need to minimize pesticide usage in managing invasive plants in protected areas was also discussed.

Considering the increasing conflict cases due to non-human primates, workshop had a dedicated session for human-macaque interactions. Group members recommended that population estimation should be the first step in resolving this issue and should be carried out in all the potential habitats (urban, semi-urban, rural, forest). Himachal Pradesh Forest Department (HPFD) has already taken a lead to solve the problem by adopting population control for managing the overabundant macaques. Satpal Dhiman (HPFD) provided a detailed account of the sterilization technique used by the department as well as associated key aspects. High cost-involvement in establishing sterilization centers, decline in capture rate of macaque at subsequent efforts and post-release monitoring are some major limitations of the existing strategy. For developing SOP for management, all the transitional steps such as capture, transportation and post monitoring of sterilized animal, etc. were discussed.

Group members strongly felt an immediate need to adopt an interdisciplinary approach for managing human-wildlife

interactions and invasive alien species. According to the group, all concerned stakeholders (e.g. horticulture, animal husbandry, forest department, police, veterinarians, social scientist, media persons and local communities) should be involved at every stage of management. Sensitization of local communities about the ecosystem services provided by the wildlife was identified as a tool for changing their perception towards wildlife. In the concluding session all the participants agreed on formulating guidelines for managing the negative interactions and high concern IAS. It was agreed that the conflict mitigation guidelines and SOPs should be species and site-specific to account for the immense economic, social and cultural diversity of our country.

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Expanding niche and degrading forests: Key to the successful global invasion of *Lantana camara* (sensu lato)

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Title

Expanding niche and degrading forests: key to the successful global invasion of *Lantana camara*
(sensu lato)

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Abstract

Estimating the distribution of invasive species and understanding the ecological reasons for their success is crucial for their management. Moreover, their ability to invade biogeographically distinct regions in short timespans poses interesting ecological questions. *Lantana camara* (sensu lato) is one such invasive species of global concern. In an unprecedented effort, we surveyed 207,100 km² of Indian forests by sampling 13715 grids of 5x5 km, each with 1 to 31 plots of 10 m diameter, to record the abundance of Lantana. For India, we modeled occupancy of Lantana in the sampled area by accounting for imperfect detection; and potential invasion outside the sampled area using MaxEnt with covariates of climate, soil, forest and human disturbance. Further, Lantana's response in comparable areas of its native and global invaded range was modeled using MaxEnt to provide a better understanding of its changing relations with environmental factors. Lantana invaded 154,837 km² of the surveyed area, and threatened 303,607 km² of total Indian forests (44%); with preference to warm, humid, fertile areas, degraded by extractive human use. By combining our large-scale ground surveys with published data, we show that Lantana has globally expanded its climatic niche, with >11 million km² suitable for its invasion. Niche comparison revealed that Lantana might have adaptive plasticity in its invaded range; where it was found to be more tolerant to higher temperatures, lower fertility and shade as compared to its native range. In light of Lantana's introduction history that suggest excessive hybridization between previously allopatric populations, and its known genetic diversity in the invaded range, the existing adaptive plasticity is suggestive of contemporary evolution. This adaptive nature can increase area under its invasion and pose an ecological conundrum of managing an evolving neophyte.

Keywords

Large-scale survey, Niche change, Occupancy modelling, Plant invasion, MaxEnt, Species distribution modelling

1. Introduction

Few decades ago, many scientists speculated that the introduction of invasive species by humans could be one of the top threats to the global biodiversity (Elton 1958, Diamond 1989, Sala 2000). Recent global studies validated these speculations by showing homogenization of global biota and increased extinction of native species catalyzed by biological invasions (Simberloff et al. 2013, Bellard et al. 2016, IPBES 2019). Biological invasions have caused enormous economic loss by affecting livelihoods, human health and ecological integrity of the invaded areas (Pimentel et al. 2001). With increased global connectivity, the chances of introducing potential invasive species have increased, particularly in developing countries that have higher demand for international goods exchange and poor quarantine policies (Meyerson and Mooney 2007). Additionally, over extraction of natural resources for livelihood in developing countries has degraded their native ecosystems, making them vulnerable to biological invasions (Byers 2002). Amongst invasive plants, *Lantana camara* L. (sensu lato) (Goyal and Sharma 2015) (hereafter Lantana), a woody shrub of tropical American origin (Figure 1), is regarded as one of the ten worst invasive species in the world (Ghisalberti 2000, Richardson and Rejmánek 2011) and a major concern in India (Mungi et al. 2019). Previous studies found multiple species and varieties of Lantana introduced during 1800s across the tropics where it was introduced. These species and varieties were introduced as hedge plants and were subsequently hybridized for improved stand and other ornamental properties (Kannan et al. 2013). This potential hybridization added to the number of varieties, which were later reported to invade native forests (Bhagwat et al. 2012). What is now identified as '*Lantana camara*' in its invaded range is thus a hybrid of many

species/varieties. This hybrid is caused by multiple sources of introductions, artificial selection and subsequent escape into natural systems to express the altered phenotype (Ray and Ray 2014). As a consequence, recent studies have categorically identified this group of Lantana as '*Lantana camara* (sensu lato)' (e.g. Goyal and Sharma 2015). Dense invasion of Lantana has been suspected to cause decline in habitat for wildlife and native plants (Aravind et al. 2010, Wilson et al. 2013). Lantana has also affected the livelihood of communities dependent on forest resources (Sundaram and Hiremath 2012). Its management is estimated to cost around \$18,700 per km² in India (Babu et al. 2009). A prerequisite to tackling macro-ecological concerns like biological invasions is at first a reliable assessment of state variables such as occurrence and abundance of species at landscape scales (Hastings et al. 2005). Despite 200 years of managing Lantana in India (Bhagwat et al. 2012), little information regarding its distribution at the country level or its biogeographic correlates is available. Published literature on these aspects relies on the potential distribution of Lantana derived through climatic niche modelling and suffers due to data deficiency (Panda et al. 2017).

An understanding of mechanisms that enable or restrict invasion would be useful in designing control mechanisms. These mechanisms can be evaluated by comparing the niche within native and invaded ranges of an invasive species (Peterson et al. 2006). For a valid comparison, it is essential that models used for explaining a species' niche be within the same ecological space (analogous areas) used for training and prediction (Barve et al. 2011). Often this basic assumption of statistical modelling is violated and inferences are then questionable (Araujo and Guisan 2006, Rodda et al. 2011, Qiao et al. 2017). To assess and demonstrate niche expansion in an invaded range, comparison of niche space should be limited to analogous areas in the native and invaded range (Peterson 2011). However, this limitation of comparing only analogous areas,

is often overlooked by many studies that demonstrate niche expansion (e.g. Rödder et al. 2009, Di Febbraro et al. 2013). Therefore, inferences from such studies cannot differentiate between actual change in the niche space in the invaded area or the species' inability to express its full niche potential due to unavailability of niche space in its native or introduced range.

Though climatic niche change in analogous areas is often used as a proxy for fundamental niche change, changes estimated from non-analogous areas can be used as a proxy for realized niche change (Escobar et al. 2016). Unlike the climatic niche expansion, which hints at physiological adaptations in a species, realized niche change provide a unique natural experiment to disentangle the biogeographic responses of the species when freed from natural controlling agents like competitors, predators and diseases. Hence, increasing number of studies include influence of biotic parameters in understanding niche changes (Tingley et al. 2014). Changes in realized niche also explain how different disturbance regimes and facilitating agents influence the spread of invasive species, thus providing insights for their management. As an example, Lantana distribution is known to be influenced by native forest fragmentation in invaded areas (Mungi et al. 2018).

Rabindranath et al 2012 estimated forest loss at a in India at a rate of $173 (\pm 39) \text{ km}^2/\text{year}$ (Ravindranath et al. 2012) which is lower than many other tropical countries (www.globalforestwatch.org). While forest loss is restricted to loss in the tree cover, changes in grasslands and savannas are more insidious and undocumented (Ratnam et al. 2016). These modifications of vegetation are known to facilitate invasion of many plants, including Lantana (Gudiel et al. 2016). However, most often conversion of native vegetation into invaded vegetation is neither reported as forest loss, nor is it quantified. As a consequence, government policies compensate forest loss by compensatory afforestation or similar measures, while the

management of invasive plants and restoration of native vegetation remains unattended. Secondly, the facilitation of invasion by degradation of forest, though significant, is often overlooked. Forests in tropical developing countries, including India, are used by people for their livelihood (e.g. timber extraction, forage extraction, etc.). These unsustainable extractive dependencies can degrade the quality of native vegetation community (Raghubanshi and Tripathi 2009). It is hence, essential to quantify and understand the effect of forest loss and degradation on biological invasions so as to prioritize the conservation investment.

We address lacunae in the invasive species management by providing evidence of how forest degradation is influencing Lantana invasion in India. In the current study, we use data from one of the largest sampling efforts undertaken for any invasive species to develop an accurate countrywide map of Lantana invasion for informed conservation actions. By combining this information with globally available presence information of Lantana, we investigate the environmental factors that facilitate Lantana invasion globally, and in India in particular. We provide a reliable estimate of the potential global range of Lantana invasion. We interpret our results in the light of phenotypic plasticity of Lantana and its implications in the era of climate change and forest degradation.

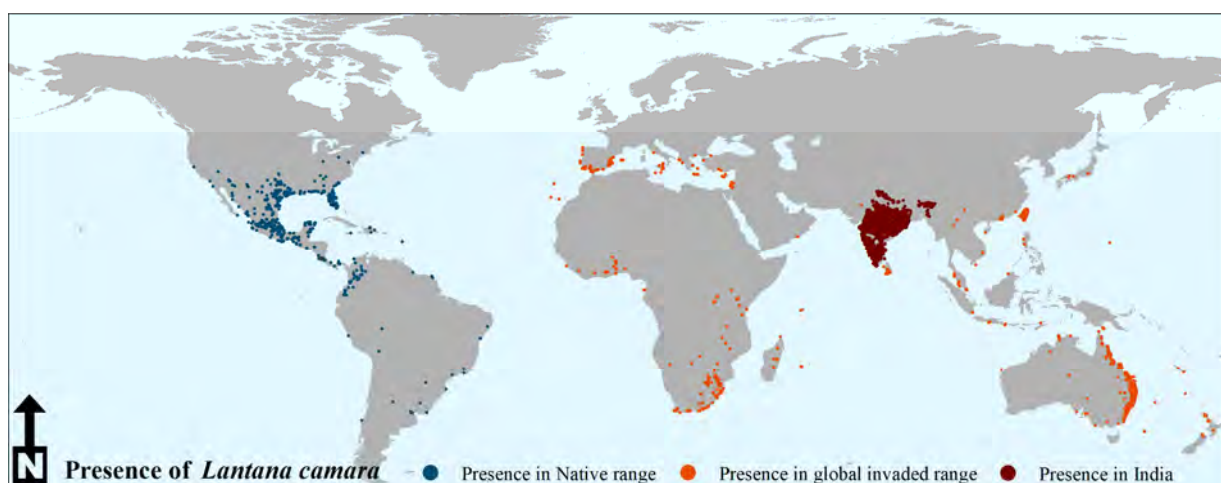


Figure 1. Lantana presence locations from its native range in tropical America (blue), and invaded range (GBIF data (orange) and field sampling based data from India (maroon)) used in the study

2. Materials and methods

2.1. Sampling and Data sources

We generated a spatial grid of 5*5 km for India in ArcGIS 10.6.1. Our study was limited to forested areas, therefore we computed area under forest within each grid. For this, we used the forest cover map from Survey of India (Indian State of Forest 2013), wherein the categories of scrub land, open forest, moderately dense forest, and dense forest were combined as ‘forests’. We sampled forested grids in 18 Indian states by laying 1 to 5 transects of 2 km length in each of these grids. On these transects, at every 400 m nested circular plots of 30 m for human disturbance and 10 m for shrub species were sampled. Shrub cover (including Lantana) was scored into four categories using modification of Daubenmire’s scale (Daubenmire 1959, Daubenmire 1968) (absent, low abundance < 10% of groundcover, moderate abundance 10-50% of groundcover, and high abundance > 50% of ground cover) (Jhala et al 2010). Lantana invasion is known to be facilitated by human disturbances and perturbation of the ecosystem (Hiremath and Sundaram 2010, Mungi et al. 2018). We therefore collected data in every 30 m diameter plot on a) the number of trees lopped, b) the number of trees cut, c) evidence of grass and bamboo cutting (as present or absent), d) number of people seen from the plot, and e) number of livestock seen from the plot and f) number of livestock-human foot trails within the plot. The forest guard, who is the front-line staff of the forest administration across the country and has an intimate knowledge of the forest, participated as a team member to sample plots. The survey path and plot locations were recorded using a handheld GPS unit (Garmin Etrix model

72). The sampling was conducted between November 2009 to March 2010. In total 117,104 plots were sampled (Figure 1) within 13,715 grids covering 207,107 km² of forested area. The field data were then spatially attached to the grids in a GIS (ArcGIS ver. 9.3).

We procured spatial presence information of Lantana from its native and global invaded range from the Global Biodiversity Information Facility Portal (accessed through GBIF.org (11 May 2018) GBIF Occurrence Download <https://doi.org/10.15468/dl.6wjktz>). Occurrence data with accurate geolocation obtained after the year 1970, within a comparable temporal range of the climate data, was used for subsequent analysis. In total 11,500 occurrences were obtained for the native region, and 25,106 occurrences were obtained for invaded regions (Asia, Africa and Australia). We subsequently plotted these locations on Google Earth and selected only those locations, which were observed in forested areas of native Central America (n=4,495) and from across the Global invaded range (n=16,633) (Figure 1). Lantana presence from ground sampling (n=38,079) in India was added to these records to get a total of 54,712 locations of Lantana in its global invaded range. This presence information was used for developing niche models.

For modelling occupancy of Lantana, it was essential to incorporate environmental covariates that determine its occurrence in the grid. To do so, we reviewed studies that incorporate distribution modelling of Lantana in India and developed following ecological hypothesis as predictors of Lantana occurrence: a) As Lantana is native to the hot and moist areas of Central and South America, as well as since it has invaded the tropical parts of the old world, we hypothesized that its distribution would be determined by climatic factors like conducive range of temperature and precipitation. Lantana would likely prefer warm and humid areas (Goncalves et al. 2014, Kannan et al. 2013, Mungi et al. 2018, Taylor and Kumar 2013). b) As most of the warm and humid forests in India are occupied by dense woody plants, the understory shrub

density is mostly determined by light availability, which is a function of forest canopy cover as well as forest degradation (Didham et al. 2005). Being an under-canopy shrub, we expected Lantana invasion to be facilitated by moderate to high light penetration through the canopy to the shrub strata. c) Studies also suggest that frequent burning of forests was likely to facilitate Lantana invasion (Mungi et al. 2018). Fire in controlled conditions was also demonstrated to facilitate seed germination of Lantana (Hiremath and Sundaram 2010) and could hence be an important determinant of its occupancy. d) We hypothesized that soils in which nutrient uptake was easier would be preferred by lantana (Osunkoya and Perrett 2011). e) Human disturbances like tree cutting, tree lopping, and livestock grazing can remove the native plants thereby reducing competition and making conditions favorable for invasive Lantana (Raghubanshi and Tripathi 2009). We use remotely sensed and global data repositories to index the above-mentioned parameters. We used minimum temperature of coldest month and rainfall of the driest quarter to represent the climatic determinants of Lantana. We indexed light availability on the below canopy strata by i) Seasonal Normalized Differential Vegetation Index (NDVI) (Huete et al. 2002) clipped by forest cover (Indian State of Forest 2013) so as to represent canopy cover and ii) Rate of forest attrition by computing change in Gross Primary Productivity (GPP) (Heinsch et al. 2003) for the past seven years. A higher positive value of GPP change indicates improvement in forest quality while a large negative value indicates forest degradation. We obtained information on fire occurrence from the Fire Information for Resource Management System (FIRMS) database, which is a composite of daily Moderate Resolution Imaging Spectroradiometer (MODIS) hotspots and Visible Infrared Imaging Radiometer Suite (VIIRS). VIIRS detects fire at 375 m resolution using multispectral bands (Schroeder et al. 2014) and complements MODIS, which detects fires at 1 km resolution through middle-infrared and

thermal infrared brightness temperature (Giglio et al. 2003). We used soil Cation Exchange Capacity (CEC) from the Global Harmonized Soil Index as an index of soil fertility (Batjes 2009). We used tree cutting, tree lopping and livestock grazing information recorded during the field sampling to incorporate the role of disturbance in facilitating the invasion by Lantana. All covariates were resampled to 25 km², the scale of inference used throughout in this paper. Subsequently, we estimated the correlation amongst different covariates, and used only those covariates for which the Pearson's Correlation Coefficient (r) was insignificant ($-0.7 > r > 0.7$). In case of correlated covariates, only one was used. Details on the source, scale and relevance of these covariates are provided in Supplementary material 1, Table S1.

2.2. Occupancy modelling

The number of sampled plots within 25 km² grids ranged between 1 to 31. Since these plots were small as compared to the grid size, there was a possibility of our sample plots not detecting Lantana presence in a grid, when in fact it was present (MacKenzie et al. 2017). We explicitly account for detection bias by modelling and correcting for detection probability of Lantana. We modeled Lantana occurrence with covariates as a logit link function in the program Presence (Hines and MacKenzie 2017). In order to reduce the redundancy of information and model complexity, only one covariate of a significantly correlated pair ($-0.7 > r > 0.7$) was used in the model. Covariates representing each of the major factors (climate, soil, forest attributes, and human disturbance) were used by themselves, and together to construct ecologically meaningful models. Covariates that substantially and parsimoniously improved model fit to the observed data based on Akaike information criterion (AIC) (Akaike 2011) were retained. Model with least AIC was considered to be the best model (Johnson and Omland, 2004) that explained occurrence of Lantana. When models differed by <5 AIC, we used model average estimates weighted by

AIC weights to incorporate model uncertainty in parameter estimates (MacKenzie et al. 2017). We used bootstrap function to generate 1300000 iterations for evaluating the goodness of fit of the best model to our data and used $\hat{c}$ statistics to correct for over dispersion, if any (MacKenzie et al. 2017).

2.3. Species Distribution Modelling

To get an estimate of areas suitable for Lantana that were not sampled by ground surveys; as well as for comparing niche disparity and similarity between the native and invaded ranges, we used Maximum Entropy (MaxEnt) (Elith et al. 2011, Phillips et al. 2004), one of the most widely used algorithms for niche modelling. MaxEnt calibrates environmental variables from species presence locations and compares them with a set of random sample locations from the study area (Presence-background model). It uses this calibrated relationship of species presence with environment variables to seek similar locations that would likely support the target species. The most unconstrained model developed is considered as the MaxEnt model (Phillip and Dudik 2008).

We divided the Lantana presence into three subsets based on the regions considered: native region (the central American), Indian invaded region (the tropical India) and global invaded range (Africa, Asia and Australia). Being presence-background model, the range of background environment substantially influences the response curve and subsequent distribution modeled through MaxEnt. It necessitates appropriate ecological criteria and sampling strategy to define the background (Elith et al. 2010, Webber et al. 2011). Since we only consider forested landscapes for this manuscript, background points were obtained only from the forested areas of the regions considered. Since, Lantana was not sampled systematically across its global range and to avoid any bias in our model by having background points that may come from areas

underrepresented in our sampling, we first modelled the kernel density of our sampling locations and specified the model to select background points from within this kernel surface in proportion to our sample distribution after dropping the pixels in which Lantana was detected. Within each region, we modeled the kernel density of the presence locations using kriging and used this surface to select background points. By doing this, we eliminate the effect of outlier in the environmental covariates that can result in overfitting the distribution of species. Within forests defined by this surface, we randomly selected 10,000 points (no more than one in 1 km²) to estimate the background environment in each region. The covariates from these background data were used to define the available environment for modeling climatic and ecological niches. Lantana presence points determined the selection of niche space in this environment by the species.

In order to avoid autocorrelation of the GBIF records, which tends to be biased towards more visited popular areas, we randomly selected only one presence within each pixel area (1 km²) in all regions. We randomly divided the presence locations into training (80%) and testing (20%) sets, using k-fold partitioning design, with k=5. We used each k-partitioned presence as an input data for MaxEnt. In the present study, linear and quadratic features were used to generate the MaxEnt model with 100 replicates for each model. Different thresholds of regularization parameter result in different MaxEnt output, where with increase in the regularization parameter, the output probability distribution gets smoothened (Elith et al. 2010). We built multiple models using these presence locations and covariate information with regularization parameter set as 0.25, 0.5, 0.75, 1, 1.25, 1.50, 1.75 and 2. MaxEnt modeled niche suitability as a probability for every pixel that varies from 0 to 1. In the present study, all pixels of the output raster that were greater than a threshold provided by the 10th percentile training presence, were considered as

potential suitable regions. Though somewhat subjective, these threshold criteria were considered as a robust cutoff in previous studies on Lantana in parts of India (Panda et al. 2018, Mungi et al. 2018). We further estimated the True Skill Statistics (TSS) for every model output in the Indian and global invaded region, wherein we used the confirmed occurrence location of Lantana from the ground surveys/GBIF and assessed the proportion of accurately classifying the testing data (20% data) (Liu et al. 2013). Area Under the Curve (AUC) of the MaxEnt model was considered as an additional criterion to assess the ability of the MaxEnt model to predict Lantana presence for each region (Hosmer and Lemeshow 1989). For Indian and global invaded region, we used the TSS as a primary indicator of accuracy and AUC as secondary, and rank different MaxEnt models generated with different settings of the regularization parameters, to select the model that yielded best TSS and maximum AUC. This regularization parameter was then used to model Lantana distribution in native region as well.

2.3.1. Regional ecological niche

We define the species' realized ecological niche as the space, where the species is constrained by abiotic and biotic factors (Colwell and Rangel 2009). We used the native and Indian invaded region to estimate the difference in realized niche, as we intend to understand the change in species relationship with its overall available environmental predictors using its realized niche. First, we used the presence points in the native range (n=2,572) along with climatic covariates (annual mean temperature, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, precipitation of wettest quarter and precipitation of driest quarter), soil CEC, summer NDVI, fire frequency and cumulative loss in GPP, in the above described MaxEnt settings. This provided us the realized ecological niche of Lantana in its native region. In order to understand the areas available for Lantana in India, we projected this native

ecological niche of Lantana to all forested areas of India. We call this the potential ecological niche of Lantana in India. Secondly, we used the surveyed Lantana presence ($n=7,238$) with the same environmental covariates (used for the native range model) in India to model the observed ecological niche of Lantana. Realized ecological niche represents suitability of area for being invaded by Lantana. We used it as an index of Lantana invasion in non-surveyed forests of India, as it was derived from a training sample of Lantana presence in surveyed forests and its eco-climatic covariates.

Further, we compared the relation between Lantana occurrence probability and environment covariates in its native and invaded range, also often known as functional response traits (Keddy 1992, Lavorel and Garnier 2002). For this, we used the response of Lantana to maximum temperature of warmest month as an index of thermal tolerance; soil CEC as an index of nutrient transfer; and pre-monsoon NDVI as an index of tolerance to the dense canopies (as explained earlier for occupancy models). In addition to this comparison of response, we plotted the distribution of Lantana along these variables in its native and invaded range and compared the difference in the distribution using a Student's t-test in the R ver. 3.5.0 environment (R Core Team 2018).

2.3.2. Global climatic niche

We define a species' climatic niche as the set of climates in which the species currently exist in its native range (Atwater et al. 2018). Unlike the covariates of ecological niche, to which the species can likely adapt in a shorter span of time and differentially in different ecological settings, adaptation to climatic covariates are known to take longer time and have an evolutionary footprint on the species (Gallagher et al. 2010, Mandle et al. 2010). However, the

evidences of change in the climatic niche are shadowed by the statistical limitations arising from data bias due to comparisons in climatically non-analogous areas.

To establish a valid comparison between the native and global invaded range, we defined the analogous climatic area by considering the following variables: annual mean temperature, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, precipitation of wettest quarter and precipitation of driest quarter for native and global invaded region (40° N to 60° S) at 30 Arc-second resolution (~1 km²).

For every pixel from within the native and global invaded region of Lantana, we extracted the values of the abovementioned variable as well as information on the occurrence of Lantana in that pixel. The entire set of these pixels from native and invaded range was then collated for each of the climatic variable. Principal components (PCs) were then extracted from the combined dataset of native and invaded range for all climatic variables to reduce dimensionality and redundancy of information (Jolliffe 2002). PCs that had Eigen values >1 were further used for assessing climatically analogous areas in native and invasive range. Subsequently, pixels with Lantana from the native and invaded range were plotted on the PC axes to visually discriminate them on the climatic niche axes. A formal analysis to identify analogous climatic space was undertaken using four different methods; NicheA, Mobility-Oriented Parity (MOP), Multivariate Environmental Similarity Space (MESS) and ExDent tool. NicheA generates two convex polyhedrons around the native and invaded climatic space, and estimates the overlap between polyhedrons, which represents similar climatic conditions in both the ranges. This overlapping climatic area of the polyhedrons was projected to the geographic space of both the native and global invaded region to identify analogous areas (Escobar et al. 2016). MOP measures Euclidean distances between climatic space of native and invaded range and excludes that

climatic space, which is outside the calibration region (Owens et al. 2013). MESS identifies dissimilar areas based on the statistical distance of climatic variables in native and invaded range from their common mean value (Elith et al. 2010). While these three methods identify univariate similarity in two areas, there might be a novel climatic combination not present in the native region, but only in the global invaded region; and is not addressed by using the abovementioned three methods. ExDent tool addressed this correlational similarity and helped identify climatic combinations that are novel in the global invaded region, as compared to the native region (Mesgaran et al. 2014). We subsequently visualize the output of these four methods for the Indian invaded region to understand the parity between the similar areas identified. The final area identified as analogous between the native and global invaded region was derived by intersecting the results obtained by these four models, in ArcGIS 10.6.1. This final analogous area was used as a conservative model of similar climatic surfaces for modelling and comparing climatic niche of *Lantana*.

We used the analogous areas between the native range of *Lantana* and its global invaded range to compare its potential climatic niche with the observed climatic niche. For this analysis we used presence locations of *Lantana* from its native range ($n=2,572$) and the climatic variables (annual mean temperature, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, precipitation of wettest quarter and precipitation of driest quarter) in MaxEnt, and projected this native climatic niche across the global invaded region. Subsequently, we used *Lantana* presence ($n=17,895$) from across its global invaded region to model its observed climatic niche using the same climatic covariates used for modelling in its native range. The difference in potential and observed climatic niche of *Lantana* across its global invaded range was estimated by using Schoener's D and Hellinger's distance I metrics available in

‘phyloclim’ package of R 3.5.0 (Heibl et al. 2013, R Core Team 2018). Secondly, the percentage of Lantana presence points that were not classified as presence by native climatic niche were used as an estimate of niche expansion within the analogous niche space in the invaded range. We used analogous climatic space between native and invaded areas to compare and understand Lantana’s response to bioclimatic variables. However, we also modelled climatically suitable areas for Lantana outside of this analogous space based on its global occurrence data. For this we used global occurrence (n=30,116), bias sampling mask file for MaxEnt to select background points (Elith et al. 2010), and the best regularization parameter determined by MaxEnt, using the aforementioned method. This approach allowed us to estimate the global potential area that could be invaded by Lantana.

3. Result

3.1. Occupancy modelling

Out of 13,715 grids surveyed, Lantana was detected in 5,334 grids (Figure 2a) giving a naïve occupancy estimate of 38.8%. Of the total 207,100 km² forest surveyed, Lantana was detected in 86,806 km². The model that best explained Lantana presence while correcting for imperfect detections differed from the next competing model by Δ AIC of 207, and from the null model by an Δ AIC value of 810 (Table 1). Lantana occupancy was best explained by a) Climatic variables: higher rainfall in the driest quarter and warm winters; b) Soil fertility surrogated by CEC and c) human impacts surrogated by logging and decline in GPP (Table 2). The model inferred Lantana occupancy was estimated to be $\psi = 39.39\%$ (SE 0.2). With high detection probability (64.3%), the increment in Lantana occupancy from 38.8% naïve estimate to 39.39% model inferred estimate was little. Since the survey was limited to forested areas, this occupancy estimate

depicts Lantana presence in forests of 18 Indian states. The bootstrap distribution of 1300000 runs from the best model did not differ from the observed data, suggesting that the model was a good fit (goodness-of-fit test, $P = 0.13$) and the $\hat{C}$ statistic was 0.97, suggesting absence of over-dispersion. Out of the total 207,100 km² of surveyed forest, 86,831 km² forests had high occupancy probability of Lantana with $\psi > 0.5$; 68,006 km² had low occupancy probability with $0.1 < \psi < 0.5$ and in 52,270 km² Lantana was practically absent, where $\psi < 0.1$. (Figure 2b).

Table 1. Model selection statistics of various models used to estimate Lantana occupancy in tropical India.

Model covariates	AIC	Δ	No. Par	-2 X loglikelihood
Null model				
ψ (.) P(.) Null model	79414.2	810.1	2	79410.2
Climate				
ψ (Precipitation of driest quarter (PD)). P(.)	79102.5	498.5	3	79096.5
ψ (Minimum temperature of coldest month (TM)). P(.)	79139.3	535.2	3	79133.3
ψ (PD+TM). P(.)	78836.2	232.2	4	78828.2
Soil				
ψ (Soil fertility (CEC)). P(.)	79374.2	770.2	3	79368.2
Anthropogenic Disturbance				
ψ (Tree lopping (TL)). P(.)	79401.5	797.5	3	79395.5
ψ (Tree cutting (TC)). P(.)	79428.9	824.8	3	79422.9
ψ (Livestock seen (LS)). P(.)	79284.4	680.4	3	79278.4

ψ (Number of human trails (HT)). P(.)	79377.2	773.1	3	792371
ψ (Cumulative loss in productivity (GPP)). P(.)	79076.5	472.5	3	79070.5
Combined climate, soil and anthropogenic disturbance				
ψ (TL+TC+LS+HT+PS). P(.)	79203.4	599.4	7	79189.4
ψ (PD+TM+CEC+TL+TC+LS+HT+PS+GPP). P(.)	78811.5	207.5	11	78789.5
ψ (PD+TM+CEC+TL+GPP). P(.)	78604.1	0	7	78590.1

Table 2. Coefficients of the best model that explained Lantana occupancy, while accounting for imperfect detections. Coefficients are listed in reducing order of importance following the intercept.

Covariates	Coefficient estimate	Standard error
Constant (Intercept)	-0.444	± 0.018
Rainfall of the driest quarter	0.316	± 0.02
Minimum temperature of coldest month	0.26	± 0.019
Soil cation exchange capacity	0.036	± 0.019
Average logging	0.016	± 0.018
Cumulative loss in productivity	-0.287	± 0.02
Detection Coefficient	0.587	± 0.01

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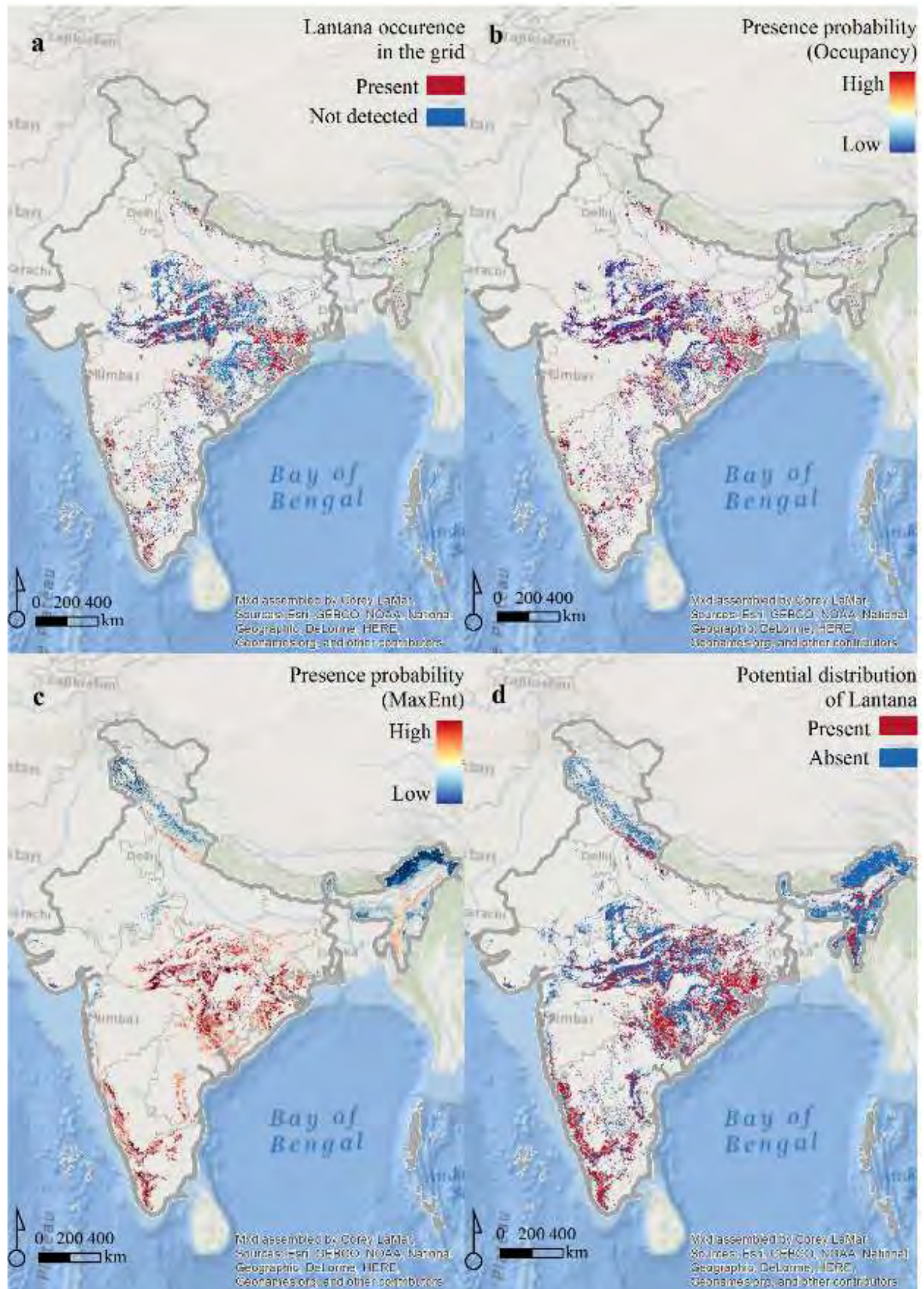


Figure 2. Lantana distribution in India. (a) Grid cells with Lantana presence (red cells) and where Lantana was not detected (blue), (b) Potential distribution of Lantana corrected for imperfect detection and site covariates in an occupancy framework (c) Areas susceptible for Lantana invasion modeled by MaxEnt for non-surveyed area using the information from surveyed area and, (d) An aggregated distribution of Lantana in forests of India, obtained by ensembling occupancy estimates for ground surveyed areas (in the year 2010) and MaxEnt models beyond ground surveyed areas.

3.2. Regional ecological niche:

Highest modelling accuracy, as depicted by TSS=0.69 (± 0.04), was when the regularization parameter was kept at 1. Minimum temperature of coldest month, soil CEC, maximum temperature of warmest month, pre-monsoon NDVI and loss in GPP explained more than 80% of Lantana presence in its native and invaded Indian range (Suppl. material 1, Table S2). Lantana's ecological niche model trained on its native environment had an AUC=0.80 (± 0.06), suggesting a good model fit. When projected to India, this potential ecological niche was a subset of its realized ecological niche, which in turn had a good model fit (AUC=0.73 ± 0.01 , TSS=0.68). Furthermore, the realized ecological niche in India estimated the area suitable for its invasion outside the surveyed area to be 148,770 km² (Figure 2c).

The relationship of Lantana occurrence with covariates differed substantially in magnitude and form between its native and invaded range (Figure 3). In case of temperature of warmest month, the distribution in India significantly exceeded (P-value < 0.005; Figure 3c) the upper range of distribution in Central America (41° C; Figures 3a and 3b). Lantana showed a parabolic relationship with soil CEC in its native range (Figure 3d) with maxima at 50 meq⁺/100g, while in India the relationship was a reverse parabolic with CEC (Figure 3e); however, the difference in

distribution against soil CEC was insignificant (P -value > 0.9 ; Figure 3f). In case of pre-monsoon Normalized Differential Vegetation Index (NDVI) that represents canopy cover, the distribution of Lantana in India was seen to be constrained within a small range which is significantly different subset ($P = 0.1$) of its distributional range in Central America (Figure 3i). However, within this range, the response of Lantana to NDVI has changed. Lantana distribution in Central America increased with NDVI till the threshold of 0.2, after which it decreased (Figure 3g); while in India the threshold was observed to have shifted to 0.7 and the response was a linear increase with a short asymptote (Figure 3h).

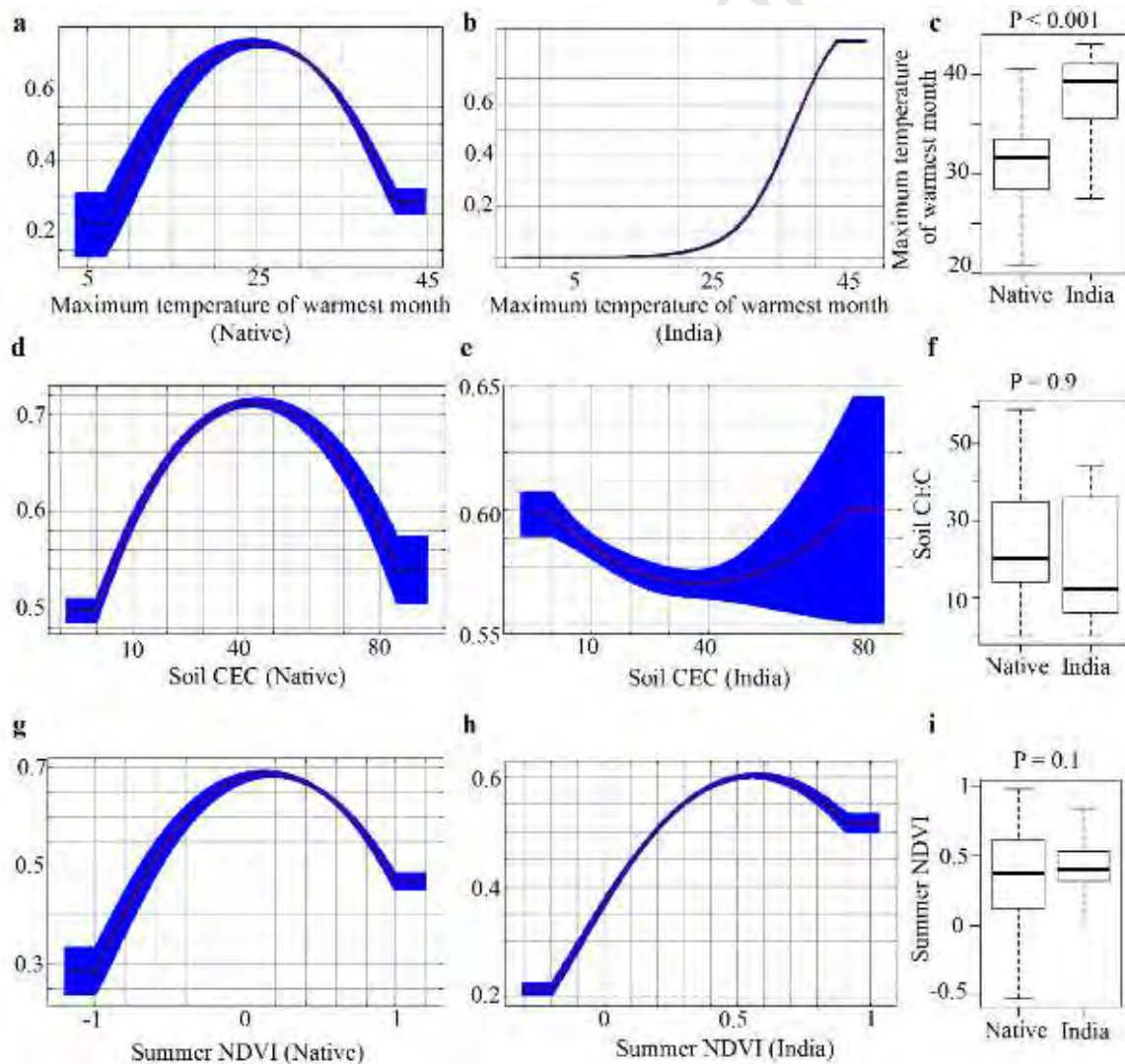


Figure 3. Response of *Lantana camara* heat tolerance, soil fertility, and light availability in native Central America and in invaded India. Response of Lantana to highest temperature in the warmest month in Native America (a), Invaded India (b), and the box plot showing the increase in high temperature tolerance in India (c); Response of Lantana to soil Cation Exchange Capacity (CEC) in native America (d), observed in India (e), and the box plot showing Lantana distributed within the same range in Native America and invaded India (f); With regard to summer Normalized Differential Vegetation Index (NDVI) Lantana decreased with increased NDVI in native America (g) and increased in invaded India (h), but the niche width of Lantana with respect to NDVI was similar (i).

3.3. Analogous areas in native and invasive range

Three Principal Components cumulatively explained 99% of the variance in the climatic data in native and global invaded region (Suppl. material 1, Table S3). The first PC comprised areas with increasing annual precipitation and decreasing temperature; the second PC represented wet areas that have lower annual temperature and winter temperature; and the third PC represents areas with increasing annual precipitation and reducing aridity (higher rainfall in driest month) (Figure 4). These PCs were used for assessing the climatically analogous areas in native and invasive range. When the subset of results for India was explicitly visualized for the four models (NicheA, MOP, MESS and ExDent) to see consistency in identifying areas of similar climatic conditions, the models were consistent in identifying a common analogous climate area in the drier areas in western and southern India, the Gangetic river basin, northeastern hills and the Eastern Ghats (Suppl. material 1, Figure S1). In doing so, the largest dissimilar area was identified by ExDent, followed by MESS, NicheA and MOP. An intersection of these model

helped derive the largest dissimilar climatic surface, and remove from the analysis of niche comparison.

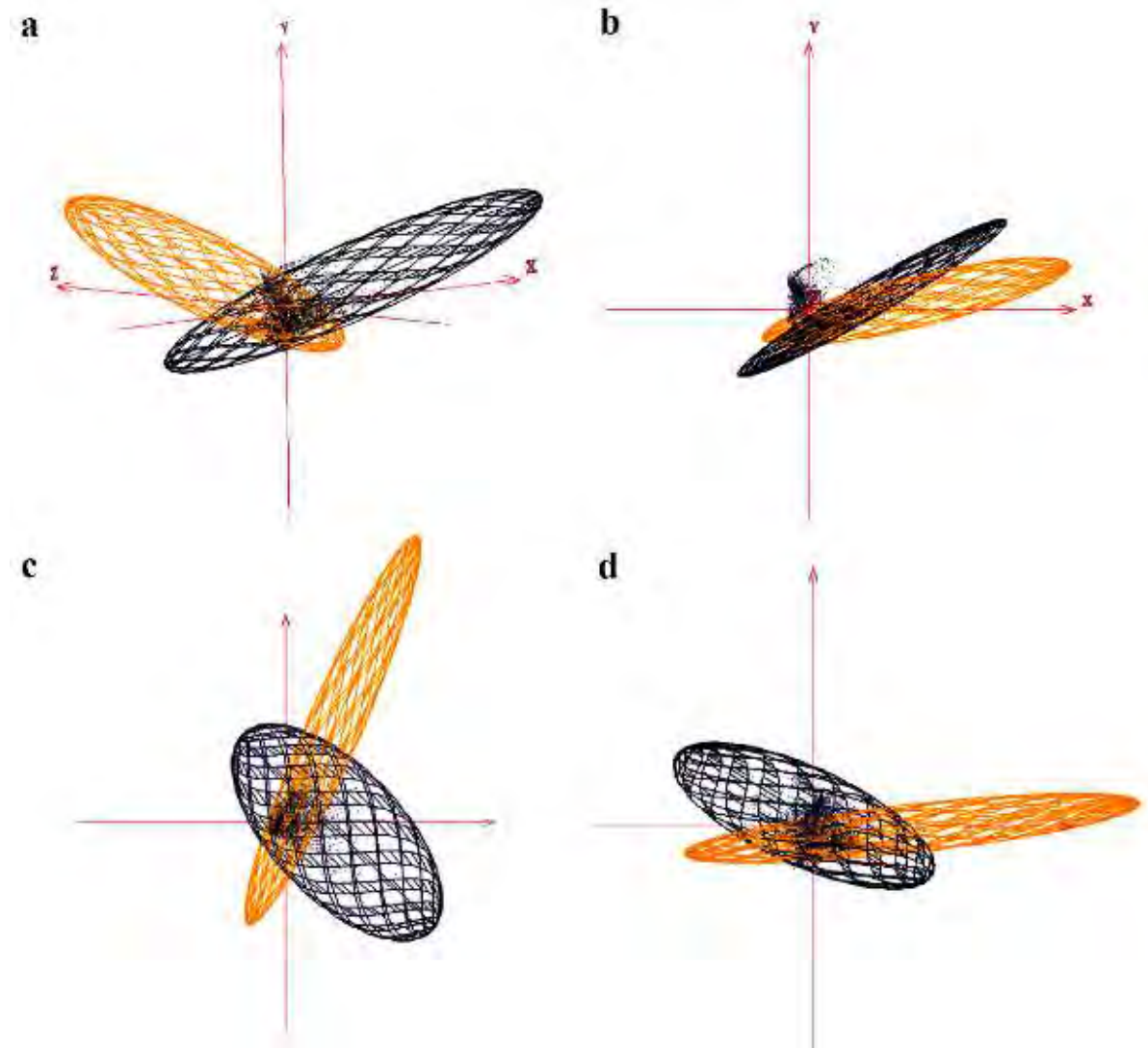


Figure 4. Distribution of *Lantana camara* along the three principal components representing climatic factors of native (Central America: yellow polyhedron) and global invaded region (Africa, Asia and Australia: black polyhedron). Grey points represent climatic space not occupied by *Lantana*. Axis X represents increasing annual rainfall and increasing temperature, axis Y represents increasing cooler winters and axis Z represents reducing aridity (Suppl.

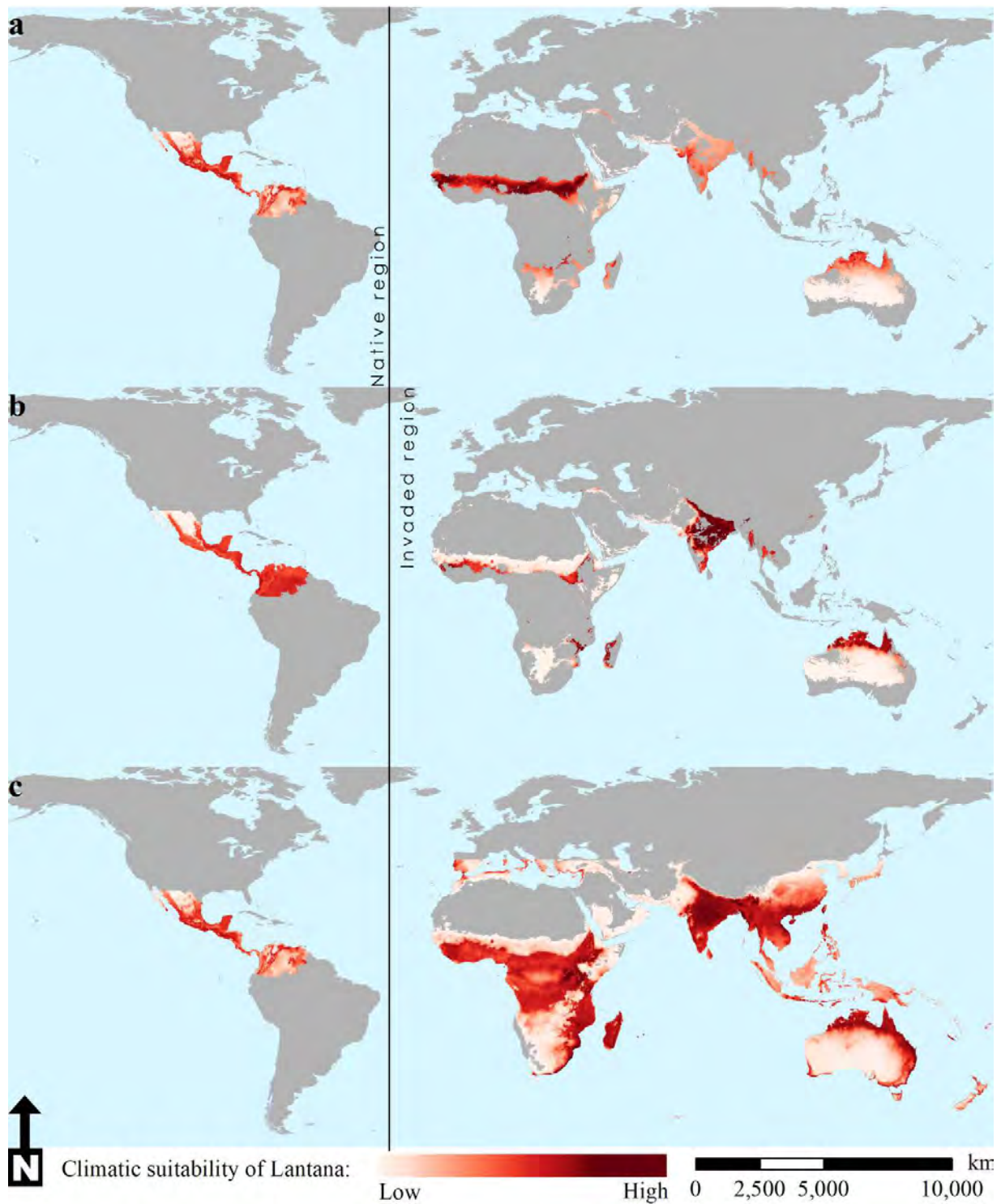
material 1, Table S3). Visualization of distribution on (a) three-dimensional climatic axes, (b) X and Y axis, (c) Y and Z axis, and (d) X and Z axis.

3.4. Global climatic niche:

Highest modelling accuracy, as depicted by TSS=0.72 (± 0.05), was when the regularization parameter was kept at 1. Annual precipitation and precipitation of the driest month together explained more than 90% of the global Lantana distribution (Table S4). The climatic niche model of Lantana had an AUC=0.74 (± 0.01) in native region, and an AUC=0.70 (± 0.02) and TSS=0.76 in global invaded region. The native niche when projected on the global invaded region (Figure 5a) was found to be a subset of the observed global invaded climatic niche of Lantana (Figure 5b). Within the invaded range 58% ($\pm 6\%$) Lantana presence points were outside the projected native climatic niche of Lantana. The Hellinger distance I and Schoener's D value of similarity in potential and observed climatic niche of Lantana was 0.39 and 0.42 (P-value = 0.12), suggesting an ecologically relevant, but statistically insignificant difference.

For the global model, highest accuracy as depicted by TSS=0.66 (± 0.08), was when the regularization parameter was kept at 1. Annual precipitation, precipitation of the driest quarter and temperature of the coldest month together explained more than 90% of the global Lantana distribution (Table S5, response curves provided in Figure S2). This climatic niche model of Lantana had AUC = 0.62 (± 0.02). Across the global range, an area of $\sim 11,631,000 \text{ km}^2$ (10,898,000 to 12,225,000 km^2) was found to be climatically suitable for Lantana invasion (Figure 5c, Figure S3). Within countries, highest suitable areas available for Lantana were in: India ($\sim 1,351,000$ (1,303,000 to 1,381,000) km^2), Australia ($\sim 867,980$ (790,000 to 929,000) km^2), China ($\sim 317,970$ (283,770 to 349,790) km^2), Mozambique ($\sim 287,280$ (263,170 to 311,250) km^2), Madagascar ($\sim 244,360$ (223,670 to 261,710) km^2), Ethiopia ($\sim 241,070$ (212,230 to

473 265,390) km²), Myanmar (~183,750 (165,550 to 195,330) km²), Vietnam (~106,340 (98,130 to
474 111,260) km²), Tanzania (~104,850 (87,560 to 121,490) km²) and South Africa (~98,710 (88,080
475 to 107,100) km²).



477 **Figure 5:** Climatic niche of Lantana in its global range: (a) climatic niche of Lantana modeled
 478 from presence in the its native range and projected to analogous areas in its global invaded range

(b) climatic niche of Lantana in analogous areas of its global invaded range as modelled from its presence in these areas (c) global climatic suitability of Lantana modelled from its global presence).

4. Discussion

Lantana was found to have invaded 86,806 km² forests (38.8%) of India, particularly in degraded forests of hot and humid areas. Lantana was found to be widely distributed across landscapes with maximum invasion in fragmented dry deciduous forests of Central India, Shivalik hills of North India and Southern Western Ghats. Relatively less area was recorded to be invaded in the Northeastern tropical forests, Northern Western Ghats and semi-arid and arid landscapes of Western India (Figure 6). With this large invaded range, Lantana is probably the most widely distributed invasive plant in India, as compared to other invasive plants (Mungi et al. 2019, Mathur et al. 2015). Addition of the recorded locations of Lantana from India to the global presence location, revealed that an area larger than ever recorded before was suitable for Lantana invasion. This expansion in its invaded range was also found to be correlated with its increased tolerance to higher temperatures, lower fertility and denser canopy cover as compared to its native range. For an invasive species, change in its thermal tolerance and resource preference within a short span of time poses interesting question on its plasticity and/or adaptability; which in either case suggests that a larger area could be globally invaded with time. Our results highlight the role of forest degradation and climate change in elevating the global risk of biological invasions, and the importance of large-scale ecological monitoring for a better understanding of invasions that can potentially guide management actions.

In the case of Lantana, we sampled plots of 10 m diameter ranging between 1-31 within each 25 km² grid cell. Detection within each of these plots was not a concern as Lantana presence would

be detected without bias, but it was possible that the placement of plots missed Lantana occurrence within the 25 km² grid. Occupancy analysis explicitly addresses the limitation of imperfect detection, while providing insights into relationships of occurrence with covariates (MacKenzie et al. 2017). We found that the average detection probability by a single plot for a grid was 0.64 (SE 0.03) and bias resulting from imperfect detection was negligible as the model inferred occupancy estimate of Lantana differed from the naive estimate by only 0.71%. Thus, we probably missed detecting Lantana on 92 out of 13,715 sampled grids. The total forested area in the 18 states covered 15,312 grids, out of which 13,715 were sampled, which amounted to ~81% of total forested area being sampled. The unsampled grids were either under political unrest or inaccessible due to logistic constraints. The occupancy model helped us understand the potential status of Lantana in these areas. The occupancy covariates enhanced our understanding on factors that facilitated and limited the occurrence of Lantana in India at a scale of 25 km², which is relevant for ecological understanding and management interventions. MaxEnt models rely on presence information, modeled against the background with covariates to predict suitable sites where the species can potentially occur (Elith et al. 2011). Additionally, occupancy models also consider imperfect detections and therefore are more reliable. For this reason, we used occupancy-inferred presence within 207,100 km² of forests that were ground surveyed and MaxEnt inferred suitable areas for invasion within the remaining 494,573 km² to get the most reliable total estimate of areas threatened by Lantana invasion to be 303,607 km² in forested landscapes of India (Figure 2d).

Previous studies used climatic niche model of Lantana as a surrogate for its distribution (not as potential habitats) using a limited number of secondary or primary occurrence data (e.g. 2,526 locations by Panda et al. 2017; 2,526 locations by Bahuguna 2015). These studies suffer from

paucity of data and faulty inferences from the models. In the current study, we use data that were obtained from one of the largest known systematic sampling for any invasive plant. Thus, the ground validation data used by us is much larger and from across an ecological scale relevant for modelling multi-landscape distribution. We subsequently used a robust approach to model-based inference using ecologically relevant covariates (e.g. Qiao et al. 2017, Beck et al. 2014).

Furthermore, previous few studies have attempted modelling the global distribution of *Lantana* using proportionally fewer occurrences from India from a smaller geographical extent, and this is likely the scenario of data from other countries as well (e.g. Taylor and Kumar 2012, Taylor et al. 2012, Bhagwat et al. 2012, Taylor and Kumar 2014, Gonclaves et al. 2014, Qin et al. 2015). By the use of a substantially larger training dataset the reliability of our inferences are better than previous estimates and we also provide estimates with the associated uncertainty. The climatic niche of *Lantana* in its global invasion range was substantially larger than the one projected from its native region. This expansion was estimated only in the climatically analogous areas of its native and invasive range, thus having a statistical power to highlight the expansion. As compared to previous global projections, we show that *Lantana* could potentially invade novel climatic regions in India, Myanmar, Thailand, Philippines, Pakistan, Northern Australia, Madagascar, Mozambique, Malawi, Ethiopia and parts of Oceania. Our global potential niche revealed large extent in Nigeria, Mali, Gambia, Sudan, and surrounding countries, from which *Lantana* presence was not available. This could either be due to paucity of sampling in these areas or actual absence. Future invasions in these countries should be monitored in order to arrest the invasion in its initial phase. It is also possible that *Lantana* has already invaded many of these potential areas which have not yet been sampled for occurrence. Our models highlight such areas across the world which should be sampled on priority. Across its invasive range, the expansion

was partial towards warm and humid climatic areas and coincided with mesic savannahs in the region.

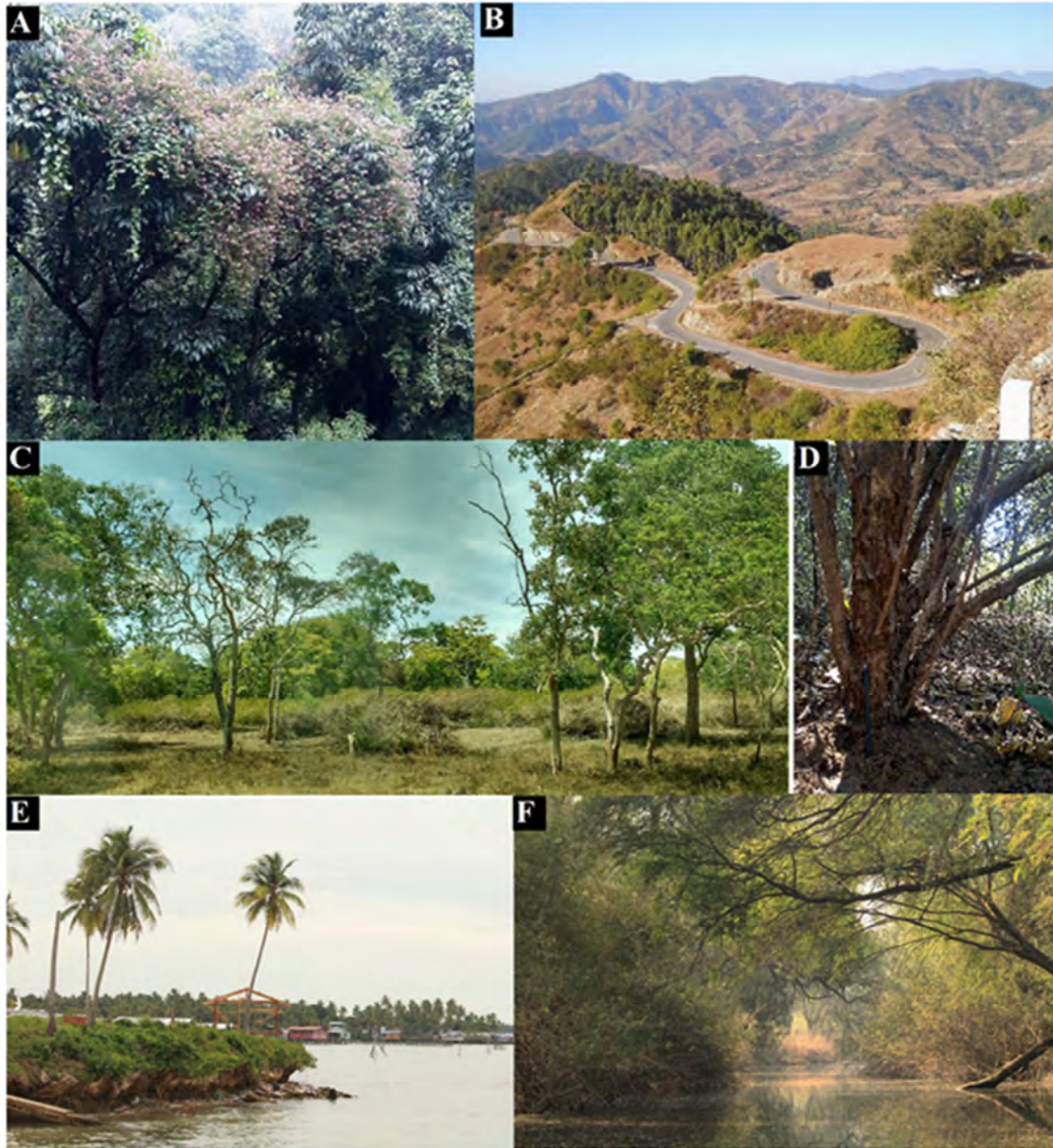


Figure 6: Diverse habits and habitats of Lantana in India: Lantana was recorded in different habits across different biogeographic realms in India. Here we show the climber ecotype of Lantana in evergreen forests of the Western Ghats (A); shrub ecotype in the Western Himalaya

(B) and dry savannas of Central India (C); Tree (bole girth > 15 cm) ecotype in the mesic savannas of central Indian highlands (D); short shrub ecotype on the coastal sand dunes (E); and emergent shrub ecotype in the wetlands of semi-arid India (F).

As a consequence of the ongoing global climatic changes, the countries invaded by Lantana are prone to have warmer winters and rainfall in the driest season (Devraju et al. 2015), which in turn will elevate the humidity of an area (Jin and Wang 2018). We show both of these traits to facilitate the invasion of Lantana across its global range. Management of Lantana, in India costs ~\$18,700 per km² (Babu et al. 2009). With the current expanse, the cost estimate of Lantana management exceeds \$5.5 billion in India (which is ~\$1 billion more than the total funds allocated to the Ministry of Environment, Forest and Climate Change, Government of India, in the year 2019), and proportionately more globally. While management of Lantana can be a costly affair, its invasion in novel climatic areas elevate the financial investment as more and more areas could be invaded by it. It further raises an ecological conundrum of managing a species that is potentially evolving to the regional environment (Mungi and Qureshi 2018). Many scholars suggest that if a species is evolving to the ecological settings of the landscape, and is being used by other species, one can categorize it as a novel 'native species' evolving in the times of global changes (e.g. Pearce 2015). These arguments might prevent any control mechanisms to arrest the invasion and can potentially lead to decline in the native biodiversity. Hence, it is critical to understand the reasons for Lantanas' potential adaptability and invasion success.

The observed success of invasion, like in many other cases, can be interpreted in the light of availability of suitable niche, inherent phenotypic plasticity that optimizes the fitness in the new environment, and/or contemporary adaptation to the new conditions (Hulme and Barrett 2013).

In India, most of the forests are used by local communities for livelihood and many areas are degraded by ecologically unsustainable uses of varying degrees (DeFries et al. 2010, Agarwala et al. 2016). In such areas the threat of Lantana invasion is higher, as inferred from our occupancy and MaxEnt models. Besides Lantana occupancy being promoted by human disturbance-induced degradation of native forests, it was also enhanced by warmer and more humid climates. Thus, the success of Lantana invasion in India is likely attributed to increasing availability of suitable climate and facilitation by reduced competition through human induced degradation. Unlike other tropical developing countries, where forested areas are reducing due to increased developmental activities, forest area in India was reported to increase at a rate of 1120 km²/year over the last decade (FSI 2019). We flag the increase shown in the forest cover which differentiates between plantations and invasive plants should be a vital element for long-term monitoring. Currently, we believe that these distinction between native forest, forest plantations and forest dominated by invasive species are not differentiated appropriately to justify increase in forest cover. We show that forest degradation caused by anthropogenic activities and/or global climatic changes could be in fact converting the native forests into invaded green patches, which could be mistaken as forest (e.g. Koulgi et al. 2019). This confusion can mislead forest policy, investment in management actions and subsequently compromise conservation objectives.

Climatic niche is used as proxy for fundamental niche, which is bounded by the environmental tolerances of the species (Hutchinson 1957). Hence, shifts in the realized climatic niche of species has been proposed as indirect evidence for adaptation by invasive species to novel environments (Gallagher et al. 2010, Mandle et al. 2010). In the present case study, the climate in parts of Africa, Asia and Australia was analogous to that observed in Central America - the native range of Lantana. Within this analogous climatic space, Lantana's climatic niche has

significantly expanded. The increase in climatic tolerance observed in invaded region could be due to either predator/pathogen/competition release or phenotypic plasticity or adaptive evolution. Considering the covariates representing climate, soil resources, dense canopies and disturbance by fire in India (analogous as well as novel) we found that Lantana has invaded an additional novel niche space on the axis of increasing temperature, lower soil fertility and loss of productivity of invaded forests.

Previous studies (Blossey and Notzold 1995) suggested that escape from specialist natural enemies could result in increased competitiveness of invasive plants leading to contemporary evolution. The invaded population of Lantana was found to be more tolerant to denser canopies, which could possibly be due to its enhanced competitiveness. A phenotypic variant of Lantana in India, which is a climber, enables it to access sunlight even in dense canopied forests (Figure 6). A recent study further demonstrated that such a phenotypic variant may increase the performance and success of Lantana invasion in forested areas (Goyal and Sharma 2018). Moreover, as a result of global climate change, many areas are experiencing warmer summers (Sharmila et al. 2015) and increased soil acidity that results in low fertility (Bhattacharyya et al. 2015). For any invasive plant an ideal phenotypic optimum will be to exploit these changes (Corlett and Westcott 2013, Richards et al. 2006), which was observed in the case of Lantana invasion. If the species shows significant difference in traits between native and invaded areas it clearly indicates its phenotypic plasticity, which, if responsible for higher fitness of the species, could be considered adaptive (Sultan 1987, Pigliucci 2001). This adaptation could be due to inherent genetic plasticity or due to genotypic change (Sultan 1987).

Genetic studies of Lantana in India (Ray and Quader 2014) have found higher genetic diversity with private alleles and multiple genetic clusters across India, suggesting multiple introductions

of *Lantana* with novel founders each time. This was further validated by naturalist record from 19th century that indicated multiple introductions from various sources in India (Kannan et al. 2013). Another study (Ray and Ray 2014) on *Lantana* in India suggested that the multiple genetic clusters could be responsible for local adaptation and it could represent early stages of ecological divergence. Thus, in addition to global climatic niche shift and shifts in response norms, both of which are suggested to be the evidence for rapid adaptation (Pearman et al. 2008, Gallagher et al. 2010, Mandle et al. 2010), genetic evidence suggests high genetic diversity as a result of multiple introductions and probable hybridization after introduction of previously allopatric populations of *Lantana*. These genetic changes can also be considered as suggestive of adaptive plasticity in the introduced populations. The above evidence supports the hypothesis (De Jong 2005) that phenotypic plasticity provides rapid opportunity for natural selection to operate and facilitates first steps in the adaptive walk by a species, which otherwise would depend on new mutations (Travis 1994, West-Eberhard 2003). Nevertheless, further experiments comparing populations from native and invasive areas are required for confirming that these phenotypic changes have a genetic basis to show conclusive support of contemporary evolution. Previous studies investigating the effects of climatic changes on invasion by *Lantana* assumed that *Lantana*-climate relation would be preserved across space and time (Kannan et al. 2013, Goncalves et al. 2014, Panda et al. 2017). Our study results flag a caution on such an approach, which assumes that the niche of a species to be at equilibrium and retain its response to climate. Such assumptions could underestimate the actual threat potential of invasive species to ecosystems. *Lantana* has invaded around 75 countries and poses a serious threat to their native biodiversity. The methodological approach used in the current study could be adapted as a model for studying and managing *Lantana* and similar biological invasions elsewhere. It can lend

support for encouraging national initiatives for large-scale intensive monitoring of ecosystems to inform policy and management decisions.

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- 890

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Figure 1. Lantana presence locations from its native range in tropical America (blue), and invaded range (GBIF data (orange) and field sampling based data from India (maroon)) used in the study

Figure 2. Lantana distribution in India. (a) Grid cells with Lantana presence (red cells) and where Lantana was not detected (blue), (b) Potential distribution of Lantana corrected for imperfect detection and site covariates in an occupancy framework (c) Areas susceptible for Lantana invasion modeled by MaxEnt for non-surveyed area using the information from surveyed area and, (d) An aggregated distribution of Lantana in forests of India, obtained by ensembling occupancy estimates for ground surveyed areas (in the year 2010) and MaxEnt models beyond ground surveyed areas.

Figure 3. Response of *Lantana camara* heat tolerance, soil fertility, and light availability in native Central America and in invaded India. Response of Lantana to highest temperature in the warmest month in Native America (a), Invaded India (b), and the box plot showing the increase in high temperature tolerance in India (c); Response of Lantana to soil Cation Exchange Capacity (CEC) in native America (d), observed in India (e), and the box plot showing Lantana distributed within the same range in Native America and invaded India (f); With regard to summer Normalized Differential Vegetation Index (NDVI) Lantana decreased with increased NDVI in native America (g) and increased in invaded India (h), but the niche width of Lantana with respect to NDVI was similar (i).

Figure 4. Distribution of *Lantana camara* along the three principal components representing climatic factors of native (Central America: yellow polyhedron) and global invaded region (Africa, Asia and Australia: black polyhedron). Grey points represent climatic space not

occupied by *Lantana*. Axis X represents increasing annual rainfall and increasing temperature, axis Y represents increasing cooler winters and axis Z represents reducing aridity (Suppl. material 1, Table S3). Visualization of distribution on (a) three-dimensional climatic axes, (b) X and Y axis, (c) Y and Z axis, and (d) X and Z axis.

Figure 5: Climatic niche of *Lantana* in its global range: (a) climatic niche of *Lantana* modeled from presence in the its native range and projected to analogous areas in its global invaded range (b) climatic niche of *Lantana* in analogous areas of its global invaded range as modelled from its presence in these areas (c) global climatic suitability of *Lantana* modelled from its global presence).

Figure 6: Diverse habits and habitats of *Lantana* in India: *Lantana* was recorded in different habits across different biogeographic realms in India. Here we show the climber ecotype of *Lantana* in evergreen forests of the Western Ghats (A); shrub ecotype in the Western Himalaya (B) and dry savannas of Central India (C); Tree (bole girth > 15 cm) ecotype in the mesic savannas of central Indian highlands (D); short shrub ecotype on the coastal sand dunes (E); and emergent shrub ecotype in the wetlands of semi-arid India (F).

931 **Author contribution statement**

932 QQ, NAM and YVJ conceived the study; YVJ and QQ coordinated the data collection; NAM
933 analyzed the data and wrote the manuscript with active inputs from YVJ and QQ.

934 **Competing interests**

935 The authors declare no competing interests.

936

Journal Pre-proof

SUPPLEMENTARY MATERIAL 1

Title

Expanding niche and degrading forests: key to the successful global invasion of *Lantana camara*
(sensu lato)

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Table S1. Summary of the covariates used for predicting *Lantana camara* distribution in India. Remotely sensed data, their sources, scale and relevance that were used as an index of environmental parameters for explaining the occurrence of *L. camara*.

Covariates	Source	Scale	Relevance
Minimum temperature of coldest month	www.worldclime.com/version2 (Fick and Hijmans 2017)	30 Arc seconds (~1 km)	Lantana cannot germinate in extreme cold temperature (Mungi et al. 2018)
Maximum temperature of warmest month	www.worldclime.com/version3 (Fick and Hijmans 2017)	30 Arc seconds (~1 km)	Lantana cannot germinate in extreme hot temperature (Gonclaves et al. 2014)
Precipitation of driest quarter	www.worldclime.com/version4 (Fick and Hijmans 2017)	30 Arc seconds (~1 km)	Rainfall in dry season help break Lantana seed dormancy (Qin et al. 2016)
Precipitation of wettest quarter	www.worldclime.com/version5 (Fick and Hijmans 2017)	30 Arc seconds (~1 km)	Rainfall in wet season induces higher productivity (Gonclaves et al. 2014)
Annual precipitation	www.worldclime.com/version6 (Fick and Hijmans 2017)	30 Arc seconds (~1 km)	Provides an index of soil water available for plant growth (Gonclaves et al. 2014)
Annual mean temperature	www.worldclime.com/version7 (Fick and	30 Arc seconds (~1 km)	Provides an index for temperature required for plant metabolism (Mungi et al.

	Hijmans 2017)		2018)
Soil CEC	Harmonized World Soil Database (Batjes 2009)	1 km	Fertility of soil needed for plant growth and reproduction (Sahu 1998)
Pre-monsoon NDVI	MODIS 16-days composite (Huete et al. 2002)	230 m (rescaled to 1 km)	Provides an index of light available for plant growth
Gradual loss in GPP	MODIS 16-days composite (Heinsch et al. 2003)	230m (rescaled to 1 km)	Provides an index for competition due to bigger/denser trees (Humphries and Stanton 1992)
Fire frequency	FIRMS (composite of MODIS fire detect product and VIIRS) (Giglio et al. 2003, Schroeder et al. 2014)	375 m	Lantana is facilitated by burning of native vegetation (Mungi et al. 2018)

Table S2. MaxEnt realized niche model. The covariates and their percent contribution for explaining the realized niche of *Lantana camara* in its native and invaded Indian region as modeled in MaxEnt. The model was built on Lantana presence in native region using climatic, edaphic, biotic and disturbance covariates and then projected to India. The contribution of different covariates to this model is placed under ‘Percent contribution in native range’. Subsequently, a model was built using Lantana presence in invaded Indian region using the same covariates. The contribution of different covariates to this model is placed under the column header of ‘Percent contribution in invaded Indian range’.

Variable	Percent contribution in native range	Percent contribution in invaded Indian range
Minimum Temperature of Coldest Month	38.8	27.9
Soil CEC	27.5	1.7
Maximum Temperature of Warmest Month	8.6	12.1
Pre-monsoon NDVI	6.9	22.2
Gradual loss in GPP	5.8	0.9
Precipitation of Driest Quarter	5.3	5.8
Fire frequency	3.9	0.9
Precipitation of Wettest Quarter	2.3	7.4
Annual Precipitation	0.6	7.9
Annual Mean Temperature	0.4	13.2

Table S3. Principal components explaining the variance in the climatic data of Central America and India. Variables with maximum loadings on the components are marked in bold. The climatic variables were downloaded from www.worldclime.com/version6 (Fick and Hijmans 2017).

Variables	Principal components		
	1	2	3
Maximum temperature of warmest month	0.03	-0.39	0.00
Minimum temperature of coldest month	0.14	-0.69	-0.19
Precipitation of wettest quarter	0.37	-0.08	0.80
Precipitation of driest quarter	0.10	0.13	-0.52
Annual mean temperature	0.09	-0.56	-0.08
Annual precipitation	0.91	0.19	-0.23
Eigenvalue	176387.91	16793.91	4502.60
Percent variation explained	88.70	8.44	2.26
Cumulative percent variation explained	88.70	97.14	99.40

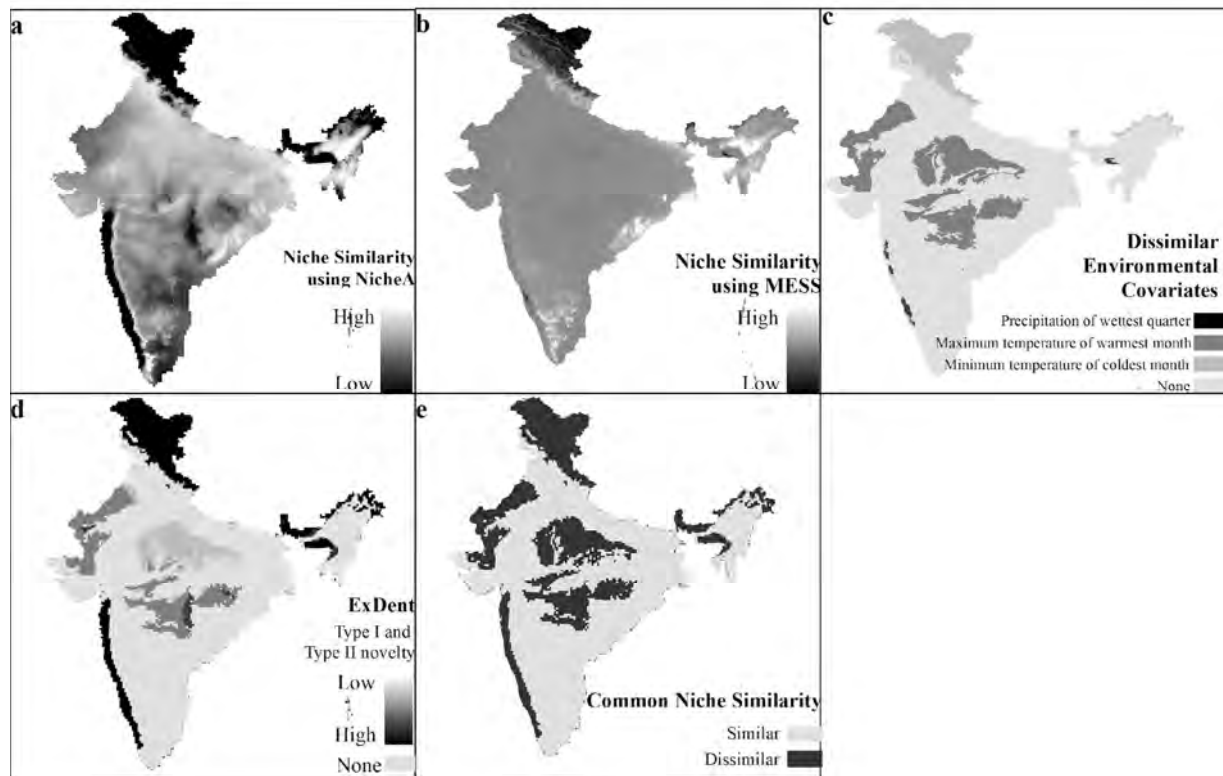


Figure S1 Map depicting similarity in climate of India as compared to Central America and estimated using NicheA (a), MOP (b) MESS (c) and ExDent (d). The climatically analogous area (e) was extracted by intersection of similar areas identified by all four methods.

Table S4. MaxEnt global analogous climatic niche model. The covariates and their percent contribution for explaining the climatic niche of *Lantana camara* in its native and invasive region as modeled in MaxEnt. The model was built on lantana presence in native region using climatic covariates and then projected to India. The contribution of different covariates to this model is placed under ‘Percent contribution in native range’. Subsequently, a model was built using Lantana presence in global invaded region using the same climatic covariates. The contribution of different covariates to this model is placed under the column header of ‘Percent contribution in invasive range’

Variable	Percent contribution in native range	Percent contribution in invasive range
Minimum Temperature of Coldest Month	53.6	20.2
Annual Precipitation	20.1	38.9
Precipitation of Driest Quarter	11.7	10.7
Maximum Temperature of Warmest Month	7.3	2.7
Precipitation of Wettest Quarter	4.9	20.6
Annual Mean Temperature	2.3	7

Table S5. MaxEnt global climatic niche model. The covariates and their percent contribution for explaining the climatic niche of *Lantana camara* across its globally invaded range modeled in MaxEnt. The model was built using Lantana presence in global invaded region using climatic covariates.

Variable	Percent contribution
Minimum Temperature of Coldest Month	18.2
Annual Precipitation	63.9
Precipitation of Driest Quarter	14.4
Maximum Temperature of Warmest Month	1.4
Precipitation of Wettest Quarter	1.8
Annual temperature	0.3

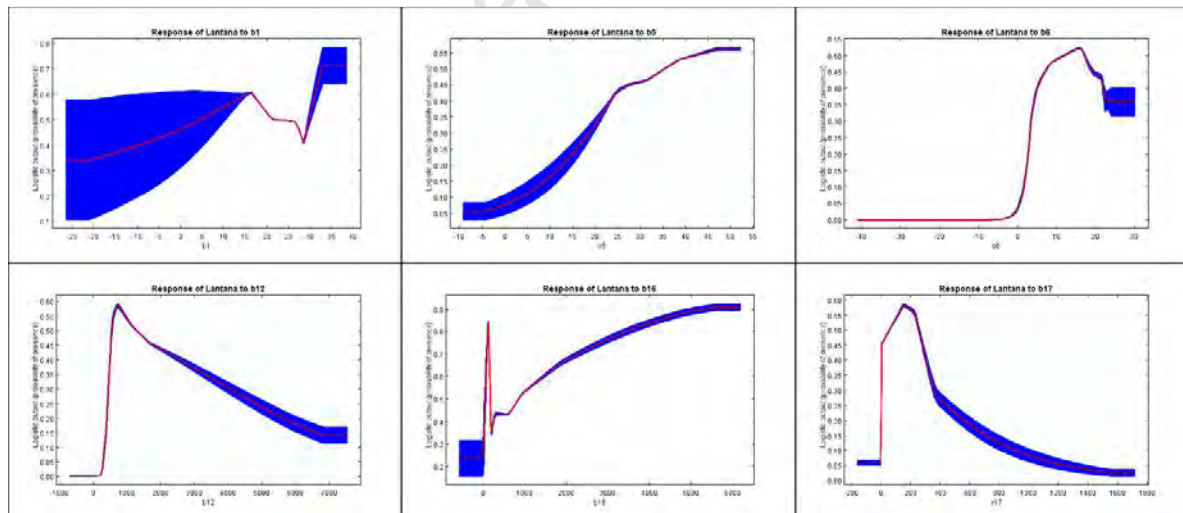


Figure S2: Global response of Lantana to annual temperature (b1), temperature of warmest month (b5), temperature of coldest month (b6), annual precipitation (b12), precipitation of driest quarter (b17) and precipitation of wettest quarter (b16).

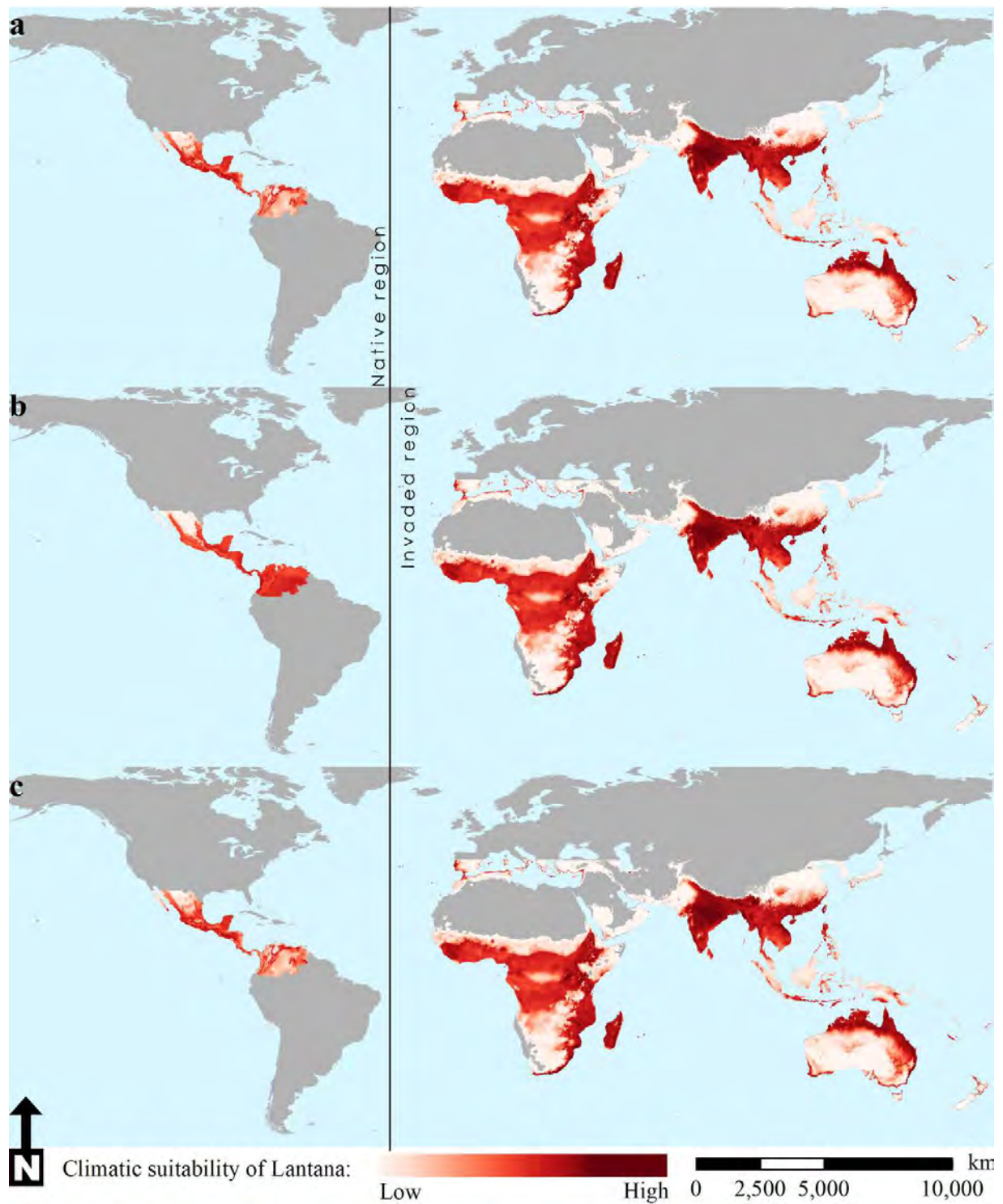


Figure S3: Standard error uncertainties around the global climatic suitability of Lantana: a) the minimum climatic suitability of Lantana, b) the average climatic suitability of Lantana, and c) the maximum climatic suitability of Lantana.

1001

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Highlights:

- *Lantana camara* has invaded more than 60 countries, depleting biodiversity and associated services.
- Through a record sampling ($>200,000 \text{ km}^2$), we found *Lantana camara* invaded in 44% of Indian forests.
- Its global invasion potential was found higher than reported before, which demands massive resources for management.
- While degrading forest and changing climate is facilitating its invasion, species' adaptive plasticity avails its expansion in newer niche dimensions.

Competing interests

The authors declare no competing interests.

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Management of
Human – Wildlife
Interactions
and
Invasive Species
in India



Wildlife Institute of India 2015

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Executive summary

Human – carnivore conflict is perceived as one of the most negative interactions in wildlife and humans, owing to the direct loss of human life associated with the presence of carnivore. Tiger, lion, leopard, snow leopard, wolf, dhole and bear are the most conflict related species. Studies on conflict related to tiger, lion, snow leopard and leopard are available while that for wolf, dhole and bear are rarely conducted. Owing to the conservation value of tiger and lion, guidelines and policies have been centered to the conflict related to these flagship species. In almost all the cases, management system has guaranteed economic compensation. Standard operating protocol (SOP) is developed for identifying and removing an individual that has repeatedly reported in conflict with humans. As few of these carnivores need healthy habitat and ample prey species for their sustenance, co-existence with increasing human pressure seems distinct from the present facts. Thus, in order to minimize the negative interaction, it is essential to relocate human settlement from the protected areas inhabited by these species. Attack by leopard on humans is amongst the major conflict cases. As leopard and snow leopard also inhabit in areas dominated by humans, it is of immense importance to amplify the social carrying capacity through awareness camps and increasing the vigilance during peak activity time of a species in the shared area. Frequency of conflicts associated to leopard in human dominated areas has triggered concern about the sustenance of these species, as shown by recent series of studies invested on subject. Results of these studies were adapted to form guidelines in order to avoid and mitigate the conflict issue and the SOP is being developed for conflict scenario management. In all the cases of carnivore conflict, economic compensation has helped to elevate the social carrying capacity. Hence, timely facilitating the desired amount of compensation can reduce the negative perception associated with conflict case. In case of snow leopard, the medical and life insurance policy has helped in building positive perception towards snow leopard conservation. However, such solutions are possible by joint efforts from multiple sectors and active participation of governmental agencies; and hence should be considered for managing conflict of other species as well.

Human - Herbivore conflicts are mainly centered towards the loss of agricultural crops. These losses are high if the crop fields are present around Protected Areas or in the forest used by herbivores involved in conflict. Nilgai, Wild pig, Elephant and Black buck are ranked as species

with highest conflict records owing to their vast distribution across India and habitat overlap with human settlements. While conflict caused by Rhino and Wild ass though restricted in few parts of the country, is similar conflict case. Particularly, in case of elephants, agricultural fields are used as corridors for colonizing or moving across adjacent protected forests. Conflicts with herbivores are speculated to be caused due to habitat degradation, absence of predator, absence of quality forage in the forest, etc. However, these speculations are not tested in field. Nevertheless, looking at increased individual and group raiding on the crops, it is essential to put a control on the reproductive rate of these individuals to avoid long-term conflict. Reproductive control needs an understanding of optimal demographic age and sex ratios to be maintained for sustenance of species. Hence, it should be practiced only in addition to the ecological population monitoring. Techniques used in reproductive control are new to the country and should be executed by expert research team. In case of a species like wild pig that can cause repeated conflict, provision of declaring such species as vermin for a particular area is available. In case of managing the on-going crop raiding, bio-fencing around the crop fields, night vigilance, alarm alerts and barricades should be used. Elevating the social carrying capacity by forming a self-help group in the conflict prone villages that includes people from various sectors can provide immediate and economical solutions.

Human - Non-human primate conflict is one of most serious issue in the negative interactions in human and wildlife. Though Rhesus macaques, Bonnet macaques and Hanuman Langur carry cultural respect from the dominant society, their increasing population in human settlements is increasingly resulting in negative interactions. Devotees and animal lovers feel gratified in feeding monkeys in temples, highways or roof tops and consider it a religious deed. Apart from many monkeys getting diseased and killed due to these habits, they have become habitual of snatching food from people and attacking them. Macaque troops involved in conflict are often translocated to the forests or enclosures in many parts of the country. Often these empty habitats are re-colonized by the surrounding macaque troops, and the conflict continues. Reproductive control is the most convenient and long term solution for controlling the negative interactions, but should be carried with regular population monitoring to keep the densities at optimal low levels. Methods such as oral administrative contraceptives, intra-uterine devices, and blockade of tubal patency following transcervical administration of polidocanol foam should be used for female monkey sterilization. Removal of specific macaque individuals that show persistent

aggressive behavior or learnt raiding behavior should be implemented. Additionally social awareness about Solid waste management and proper disposal of rural organic waste as well as prohibition on feeding of monkeys in public places is of immense importance; as most of these troops colonize the area due to readily available food.

Management of prioritized invasive species by 2020 is India's 4th target of Fifth National Report to the Convention of Biological diversity. In total, 21 species were identified as high concern invasive species for 4 different ecosystems of India viz., terrestrial ecosystem (*Lantana species complex*, *Prosopis juliflora*, *parthenium hysterophorus*, *Mikania micrantha*, *Chromolaena odorata*, *Ageratina adenophora*, *Ageratum conyzoides*, *Xanthium strumarium*, *Mimosa diplotricha*, *Hyptis suaveolens*, *Senna tora* and Great African Snail (*Achatina fulica*)) island ecosystem (*Axis axis* and *Hoplobatrachus tigerinus*), freshwater ecosystem (*Oreochromis mossambicus*, *Salmo trutta fario*, *Clarias gariepinus*, *Cyprinus carpio*, *Ipomoea carnea* and *Eichhornia crassipes*) and marine ecosystem (*Kappaphycus alvarezii*). As a response to the impacts of these species, many regional managerial interventions are carried to remove the species. Most of these management practices are guided by the umbrella legislation of Wildlife (Protection) Act, 1972 and National Biodiversity Action Plan, 2008. It was also concluded during the workshop, that restoration of the native ecosystem should be the focus of management in the terrestrial ecosystem and hence the removal of any species should be followed by active/passive restoration of native ecosystem. The major gap that was observed was in the information about distribution and magnitude of invasion across country for any invasive species; and in the studies of restoration techniques in terrestrial ecosystem. The repeated introduction of fishes via aquaculture and escape through the controlled culture are the main invasion pathways in freshwater ecosystem. It should be addressed by enhancing the present quarantine techniques to identify the fry of these species during the import, and safeguarding the outlets of culture discharge (particularly in the floods).

Introduction

Managing human-wildlife negative interactions (HWI) and Invasive species are two major challenges faced by wildlife managers in India. Apart from the negative public perceptions towards wildlife and the Forest/Wildlife Department, managing HWI and invasive species also incurs heavy expenditure of the limited funds and other resources available to the department. Human-wildlife interactions and biological invasion may appear as distinct problems but in many occasions reduction in native food plants due to increase in cover of invasive plant species have been stated as one of the reasons of straying out of wild herbivore in search of food. For example, invasive species such as *Desmodium trifliatumum*, *Cardiospermum helicacabum*, *Ipomea cornea*, *Argemone maxicana* in Pabitora wildlife sanctuary are rapidly increasing in cover and competing with native fodder species leading to increase in crop-raiding incidents by Rhino. Similarly, increase in *Lantana camara* cover has resulted in decreased habitat use by elephant in dry deciduous forest of Mudumalai Tiger reserve.

While biologists have generated some scientific information on these issues in a few study areas, field managers at the site and the State Forest/Wildlife Department in general have taken up various measures to manage HWI and Invasive species in their respective areas. Although, we have a few site specific success stories and best practices, the problem is yet to be tackled at the State or National level in a holistic manner. Moreover, lack of basic research on the efficiency and consequences of available management often raises serious questions in front of forest department and scientific community.

Keeping this in view, the Wildlife Institute of India (WII), Dehradun, conducted a “*Workshop on Human-Wildlife Interactions and Management of Invasive Species*”, at WII, Dehradun on 23rd & 24th July 2014. A total of 110 participants actively discussed these issues over the two days of the workshop. Objective of this workshop was to bring together, scientist, forest official, researchers, and representative of leading NGOs dealing with these issues for a better knowledge about the current state of the problem and to find out a way forward. Workshop was conducted under five major themes 1) Human – Carnivore interaction, 2) Human – Herbivore interaction, 3) Invasive species management, 4) law and policy and 5) Human-macaque interactions.

Workshop was structured in such a way that the expert presented the overview of the current state of affairs, available management/ mitigation options and policies for human-wildlife interactions and invasive species on the first day to all the participants. Later, streamlined brainstorming session was held under above mentioned themes to identify the gaps in the current state of knowledge and to develop guidelines and on the second day.

On the first day of the workshop, Dr. V. B. Mathur, Director, Wildlife Institute of India, welcomed all the distinguished guest and participants and mentioned about the special request from the Ministry of Environment, Forest and Climate Change which laid foundation for this workshop. Ministry assigned this responsibility to Wildlife Institute of India with the hope to receive a road map for resolving these two biggest threats to the country's biodiversity. He highlighted the conscious effort of the institute for using the term "interaction" in workshop's title instead of the commonly used term "conflict" in an order to acknowledge both positive and negative aspects of the interaction between human and wildlife. Dr. Mathur mentioned about developing a combination of preventive and mitigative strategies to reduce the negative interactions between human and wildlife. He stated about the huge economic losses worldwide due to biological invasion and the efforts at international (CBD Aichi Biodiversity target-9) and national levels (National biodiversity target-4) to combat the ill and sometimes irreversible effects of the invasive species. He further added that lack of basic knowledge and management efforts at the local level especially in the protected areas is leading to downscaling of their fundamental role of biodiversity conservation.

This report has been compiled by a team of researchers from the Wildlife Institute of India under the supervision of Sh. Qamar Qureshi, Dr. Sathyakumar and Dr. K. Sankar. This report first provides the synthesis of existing information on the issues pertaining to human-wildlife interactions under the themes of carnivore, herbivore & macaque and a section dealing with invasive species. Later, it summarizes the key issues and suggestion provided by experts during the workshop in form of proceedings of the workshop. Finally, using existing literature and essence of discussion over the two days, draft guidelines has been designed to help in decision making process while dealing with these issues. Also, the existing Standard Operating Procedures (SOPs) relevant to the workshop have been provided as annexures.

Synthesis of Human-Carnivore Negative Interactions



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Human-Lion Interaction in India

Current population status and distribution of species

Asiatic lions (*Panthera leo persica*) once ranging from Persia to Palamau in the eastern India, were almost extinct by indiscriminate hunting and habitat loss. A single relict population of about 50 lions persisted in the Gir forests, Gujarat by 1880's. With stringent protection by the Junagadh Nawabs and subsequently by Gujarat forest department, lions have increased with an annual rate of 2% to a current population of over 400 (Banerjee & Jhala, 2012). Lions were restricted to the Gir forests (1,800 km²) till 1980's, but have since dispersed occupying over 10,000 km² of agro-pastoral Saurashtra landscape. Although the population is stable but due to its low size the species has been designated as endangered by IUCN (www.iucnredlist.org). CITES keeps a vigil on illegal trade of the species or its parts by listing lion in appendix-I (www.cites.org). Within India, Asiatic Lion is classified in the Schedule-I of the Wildlife Protection Act (1972) which accords the highest legal protection available to any species.

Status of negative interaction

Owing to timely protection provided by the Nawab of Junagadh and the state-run Gujarat Forest Department against hunting, the population of the Asiatic population has increased from less than 50 individuals, in the 1920s, to the currently estimated total of more than 400 individuals at an annual growth rate of about 2% (Banerjee & Jhala, 2012). Also, there was a range expansion after the mid-1980s, with the current lion population occupying over 10,000 km² of the Saurashtra landscape, which comprises Gir Protected Area (Gir PA, 1800 km²), Girnar Sanctuary (180 km²) and human-dominated agro-pastoral landscapes of Saurashtra (Banerjee & Jhala, 2012; Singh & Gibson, 2011). Lions have been locally extinct in these areas at least for the past five generations, and the people have no experience of living in the lion's habitat. Thus, with lions re-appearing in these areas and living close to humans, conflicts are inevitable. Major lion-human conflict documented in the Gir landscape included a) livestock predation by lions (Banerjee et al., 2013; Joslin, 1973; Meena et al., 2011; Singh & Kamboj, 1995; Srivastav, 1997), b) human-lion confrontations resulting in human injuries and death (Banerjee 2012; Meena & Kumar, 2012; Saberwal et al., 1994) and c) human-induced lion mortality (Banerjee & Jhala, 2012; Joslin, 1973; Pathak et al., 2002; Meena & Kumar, 2012).

Reasons for negative interaction

Decrease in wild prey, high density and easy catchability of livestock (especially cattle) compared to wild prey were the main reasons behind livestock predation inside the Gir PA (Joslin, 1973; Saberwal et al., 1994; Singh & Kamboj, 1995; Srivastav, 1997). Some authors have ascribed thickening of habitat within the Gir PA unsuitable for hunting of wild ungulates by lions (Sinha et al., 2004). Change in cropping patterns (more cash crops such as sugarcane and mango orchards) and rapid fragmentation of the peripheral forests (grasslands) were also ascribed as major cause of lion-human conflict in and around Gir PA (Meena & Kumar, 2012; Sinha et al., 2004). Srivastav (1997) identified lower vigilance of *Maldharis* (pastorals) on grazing livestock herds owing to Government compensation scheme significantly offsetting their losses.

Banerjee (2012) identified major reasons of lion-human conflicts in the human-dominated Saurashtra landscape; these are a) rapid change of traditional land use pattern, b) loss of habitat refuge patches for lions, c) change of human attitudes toward lions outside Gir in absence of any incentive, d) little experience of staying with lions in memorable time and e) human psychology of fear & retaliation. Open irrigation wells, electrocution as a non-target species, poaching and road/rail kills were major factors behind human-induced lion mortality (Banerjee & Jhala, 2012; Meena & Kumar, 2012). People suddenly encountering a lion and/or attempting to deter lions from killing their livestock were more prone to lion attacks in the human-dominated Saurashtra landscape (Banerjee, 2012).

Management of negative interaction

→ Current mitigation measures

- Several mitigation measures have already been put in place by the Gujarat Forest Department (Meena & Kumar, 2012; Pathak et al., 2002; Singh & Kamboj, 1996)
- Compensation scheme for livestock predation.
- *Ex-gratia* for damages due to wildlife is provided by Gujarat Forest Department. *Ex-gratia* in case of human injury varies from 2500-10000 and 100000 in case of human death (<http://www.gujaratforest.org/gr-man-animal>).
- Strong protection regime for lions and wildlife crimes across the landscape.

- Geographic Information System & on-ground surveillance for controlling illegal activities (encroachment, illegal grazing, lopping, wood cutting etc.).
- Covering of open irrigation wells with permanent rubble walls or parapets.
- Capture, rescue and translocation of ‘problem’ animals.
- A village level network of informants (*Vanya Prani Mitra*) vigilant on livestock predations, suspicious movements of people etc.
- A mobile team from the forest department monitoring and evaluating conflict issues across the landscape.
- Capacity building & training of staff to mitigate & handle conflict situations in field.

→ **Mitigation measures suggested**

- Maintaining lion density within social threshold outside the PA & management (capture and removal) of problem lions from the landscape (Banerjee, 2012; Meena & Kumar, 2012; Pathak et al., 2002). These lions may be sent to various national and international zoos for building up a conservation breeding program for Asiatic lion (Chellam, 1993; Saberwal et al., 1994).
- Government compensation for livestock depredation should include capital loss (market price of predated livestock unit) and incorporate lost opportunity cost i.e. opportunity to earn from the predated livestock in the years to come had it not been killed (Banerjee et al., 2013). Funds can be disbursed through community based institutions, instead of direct disbursement by the Forest Department.
- Regular revision of livestock compensation scheme (3-5 yrs.) with reflectance to change in market prices (Banerjee et al., 2013; Mena & Kumar, 2012).
- Prompt & timely payment of the compensation amount. The compensation scheme should be transparent and the amount should be in proportion to loss incurred by the family (Banerjee et al., 2013; Mena & Kumar, 2012).
- Livestock insurance scheme was proposed at village level (Banerjee, 2012; Meena & Kumar, 2012; Sinha et al., 2004). Improved livestock husbandry practice in the region (Meena et al., 2011) and fencing of livestock holding areas of villages to minimize carnivore attacks at night (Meena & Kumar, 2012).

- Encouraging Gaushalas and Panjrapoles in the landscape with veterinary inspection. These would provide lions with food sources in terms of surplus unproductive cattle and thereby predation on high priced productive domestic livestock would be low (Banerjee, 2012).
- Injuries caused by lion attacks may permanently cripple a victim. Therefore, one-time compensation may not always be sufficient for an affected family. Besides providing compensation for human deaths/injuries, some provision for giving the nearest kin of the victim employment in the forest department (or some other departments) could be explored to gain better support from the local communities for lion conservation (Banerjee, 2012).
- Management of the habitat inside GPA to enhance the carrying capacity for the wild ungulate population (Johnsingh et al., 1998; Joslin, 1973; Singh & Kamboj, 1995). Conservation of habitat refuges and lion breeding patches outside GPA through legislation (designation of areas as 'Eco-sensitive', 'Conservation Reserve', etc. and eco-restoration without compromising the local communities' livelihood needs (Banerjee, 2012; Meena & Kumar, 2012; Saberwal, 1994; Sinha et al., 2004). Intensive management of grasslands (*vidis*), wastelands and pasture lands in the landscape to increase fodder production and develop buffers/corridors for lions and other wildlife (Mahadev & Chauhan, 2000; Srivastav, 1997).
- Improving protection against poaching, human-caused lion mortality, illegal encroachments and other wildlife crimes (Chellam, 1993; Joslin, 1973; Meena & Kumar, 2012; Pathak et al., 2002).
- Translocation of lions in some other parts of the species' historical range (Chellam, 1993; Johnsingh et al., 1998; Saberwal et al., 1994).
- Making the land policy of the forest department lion friendly and instituting inter-sectoral collaborations (revenue, police, tourism, electricity, railway, highways, agriculture, etc.) to monitor and mitigate conflicts in the landscape (Banerjee, 2012; Meena & Kumar, 2012).
- Awareness campaigns educating people about the biology, movements and activity peaks of the lion, conservation issues and ongoing government schemes and programmes and

providing other relevant information to foster better tolerance (Banerjee, 2012; Meena & Kumar, 2012; Pathak et al., 2002; Sinha et al., 2004; Saberwal et al., 1994).

→ **Existing policies**

- Standard operating procedure have been formulated by the National Tiger Conservation Authority to deal with the straying carnivore in human dominated landscape (http://projecttiger.nic.in/Final_SOP_11_01_2013, Annexure 1)
- Guideline for monitoring the lions, co-predators, prey, habitat and conflicts in the Gir Conservation Area was prepared by the Wildlife Institute of India in 2004 (Jhala, 2004). Many of the monitoring protocols and management recommendations prescribed therein were included in Gir Management Plans (Meena & Kumar, 2012; Pathak et al., 2002; Singh & Kamboj, 1996; see mitigation measures).

Human-Tiger interaction in India

Current population status and distribution of species

In India, the tiger (*Panthera tigris*) is currently distributed across seventeen states. It occurs in a variety of habitats, from rainforests to grasslands and from dry deciduous forests to mangroves. Considering its role as a top predator in various ecosystems and as a flagship species, the Government of India started a countrywide effort for conservation of the tiger, named Project Tiger, in 1972 (<http://envfor.nic.in/division/introduction-18>). A recent census conducted in year 2014 indicate numbers of tigers to range from 1949 to 2491 (Jhala et al., 2015).

The IUCN has designated the tiger an endangered species due to the decline in its occupancy as well as population size within its geographic range over the past three tiger generations (www.iucnredlist.org). It is listed in the Appendix-I of CITES, which makes it illegal to trade in the species. Indian laws provide the highest degree of legal protection to the tiger by listing it in Schedule-I of the Wildlife Protection Act (1972).

Status of negative interaction

Human–tiger conflicts can be grouped into three categories: (1) attacks on humans, (2) livestock depredation and (3) tigers that stray into human-dominated areas. Depredations on domestic animals are the most common type of human–tiger conflict. In extreme situations, losses might be as high as 12% of local herds and 17% of annual household incomes (Madhusudan & Mishra, 2003; Sangay & Vernes, 2008; Wang & Macdonald, 2006), and livestock can make up over 25% of the tiger’s diet (Wang & Macdonald, 2006). India harbours the highest number of tigers (Jhala et al., 2014) and has the largest number of man-eating cases (Corbett, 1991; Khan, 1986; McDougal, 1987). Tigers killed 19% of all the livestock killed by carnivores in Bhutan from 2003 to 2005 (Sangay & Vernes, 2008).

Reasons for negative interaction

Tigers require abundant large prey (Smith et al., 1987; Smith et al., 1998) and extensive forested habitats to sustain themselves (Smith et al., 1987; Smith et al., 1998; Sunquist, 1981). With the rising human population and increasing requirement of resources to sustain it, vast stretches of wild lands have been fragmented and cleared to make way for agriculture. Rapid encroachment and habitat fragmentation have resulted in tigers occupying only isolated small pockets of forest

(Jhala et al., 2011, Smith et al., 1998,). For instance, in Tadoba-Andhari as well as in the Sundarbans, local people frequent the forested areas to collect firewood and other forest products. This has been identified as the major reason of conflict (Das, 2012; Dhanwatey et al., 2013). Corridors are crucial to connect source populations to other protected areas for tiger movement, which is important for long-term tiger conservation and conflict management (Qureshi et. al., 2014).

Poaching is the primary reason for local extinction, followed by prey depletion, in the past 100 years (Karanth & Stith, 1999). Tigers readily kill livestock and dogs in areas where the wild prey is depleted, the reasons for which are usually hunting, habitat degradation and competition offered by livestock (Johnson et al., 2006; Miquelle et al., 2005; Sangay & Vernes, 2008; Wang & Macdonald, 2006). Local people have poisoned and hunted down tigers to avenge personal and economic losses.

Management of negative interaction

→ Current mitigation measures

- Tiger involved in attacks on humans (especially man-eaters) are either translocated to a captivity or killed. Often, it's the only resort available to the managers for a strayed out or alleged “problem” animal. However, in areas with small population such repeated lethal control may result in local extirpation of the species, as many non-problem tigers are generally killed in the process of controlling the problem one (Karanth & Gopal, 2005).
- The traditional method of guarding and fencing was found to be the most effective measure in reducing livestock losses across protected areas in different biogeographic zones (Karanth et al., 2013a).
- WWF-India and the Corbett Foundation, apart from the government, provide “interim relief” compensation for loss of livestock and human lives for providing immediate assistance to the victim. The two biggest problems with this approach are the high level of donor input required and unavailability of the scheme in remote areas with potentially high levels of conflict.
- In Sunderbans, a couple of innovative preventive methods have been tested so far. The use of nylon mesh in villages vulnerable to tiger entry is one of these. The use of electrified human

dummies as an aversive conditioning of tigers is another. Although the authorities involved claim that the deployment of these methods has resulted in a reduction in the number of conflict cases, no experiment have been conducted to test their efficacy (Karanth & Gopal, 2005).

→ **Mitigation measure suggested**

- Translocate problem animal and/or dispersing individual, reaching to close proximity of human settlement, in suitable tiger habitat based on sound science i.e., accounting for biogeographic differences in tiger population, proximity to other tiger populations and prey densities.
- Reducing the dependence of local people on forest products by providing alternate energy sources (i.e., biogas, solar power, etc.) could reduce the frequency of entry of humans into forests and therefore conflicts (Dhanwatey et al., 2013).
- Regulating grazing activities within protected areas and having human herders guard herds are expected to reduce the number of livestock depredation cases (Karanth & Gopal, 2005; Karanth et al., 2013).
- Rapid response teams should be formed to deal with emergencies. This could prevent and mitigate conflicts in affected areas. The teams should be composed of experts in wildlife capture, veterinarians and officials of the forest department (Dhanwatey et al., 2013)
- Spatial segregation or zoning of human and tigers by translocating human- settlements outside protected areas has been advocated as the most effective measure for preventing conflict and ensuring the long-term survival of the tiger. Moreover, local communities also gain access to better living conditions. In a recent study conducted in the western part of the Terai Arc Landscape, the forest-dwelling Gujjar community was found to be willing to move outside the protected area. The major reasons for this were (i) reduction in forest productivity affecting the income and (ii) lack of education as well as health facilities within the protected area (Harihar et al., 2014). However, attitude and willingness to move out of protected could vary across communities.

→ **Existing Policies**

- Standard operating procedures have been formulated by the National Tiger Conservation Authority (NTCA) to deal with straying carnivore in human dominated landscape ([http://projecttiger.nic.in/Final SOP 11 01 2013.pdf](http://projecttiger.nic.in/Final_SOP_11_01_2013.pdf)).

- The Government of India has decided to request the State Governments of increasing the amount of ex-gratia payment in cases of death or permanent incapacitation of any person by a wild animal from 20000 to 100000.
- The National Tiger Conservation Authority (NTCA) and state forest departments help resolve human–tiger conflicts in India by providing compensation for livestock injured or killed by wild animals and by providing cages/traps, tranquilizers and rescue vehicles for capturing problem animals (projecttiger.nic.in).

Human-leopard interaction in India

Current population status and distribution of species

The leopard (*Panthera pardus*) is widely distributed throughout India except in the deserts and Sundarban mangroves (<http://www.iucnredlist.org>, Johnsingh et al., 1990; Khan, 1986). Due to its wider niche breadth and ability to adapt to human-induced land use patterns, it also occupies human-dominated landscapes (Athreya et al., 2014).

The leopard is included in Schedule-I of the Wildlife Protection Act 1972, as a result of which it enjoys the highest degree of legal protection available under Indian legislation. The IUCN has recognized the leopard as a Near Threatened species (<http://www.iucnredlist.org>), and because of a thriving international illegal trade in leopard parts, the species has been listed in Appendix-I of CITES (www.cites.org/eng/app/appendices.php).

Status of negative interaction

Leopard owing to their adaptable nature, high density of food resource in human use landscapes in the form of domestic animals and the strict laws in India which do not allow the killing of species like leopards, it occur in human use landscapes (Singh, 2005). The behavioural plasticity of the leopard and its wide choice of prey make it adapted to a wide range of habitats altered by humans and capable of tolerating human pressure.

Uttarakhand report large number of human deaths due to leopard attacks with about 50 reported each year. Mumbai used to face large number of attacks on humans a decade ago with an average of 30 attacks on people in areas adjoining Sanjay Gandhi National Park but today there are no more than handful of attacks around Mumbai even though large numbers of leopards are present. Junnar in Maharashtra reported about 25 attacks on people each year for 2001 and 2002 but today, despite leopard presence there is no comparable conflict. Himachal Pradesh reported about 73 attacks in the year 2007 - 2008 which has reduced to about 23 in 2013 - 2014. West Bengal reports large number of attacks but very few deaths with 74 people injured due to leopards, one person killed in 2013 - 2014. However chronic conflict still occurs in Uttarakhand whereas in other sites, the severity of the conflict has decreased. With respect to losses on the other side of this negative interaction, leopards are killed in large numbers. A recent report by

TRAFFIC India (Raza et al., 2012) finds that four leopards have been killed each week for the last ten years.

Reasons for negative interaction

Reduction of prey, fragmentation and degradation of habitats are often stated to be the key reason for the increasing number of conflict cases involving the leopard in India (Chauhan & Goyal, 2000; Edgaonkar & Chellam 1998; Kala & Kothari 2013). However these have not been tested and baseline information on conflict itself is sorely lacking. Furthermore, 100 year old documents such as Gazetteers and/or hunting records by the British also mention leopards visiting settlements to prey on domestic animals at a time when there were more wilderness areas and prey. Increasingly, all over the world, there is a greater understanding about wild carnivores such as bears, wolves, coyotes, foxes, leopards, mountain lions and others do use human use landscapes due to the abundant food resources by way of domestic animals, organic garbage, pet food (Gehrt et al. 2010).

Leopards being an extremely adaptable species, occupies a variety of landscapes across its global range, as well as in India. Leopards are found in croplands, tea gardens, adjoining the metropolis of Mumbai, city of Shimla, Guwahati, Gurgaon. They are found on the rocky areas of Rajasthan and the Aravallis. Their diet includes domestic animals, dogs appear to be preyed upon commonly. Recent information from GPS collars finds that they are largely nocturnal where they share space with humans and that their presence, even in dense human use landscapes does not imply attacks on people (Odden et al. 2014).

Athreya et.al. (2011, 2006) have found that uninformed mitigation strategies such as translocation could also lead to increased attacks on humans. It has been suggested that translocation of straying leopards in areas with other leopards, with human populations and the associated stress and behavioural changes the translocation process could be the reasons for increased human attacks (Athreya et al., 2011). Similar cases have been reported from near protected areas such as Buxa, Gorumara and Jaldapara, resulting from territorial fights and disruption of the socio-biology of leopards (WWF-India 1997).

Management of negative interaction

→ **Current mitigation measures**

- Translocation of “problem” animals to captive facility or other potential habitat has been used by the forest department as the immediate measure for mitigating conflicts (Athreya et al., 2011; Edgaonkar and Chellam, 1998).
- Paying compensation for loss of livestock (Edgaonkar and Chellam, 1998).
- Paying compensation for loss of life or injury to humans.

→ **Mitigation measures suggested**

All the mitigation measures currently in use are reactive. We recommend moving focus of mitigation for livestock depredation from reactive to proactive, incentivising better protection of livestock. Furthermore a survey of all the mitigation measures indicates that traditional proactive methods are the best at reducing losses (Linnell et al. 1996). India has a variety of traditional methods that have been used to deal with predators and it is important that we focus on them from a research and management viewpoint.

- Payment of compensation in case of human death and injury.
- A few researchers have suggested lethal controls for managing conflict. However Indian legislation has banned lethal control since 1972. Moreover, lethal control may even increase the conflict if an individual involved in a conflict is misidentified and if it disrupts the social structure of the population (Karanth & Gopal, 2005).
- Translocation should not be carried out as it could endanger the lives of people living near the release sites. Indian conditions are extremely different than countries in Africa where translocations are carried out because those countries have very low human densities (Weise et al. 2015). Studies across species indicate that translocations are not a management option if there are no large areas devoid of other individuals of the translocated species (Linnell et al. 1997) and in India with high density of humans, such interventions could have disastrous consequences (Athreya et al. 2011).

→ **Existing Policies**

There are no policies for dealing with wildlife outside Protected Areas in India, however following guidelines have been issued by the MOEF and NTCA to deal with the human-leopard negative interaction.

- Standard operating procedures have been formulated by the National Tiger Conservation Authority to deal with straying carnivores in human-dominated landscapes ([http://projecttiger.nic.in/WriteReadData/CMS/Final SOP 11 01 2013.pdf](http://projecttiger.nic.in/WriteReadData/CMS/Final_SOP_11_01_2013.pdf)).
- The Ministry of Environment and Forest has also formulated guidelines for managing the leopard-human conflict (<http://moef.nic.in/downloads/publicinformation/guidelines-human-leopard-conflict-management.pdf>).

Human-Snow Leopard interaction in India

Current population status and distribution of species

The Snow-leopard (*Panthera uncia*) is found in the Trans-Himalayan area of Jammu and Kashmir, Uttarakhand, Himachal Pradesh, Sikkim and Arunachal Pradesh. It inhabits cold arid, semiarid shrub-lands and grasslands habitats (Jackson and Hunter, 1996). India is believed to support a population size of 400-700 snow leopard (Fox et al., 1991; Rodgers & Panwar, 1986). Loss of habitat, prey base depletion, illegal trade for pelt or other body parts and retaliatory killings to reduce livestock depredation are the major threats faced by the species causing its decline. The IUCN has categorized the snow-leopard as 'Endangered'. To put a halt on commercial trade, CITES has listed it in Appendix-I since 1975 to put a halt to the commercial trade in this species (www.iucnredlist.org, www.cites.org). The country's legislation lists the species in Schedule-I of the Wildlife (Protection) Act, 1972 to ensure that it gets the highest degree of legal protection.

Status of negative interaction

Livestock depredation is the major conflict involving the snow leopard, especially where there are people living in areas with underdeveloped economies (Bagchi & Mishra, 2006, Jayapal et.al., Suryawanshi et.al., 2013). The annual livestock loss varies from area to area. For example, in Bhutan, from 2009 to 2011, snow leopards killed 10% of the livestock. This amounted to a monetary loss of \$646 per household. But in Phoo village of Nepal, the corresponding figure was only 4.07% (Gurung & Thapa, 2004). Fox et.al. (1991) reported a 2% annual loss of livestock due to the snow leopard. In Spiti valley, Suryawanshi et.al. (2013) recorded 809 livestock mortalities in 25 villages over two years out of which only 24% (194) was predated by Snow-leopard and feral dogs instead, killed 42% (338) of livestock. Snow leopards have been killed by local herders in retribution. In Zankar, northern India, between 1998 and 2006, a total of 16 snow leopards were reportedly killed (Spearing, 2002), whereas 12 individuals were killed in just a single year in Xinjiang Province, of western China, in 1985–1986. Osborne et al. (1983) reported that 5-10 snow leopards were killed in southern Ladakh from 1978 to 1982 and that in central Ladakh a total of five leopards were killed between 1983 and 1988 (Fox et al., 1991).

Reasons for negative interaction

Fragile snow-leopard habitats are being overstocked with domestic livestock which compete with the wild ungulates for food resources. Local communities also hunt wild prey of snow-leopard. All these factors have led to a decline in the prey base of the snow leopard, leading to predation on domestic livestock (Jackson and Hunter, 1996; McCarthy et al., 2003). In turn, local herders kill snow-leopard in retribution. This has resulted in the increase in conflict cases. It's noteworthy that, it's not only quantum of conflicts that lead to heightened negative attitudes. But also restrictions to access resources, or awareness programs can influence perceptions negatively or positively, respectively as suggested by Bagchi & Mishra (2006).

Management of negative interaction

→ Current mitigation measures

- Livestock insurance schemes initiated in certain parts of India, Pakistan and Bhutan with the help of villagers and local NGOs have proved to be highly successful by reducing the killing of snow leopards and leading to the recovery of their wild prey species (Hussain, 2000; Li et al., 2013; Mishra et al., 2003). These programs also help in inculcating more positive attitudes and tolerance for conservation among the local population.
- In country, compensation for the loss of livestock, human injury and death due to carnivores is in place and have been suggested to reduce the animosity of people towards losses due to large carnivores (Banerjee & Jhala, 2012). However, Bulte and Rondeau (2005) have argued that conventional compensation schemes have failed and had unexpected outcomes in terms of agricultural expansion, inflows of migratory people and changes in land use, with potential negative effects on wildlife.
- In Hemis National Park, Ladakh and Kargil, NGOs are collaborating with the local herder community to build improved corral structures. In return, the local people have promised to protect the snow leopard and its wild prey (Anon, 2004).
- International and national agencies are working in collaboration with local bodies in Hemis National Park, Ladakh, for improving eco-tourism by promoting homestays, nature guiding and a parachute café. All these incentive help offset the economic losses due to unavoidable depredation cases. In Mongolia, efforts have been made to train local

communities to produce handicrafts (Mishra et al 2003). The locals, in turn, sign a contract to stop any hunting or retaliatory killing of the snow leopard (Anon, 2004).

→ **Mitigation measure suggested**

- Improving guarding techniques for livestock by using guard dogs and community-appointed experienced shepherds and stall feeding of calves, sub-adults and lactating females will reduce the vulnerability of individuals to predation and thereby reduce the chances of attacks (Jackson & Hunter, 1996). Guard dogs should be used only for corralled animals and not in wild areas. However, considering the case of Spiti valley (Suryawanshi et.al., 2013) where feral dogs were the major predator of the livestock, guards dogs need to be professionally trained and monitored.
- Improving the animal husbandry techniques used and the veterinary care of the livestock could improve the monetary returns and reduce the pressure on the rangelands, which in turn will reduce the depredation on domestic animals (McCarthy et al., 2003).
- WWF-India has been constructing reasonably priced predator proof corrals in the state of Jammu & Kashmir for past few years that has helped in avoiding conflict. Necessary expertise could be provided by WWF-India in this regard (*pers. comm.* Dipankar Ghose).
- In Phoo village of Nepal, the rate of depredation on small-bodied domestic prey such as sheep and goats was higher than the large-bodied prey such as yaks therefore author suggested that encouraging large bodied domestic livestock would reduce the depredation (Gurung and Thapa, 2004).
- Creating inviolate areas for wild prey and snow leopards devoid of any human activity could help humans and wildlife coexist (Jackson & Hunter, 1996; Karanth & Gopal, 2005; Mishra et al 2003).
- The poor structure of livestock's corrals could be making it easy for snow leopards to prey on domestic livestock. Therefore predator-proof livestock pens and corrals built using stone and mortar, with wire-mesh roofs, built either for individual families or for entire communities, could reduce the attacks on livestock during the night time (Gurung & Thapa 2004; Jackson & Hunter, 1996; Jackson *et. al.*, 1996, Jackson & Wangchuk 2001, 2004; McCarthy et al., 2003).

- Minimizing the high dependence of the local communities on their livestock for their livelihoods can bring down the number of conflict cases. Researchers advocate promotion of eco-tourism (Jackson & Hunter, 1996) and making handicrafts (McCarthy et al., 2003) as alternative livelihood options for the peasant in the snow leopard range.

→ **Existing Policies**

- The Project Snow Leopard is an Indian initiative for strengthening wildlife conservation in the Himalayan high altitudes. One of the objectives of the this project is to find a balance between wildlife conservation and interest of pastoralist (Anon., 2008). The PSL recognizes that since snow leopard is a wide ranging species, where its interface with marginal communities can extend far beyond PAs, effective and proactive conflict mitigation activities need to be put in place at larger spatial scales.
- The snow leopard has been listed in the Appendix-I of the Convention on the Migratory Species of the wild animals since 1985. Five of the twelve snow leopard range States are signatory to CMS and therefore under the oath to protect the species. At the seventh Conference of the Parties to CMS held in September 2002, the Snow Leopard attained the status of a species designated for “concerted and co-operative actions” for its conservation. Recently, the MoEFCC, GoI, has been participating in the Global Snow Leopard Ecosystem Protection (GSLEP) programmes to further strengthen commitment and funds for snow leopard conservation in the country (Y. S. Bhatnagar *pers comm*).

Human-wolf interaction in India

Current population status and distribution of species

Two sub-species of wolf are found in India (Sharma et al., 2004), the Indian wolf (*Canis lupus pallipes*) and the Himalayan wolf (*Canis lupus chanco*). Himalayan wolf is found in the Trans-Himalayan region and recently from Uttarakhand and Sikkim (Bhattacharya and Sathyakumar, 2010; Chanchani et al., 2011; Maheshwari et al., 2013). Indian wolf ranges in the rest of the peninsular India. Indian wolf inhabits arid and semiarid and grassland. Population estimation for Indian wolf done by Shahi (1982) indicate population size of approximately 800 individuals for the entire country. Based on intensive surveys population size in the country was estimated between 2000-3000 individuals (Jhala, 2003; Jhala and Giles, 1991). Himalayan wolf population is very scanty studies and no reliable estimates of the population size or basic ecology exists (Habib et al., 2013). Fox and Chundawat (1995) provides conservative estimates of no more than 350 individual of the Himalayan wolf.

The peninsular Indian wolves as well as the Himalayan wolves are considered endangered and both are kept in the schedule-I of the Wildlife Protection Act 1972 (Jhala, 2003). Indian wolf is categorized in the appendix-I of the CITES which prevents any illegal trade of the species (www.cites.org).

Status of negative interaction

The Himalayan wolf is the top-predator in Ladakh region accounting for more than 60% of the livestock depredation due to wild animals. The predation due to the Himalayan wolf was lower in Himachal Pradesh (16% of all the livestock depredation) and absent in the Uttarakhand state (Habib et al., 2013). This may be related to the low abundance of Himalayan wolf in Himachal Pradesh and Uttarakhand where the mountainous habitat may not provide a suitable terrain to the occurrence of this sub-species.

Conflicts involving Indian wolves have been in the form of (1) livestock depredation, (2) attacks on adult humans and children by rabid wolves (Jhala, 2003; Linnell et al., 2002). Even normal wolves in the absence of availability of wild prey may prey on unprotected children (Johnsingh A.J.T. *pers comm*). A single pack of wolves in Nannaj, Maharashtra killed 70 goats and 24 sheep in 3 years (Kumar & Rahmani, 2000). The published reports indicate a long history of attacks on

children by wolves. In Uttar Pradesh, between March and October 1996, a total of 76 children less than 9 years of age were attacked by wolves, and 50 of these attacks proved to be fatal (Jhala & Sharma, 1997).

Reasons for negative interaction

Studies conducted at national and international level have shown that areas with readily available wild prey experience very few cases of livestock depredation. Shifts in farming agricultural practices from dry to irrigated agriculture with multiple cropping result in the loss of rendezvous and denning sites as well as the loss of wild prey (Jhala, 2003). With reduced prey densities, the level of conflict between humans and wolves increases as the animals kill livestock more frequently (Jhala, 2003). Suryawanshi et al. (2013) expect an increase in conflict levels in the Trans-Himalayan region as the demand for cashmere is leading to an increase in the numbers of livestock. Canine distemper and rabies are the reasons for attacks on humans by wolves (Jhala & Sharma, 1997).

Management of negative interaction

→ Current mitigation measures

- Wolves have been persecuted since the British period in India, mostly involving the payment of bounties. In some areas wolf dens are identified and pups are killed by smoking the dens. In some areas people even use poison to control the wolves. This could be highly detrimental not only for the wolves but for other non-target carnivores (Jhala and Sharma, 1997).

→ Mitigation measures suggested

- Removing a child-lifter is an important measure in keeping conflict levels low. However, it is very difficult to identify a problem animal in a population and sometimes results in killing of non-problem individuals. Jhala and Sharma (1997) provided a detailed account of identifying and controlling the child lifter.
- Compensation due to wolf is available in the state of Maharashtra but public seems to be unaware of the scheme (Krithivasan et al., 2009). However the inherently long process of filing a case and proving the identity of the convict can be really difficult in the case of wolves.

- Replenishing lost or depleted wild prey is expected to reduce livestock depredation and consequently the frequency of conflict cases. Reintroduction of the wild prey is a long-term process, with a lot of effort and funds involved. Moreover, predation on wild prey by co-occurring feral dogs could impede the reintroduction efforts (Krithivasan et al., 2009). Therefore, reintroduction of wild prey should be accompanied with the removal of feral dogs (Jhala and Sharma, 1997).
- Jhala and Sharma (1997) listed a number of preventive measures to avoid attack on children. These measure are very intuitive (children below 9 years of age should sleep indoors, appointing night watchman in affected areas etc.) and are expected to frequency of reduce the conflict cases.

Human-Dhole interaction in India

Current population status and distribution of species

Three subspecies of dhole have been reported from India, *Cuon alpinus laniger*, *Cuon alpinus primaevus* and *Cuon alpinus dukhunensis*. Only *Cuon alpinus dukhunensis*, found south of Ganges, faring better. Historically distributed throughout Indian subcontinent, the Asiatic wild dog or dhole currently exists in fragments of its past distributional range. Presently dholes are found in the Ladakh area of Kashmir, central Indian highlands and peninsular India and North-East India. Recent estimates indicate a population size of no more than 2500 individuals in the wild (<http://www.iucnredlist.org/details/5953/0>). Various threats in the form of prey depletion, persecution, disease and competition with other wild and free-ranging carnivores are responsible for the decline of the species. Recognizing these threats, the IUCN has categorized the species as Endangered (<http://www.iucnredlist.org/details/5953/0>), and CITES has placed dholes in its Appendix-II (www.cites.org). In India, bounties were paid for carcasses until the Wildlife Act (1972) was enacted. Under this act, dholes were given legal protection and classified under Schedule-II.

Status of negative interaction

In Arunachal Pradesh, north-east India, dholes are persecuted for livestock depredation (Mishra et al., 2006). In Kanha-Tiger Reserve of central India, 16 of a pack of 24 were found dead due to strychnine poisoning (<http://www.iucnredlist.org>).

In Nepal, dholes were reported to have killed 14 large-sized prey animals (yaks and cattle) in 2007, which led to retaliatory killing by locals (Khatriwada et al., 2011). In Bhutan, the dhole was the fifth largest predator and accounted for 13% of the total livestock loss (Wang & Macdonald, 2006). Local communities use guns and poison to kill dholes. They also steal their kill and steal pups from dens.

Reasons for negative interaction

Dholes were not found to be in conflict with people in a study conducted across five tiger reserves in southern India (Karanth et al., 2013a). A few studies on the diet and foraging ecology of dholes in southern India indicate that their dependence on domestic prey and livestock is low (Karanth & Sunquist, 1995; Selvan et al., 2013; Madhusudan, 2003). However, occasional

attacks on livestock in the distributional range of the dhole have resulted in retaliatory killings even without proof of depredation. Wild prey densities in most of the dhole's distribution range have declined considerably, especially in north-east India. Therefore, prey depletion in the dhole's habitat could be one of the reasons for livestock depredation. In southern India, the densities of the food resources of dholes are good, which might be responsible for the low conflict level in this region (<http://www.iucnredlist.org/details/5953/0>). On the other hand, conflict rates are higher in North-East India, where the wild prey densities have declined drastically. An increased inflow of livestock in the Kanchenjunga Conservation Area, Nepal was considered to be a reason for increased interaction with dholes and loss of livestock (Khatiwada et al., 2011).

Management of negative interaction

Due to the low frequency of conflicts with the dhole, there are hardly any special mitigation measures adopted by locals. Dholes co-exist with other large carnivores (tigers, leopards, etc.) that are more frequently involved in conflicts. Therefore measures used to protect livestock help reduce the damage caused by dholes as well.

→ Current mitigation measures

- The traditional methods of guarding and fencing were found to be the most effective measure in reducing livestock losses across protected areas in different biogeographic zones (Karanth et al., 2013a). Grazing livestock should be accompanied to keep away dholes which are shy of people.

→ Mitigation measures suggested

- Regulating grazing activities within protected areas and guarding of the herd are expected to lower the livestock depredation cases (Karanth and Gopal, 2005; Karanth et al., 2013a).

→ Existing policies

- State-wise “*ex-gratia*” funds are released by government to provide relief to local people and the funding amount depends upon the intensity of the conflict. However, seldom compensation money is paid for cattle kills.

Human-Bear interaction in India

Current population status and distribution of species

Four of the eight species of bear, namely the Himalayan brown bear (*Ursus arctos isabellinus*), Asiatic black bear (*Ursus thibetanus*), sloth bear (*Melursus ursinus*) and sun bear (*Helarctos malayanus*) are found in India. The distribution of the Himalayan brown bear in India is restricted only to the high altitudes of the northern Himalaya, with there being no more than 300 individuals (Sathyakumar et al., 2012). The Asiatic black bear is distributed in the forested habitats of the Greater Himalaya as well as in the hills of north-east India. Conservative estimates of Asiatic black bear population indicate numbers in the range from 5,400 to 6,750 (Sathyakumar et al., 2012). The sloth bear (*Melursus ursinus*), endemic to the Indian subcontinent, is the only most widely distributed bear species. Its range extends from the Himalayan foothills, in the north, to the Western Ghats, in the south. The total population size in the entire Indian subcontinent has been estimated from a few studies to be approximately 20,000 individuals (Sathyakumar et al., 2012). According to all India tiger monitoring report, forest area occupied by the sloth bear in 17 states of country was 223553 km² (Jhala et al., 2011). The sun bear is the rarest of all the bears and it is patchily distributed in all the north-east Indian states. No reliable population estimates are available for this species.

Three bear species (Himalayan brown bear, sloth bear and sun bear) are listed in the Schedule-I and the Asiatic black bear in schedule-II of the Wildlife (Protection) Act (1972). Illegal trade in bear parts is one of the main reasons for the decline of the populations, and therefore all bear species are listed in Appendix-I of CITES (www.cites.org). Considering the rapid decline of all the bear species, IUCN has listed the four species in the 'Vulnerable' category (www.iucnredlist.org).

Status of negative interaction

The conflict with the Himalayan brown bear is largely in the alpine and sub-alpine regions of the Greater Himalaya and some parts of the Trans-Himalaya. In Zaskar Valley, of Ladakh and Jammu and Kashmir, the Himalayan brown bear accounts for a significant proportion of livestock depredation (Sathyakumar et al., 2012). Brown bear accounted for 33% of livestock

depredation cases in Zaskar and about 7% cases in Suru Valley. In both valleys, Sheep and Goats comprised the major domestic prey (52%), followed by Cattle (38%) and Equids (10%). Brown bear killed livestock mostly around villages (54%) and 'Doksa' or summer grazing camp (42%), and largely during summer (64%). Local people reported brown bear sightings on livestock kills (38%) or have confirmed it based on tracks and signs (42%) found near kills (Sathyakumar & Qureshi 2003). In Pakistan, livestock damage due to the Himalayan brown bear was 15% of the total livestock depredation by wildlife (Nawaz, 2007). In the Great Himalayan National Park conservation landscape, from 1989 to 1998, black and brown bears were together involved in 26% of the total livestock loss ascribed to carnivores (Chauhan, 2003). To reduce potential losses to crops and livestock, migratory herders and villagers often kill brown bears. Human- Asiatic black bear interactions are on the rise in the Dachigam landscape, Kashmir (Charoo et al., 2011). Crop- depredation was the major conflict between 2005 and 2007 according to the villagers. Attacks on humans and livestock depredation were also increasing gradually in Dachigam landscape and Kupawara district of Jammu and Kashmir (Charoo et al., 2011; Sanwal and Lone, 2012).

In central and southern India, the number of conflict cases due to sloth bears are increasing. They raid crops, predate livestock and attack humans. From 1989 to 1994, sloth bears were responsible for 67% of the 1094 casualties caused by large mammals (Rajpurohit & Krausman, 2000). Especially in North Bilaspur forest division, where the sloth bear is considered a nuisance, 137 people were attacked between 1998 and 2000 (Bargali et al., 2005).

The sun Bear has been reported to be involved in crop depredation and rarely attacking human in North-Eastern states of India (Sathyakumar et al., 2012).

Reasons for negative interaction

It has been suggested that habitat loss, degradation of remnant forest patches and NTFP collection are the major reasons for the increasing bear-human conflict.

Increased human activities and encroachment into bear habitats have also led to increased human-bear interactions. Unsupervised grazing and poorly constructed night shelters have added to the increased incidents of livestock depredation by brown and black bears. Degradation due to developmental projects and other anthropogenic pressures have led to depletion of bear food

resources (Chauhan, 2003; Nawaz, 2007; Rathore, 2008). In the Dachigam landscape, crop depredation by black bears has increased with changing agricultural practices (Charoo et al., 2011).

The reasons of conflict may also differ depending upon the quality of bear habitat. For example, in Madhya Pradesh, more than 70% of the attacks on humans by sloth bears were reported to have taken place in forests when people were collecting NTFP. However, in North Bilaspur, crop fields were the hotspots of the attacks. The bears were residing there, with forests having been fragmented (Rajpurohit & Krausman, 2000).

Management of negative interaction

→ Current mitigation measures

- Traditional methods such as making noise and lighting fires are used as preventive measures.
- In Jammu and Kashmir, inter-institutional teams consisting of members of forest departments, local NGOs and veterinarians have been constituted to help in case of any emergency (Charoo et al., 2011). Researchers suggest that additional teams should be formed in order to deal with more cases at a given time.

→ Mitigation measures suggested

- The biggest hurdle in mitigating the conflict with bears is the lack of scientific research. Therefore, making country-wide population estimates and gaining an understanding of the behavior of the species is advocated as the first step towards mitigation of the conflict in the long term (Sathyakumar et al., 2012).
- Improvement of guarding techniques (using guard dogs, metal doors, etc.) in houses and husbandry areas has been suggested. These measures have been observed to be efficient in reducing the frequency of conflict cases (Charoo et al., 2011).
- Regulation of livestock pressure and restoring the abundance of wild prey in bear habitats (Rathore, 2008).
- Reducing the dependence of local people on forest resources by training them to adopt alternative livelihood options (Bargali et al., 2005).

- Changing the attitude of local people as well as creating awareness among them about the ecology and behaviour of bears could avoid conflict situations (Bargali et al., 2005).
- Spatio-temporal segregation of food resources shared by bears and humans will reduce the chances of encounters. However, few researchers advocate a complete ban on collection of NTFP during the dry season.
- In highly fragmented forests, bear population management and translocation of remnant populations to suitable habitats have been proposed as mitigation and long-term conservation measures (Rajpurohit & Krausman, 2000). However, the efficacy of these methods is debatable.

→ **Existing policies**

- Almost all states provide compensation for crop loss, damage to property, human and livestock injuries and death caused by wildlife. The compensation amount varies a lot across states, and there is an urgent need to re-structure the schemes as well as the relief amounts.
- All bear range States in India now developed a State Action Plan for Bears through a consultative process but require funds from the Central Government for implementation. Draft Standard Operating Guideline for bears have also been developed by the Wildlife Institute of India (see annexure 3).

Synthesis of Human-Herbivore Negative Interactions



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Human-Elephant interactions in India

Current population status and distribution of species

Historically elephants (*Elephas maximus indicus*) were distributed all across India, starting from the southern Himalaya, excluding only the arid tracts in the country. The current distribution is restricted to only the Himalayan foothills in the north, the hills of the Western Ghats in the south, forests of north-eastern states and the forests of east-central India (Baskaran et al., 2011; Sukumar, 2006). Current estimates indicate a countrywide population size of 27,000-28,000 in the wild (www.moef.nic.in). Habitat loss, poaching and other threats in Asia have reduced the elephant population by more than 50% over the last three generation as a result, the elephant have been listed 'Endangered' by the IUCN (www.iucnredlist.org). Elephants have been listed in Schedule-I of the Indian Wildlife (Protection) Act, 1972. The elephant is listed in Appendix-I of CITES which prohibits any form of international trade (www.cites.org).

Status of negative interaction

Statistics indicate that the interactions between humans and elephants are becoming more hostile over the years, leading to loss of human life (> 400 deaths annually), crop-damage (~ 330 km² every year) and elephant deaths (100 annually in retaliation) (MoEF, 2010). Since 1987, 150 elephants died due to train hit (Rangarajan et.al., 2010)

Reasons for negative interaction

Elephant habitats are disappearing, and the quality of the fragmented landscape is deteriorating across the country at an alarming rate. These two factors are being established as the prime reason for the escalating conflict between humans and elephant (Bist, 2002; Choudhury, 2004; Fernando et al., 2008). It has been suggested that infrastructure development leading to fragmentation of elephant habitats is an overriding factor in conflict cases across Asia (Leimgruber et al., 2003). Depletion of food resources directly due to degradation of habitats caused by humans and biomass extraction and indirectly due to spreading of weeds in elephant habitats are resulting in aggravated crop-depredation episodes (Boominathan et al., 2008). Behavioural changes and the associated increased stress levels caused by poaching are a causative agent of damage by elephants in Africa (Ruggiero, 1990).

Management of negative interaction

→ Current mitigation measures

- A variety of short-term strategies are used to mitigate the elephant conflict in the country. Lenin and Sukumar (2008) provide a detailed account of all the mitigation measures used at the national and international levels to alleviate the conflict. Short-term strategies have been used as an immediate tactical strategy to deter elephants: creating a barrier (i.e., electric fencing, boundary wall, ditches etc.), compensation schemes and eliminating “problem” individuals from the population. Elephants have been shown to become habituated to strategies used for conflict management, and therefore these short-term measures should be used to develop strategies that could provide long-term solutions (Lenin & Sukumar, 2008). Additionally, it is important to study (1) the impact of short-term methods on elephant behaviour and (2) their effectiveness at the landscape level, as localized success might result in only shifting the conflict to another location (Lenin & Sukumar, 2008).

→ Mitigation measures suggested

The Elephant Task Force (ETF) appointed by the MoEFCC in 2010 (Rangarajan et al, 2010) and Karnataka Elephant Task Force (KETF) appointed by the Karnataka Forest Department in 2011 in pursuance of directives of the Hon’ble High Court of Karnataka (Sukumar et al, 2012) have examined the issues relating to Human-Elephant Conflict (HEC) in the country in great details and made several suggestions.

1. The KETF has recommended a zone-based approach, combining science and pragmatism, for conserving elephants in the long-term as well as substantially reducing the levels of HEC. Three zones are proposed for this purpose, each with a different set of conservation objectives and goals:

i) Elephant Conservation Zone (ECZ) would encompass the landscapes of larger and more viable populations of wild elephants, with emphasis on maintaining habitat integrity through protection of existing corridors, and mitigation of HEC through containment of elephants within this natural range using barriers such as high-voltage, non-lethal electric fences, elephant-proof trenches and other means. This zone could also include a certain number of

human settlements having hard and clear interface with elephants. In ECZ, conservation of elephants should get the maximum priority.

ii) Human- Elephant Co-existence Zone (HECZ) would include intermediate zones between the larger, integral habitats and small, fragmented forest patches for implementing the co-existence model through negotiated sharing of space between elephants and people. Emphasis in this zone should be on enhancing the social carrying capacity of the people.

iii) Elephant Removal Zone (ERZ) would include regions with small, isolated patches of forests or human-dominated areas with unacceptably high levels of HEC and / or where the viability of the elephant groups is in serious doubt. Elephants would have to be captured from ERZ and either relocated to the first two zones or retained in captivity.

2. ETF has suggested formation of Conflict Management Task Force (CMTF) (consisting of a biologist, animal welfare specialist, wildlife veterinarian, social scientist, elected public representative, representative of Revenue / Civil Department, etc.) in identified areas of high conflict.

3. According to ETF, anti-depredation teams are crucial for drives in high conflict areas, but they cannot be a permanent solution. It has suggested use of short drives to placate people in a crisis situation but not as a routine measure.

4. ETF has opined against **culling elephants** (killing of herds or whole groups of elephants as a technique of population management) as it is ethically unacceptable in the Indian context*. ETF has suggested that **killing of problem elephant** permitted by the Chief Wildlife Warden (CWLW) under S.11 of WPA-1972 should be done under strict supervision, after proper identification of the elephant and after observing due protocols, and all such cases should be reported to the MoEFCC.

5. ETF has recommended serious and sustained research for **reproductive control** of elephant populations in unviable situations.

6. ETF has recommended **translocation of elephant populations** only subject to strict conditions. It has pointed out that translocation will work best if done for whole herds, but in

*Also prohibited under S.12 (bb), Explanation (ii), of WPA-1972.

case of an individual bull, viability of the approach should be carefully examined. ETF has suggested that the translocated animals should be compulsorily monitored through the best possible means (such as telemetry) and Forest Department (FD) should recapture them if they cause conflict elsewhere. KETF has suggested that translocation must be seen as an experimental management tool, and should invariably be accompanied by close monitoring through radio- and GPS-collaring of at least one individual per group to observe its behaviour and movement so that corrective action such as removal into captivity could be taken in the case of continued conflicts.

7. ETF has suggested that **capture of elephants** from the wild as a conflict mitigation strategy should be done only “under the assessment and monitoring by a consortium of research institutes, individuals, other stakeholders and government departments with the requisite capacity”. The captured elephants are to be a government monopoly and not transferred. KETF has suggested that, if dispersing elephants have remained for several years outside their native habitat, it may be best to capture and retain these elephants in captivity. KETF has also provided guidelines for ensuring the welfare of elephants in captivity.

Use of Barriers:

- According to ETF, **fences and trenches** can only work as a part of a large landscape-level intervention. It has suggested moratorium on Elephant-proof Trench (EPT) and sought to discourage expensive electric fences without involvement of community for their maintenance.
- KETF has accepted **physical barriers** (EPT) as one of the main strategies to minimise HEC, particularly in reducing crop losses and recommended creation of such barriers where unbroken interfaces exist between farming and elephant habitats. However, it has cautioned that, in situations where the farm-forest fringe is more dissected /broken, the creation of physical barriers without first understanding patterns of elephant movement may aggravate conflicts as these barriers could impede elephant movement and temporarily restrict them within cultivated areas. KETF has, therefore, recommended a more comprehensive site-specific strategy on physical barriers. It has emphasised upon regular maintenance of these barriers and asked for a system of auditing the effectiveness of these maintenance measures.

- KETF has pointed out that **involving local communities** in the creation and maintenance of barriers is often vital in ensuring its effectiveness and durability and recommended that, wherever possible, the FD should partner with local eco-development committees (EDCs), or even panchayat raj institutions to secure farm landscapes from elephants.
- ETF has suggested that in agricultural areas adjacent to or within elephant range, priority should be given to increase effective protection to farmlands by creating non-lethal barriers. It has suggested that barriers may be raised under PPP model or community-led collective action or public service initiative by the business class. There should be a clear agreement between the FD (or other investors) and the beneficiaries (local communities) about their roles and responsibilities in the creation and maintenance of barriers.

9. ETF has emphasised the role of **crop-guards** and suggested that payments for the work of **crop protection** may be considered under the auspices of the MGNREGS.

10. ETF has recommended holding of **Public hearings** at least twice a year at taluka level (at the start of the kharif and rabi sowing seasons). These must mandatorily require presence of not only the Wildlife Wing and Territorial Wing staff but also the revenue and civil authority and elected people's representatives such as the MLA.

11. ETF has suggested that **transparency of information** (e.g. claims for loss of life, crops or property; loss of lives of people; and elephants captured or killed) should be maintained.

12. KETF has suggested that **toll-free helpline telephones** should be set up at the level of Forest Ranges to provide timely assistance to people who may be injured by elephant attacks, or need help from the anti-depredation squads.

9. Insurance:

- Government of Kerala provides insurance support to its tribal population against death and injuries caused by wild animals.
- A few EDCs in Northern West Bengal buy group insurance policies for their members covering death by wild animals. Many tea estates in the same region also buy insurance cover for the labour huts and other properties against damage by wild elephants.

- All efforts made by the MoEFCC and various FDs in the past to persuade Public Sector Insurance Companies to extend insurance cover to farmers against crop damage caused by elephants have been unsuccessful.
- ETF has suggested that, after creation of barriers and finalisation of agreements with the beneficiaries, insurance must become the standard means of offsetting further crop losses. It has further suggested that Modified National Agriculture Insurance Scheme should be adapted and implemented in collaboration with the Agriculture Insurance Company of India in a few sites on a pilot basis. ETF has recommended that the premium must ideally be shared between FD and farmers and payment of insurance should be contingent upon efforts to maintain barriers.

10. *Ex-gratia* relief:

- All elephant range States and Maharashtra have rules for providing ex gratia relief to the victims / their dependents in case of human deaths / injuries / crop damage caused by elephants. Some State Governments (e.g. West Bengal, Uttarakhand and UP) also provide ex gratia relief for damage to huts caused by elephants. MoEFCC also provides financial support to FDs under various Centrally Sponsored Schemes for the purpose of ex gratia relief.
- KETF has recommended that a careful and critical review of the current system of ex gratia relief should be carried out, and, in the interim, the State (Karnataka) Government should speed up disbursement of relief to people. It has suggested that the budget head in the office of the CWLW for payment of ex gratia should be managed on the lines of the Calamity Relief Fund being managed in the office of the District Magistrate and availability of funds in this budget head should be always ensured in order to make quick payments in respect of people killed or injured by elephants. ETF has recommended that a standard guideline for assessment of damage should be developed; compensation claims should be cleared every month; and a transparent verification system involving FD personnel and village representatives should be put in place.
- ETF has recommended that ex gratia relief for loss of human life should not be less than 3 lakh rupees while for the injured person, full hospital bill including transport;

lodging/boarding charges for the accompanying family member; and cost of treatment and medication post-discharge should be paid for. It has recommended that loss of wages /pay of the victim for the duration of treatment should be compensated.

- ETF has recommended that crop compensation should be available if and only if other methods (barriers) have failed despite being properly put up.
- ETF has proposed schemes like “Grain for Grain” as alternative to crop-compensation.
- ETF has proposed a structured approach to crop compensation to ensure social justice. It has suggested that maximum amount payable to a family should be based on some predetermined percentage (say 80% to 100%) of what the minimum wages a person would earn in a year or the actual crop loss (including labour and input cost) whichever is lower. It has proposed full compensation to people under BPL/SC/ST or anyone holding less than 2 acres of agriculture land; 50% to 70% compensation for people holding 2-5 acres of agriculture land; and 25% compensation to those holding land above 5 acres.

→ **Existing Policies:**

1. Elephant is included in Schedule I of the WPA-1972. Cases of HEC are handled under S.11(1) which stipulates that the CWLW may permit the hunting of an elephant if he is satisfied that it has become dangerous to human life or is so disabled or diseased as to be beyond recovery. The provisions of S.11(1) are subject to the following riders:
 - a) No elephant shall be ordered to be killed unless the CWLW is satisfied that such animal cannot be captured, tranquilised or translocated.
 - b) No elephant shall be kept in captivity unless the CWLW is satisfied that such elephant cannot be rehabilitated in the wild and records his reasons in writing.
 - c) The CWLW cannot delegate his powers under S.11 in respect of elephants to any other authority [Ref. S.5(2)].
 - d) Killing or wounding in good faith of any elephant in defence of oneself or any other person is not an offence except when the said person, when such defence becomes necessary, was committing any act in contravention of this Act or any rule or order made thereunder.

e) Provisions of S.11 are not applicable within a National Park or a Wildlife Sanctuary.

2. S.11(1) is applicable only when an elephant poses a direct threat to human life. As a corollary, elephants known to be habitual crop-raiders or habitual house-breakers cannot be dealt with under this Section. This places the forest officers in an awkward position since elephants are the largest destroyers of crop and property among the wild animals (excluding rodents and birds) in the country. The matter needs a serious review.

3. Forest officers sometimes invoke S.12 to deal with elephants which may not be posing a direct threat to human life. S.12 empowers the CWLW to permit, with prior permission of the Central Government, hunting of wild elephants for certain specified purposes which include education, scientific research and scientific management. The expression “Scientific Management” in this Section has been defined as:

— translocation of any wild animal to alternative suitable habitat; or

— population management of wildlife, without killing or poisoning or destroying any wild animal.

4. HEC is showing an upward trend in the country and over-abundance of elephants in some parts of the country is adding to the problem. The option of translocation under Sections 11(1) and 12 is not without limitations. The State may not have a safe and suitable area where the elephants can be relocated. The local people may also resent the translocation of problematic elephants into their neighborhood. Mass translocation of elephants has not been attempted in India for want of necessary expertise as well as doubts about suitability of areas for translocation. In a few attempts with relocation of elephants in ones and twos, they are mostly known to have returned to the original sites. So, translocation of elephants remains a doubtful option. As mentioned earlier, the option of killing an elephant is not available under S.12 while it can be exercised under S.11(1) only after exhausting the options of translocation and capture. The net result of all these legal and technical hassles is that FD in most cases has no option but to capture the problem elephant and retain it in captivity.

5. An important issue in capture of elephant is about its subsequent use and maintenance. Elephants, given their huge size and strength, are not kept in captivity literally. Fortunately,

they can be tamed, trained for certain jobs, handled by mahouts, and kept in restrained conditions. India has an old tradition of capturing and keeping elephants in captivity and using them for a variety of jobs. But the existing policies in India are not conducive to captive elephants as explained below:

- In view of the provisions of the Forest (Conservation) Act, 1980 and various orders of the Hon'ble Supreme Court, logging operations have either been stopped or restricted in various parts of the country. As a result, a large number of elephants used for logging in the North-Eastern India and Andaman & Nicobar Islands have been rendered jobless making it difficult for the owners to find money for taking proper care and upkeep of their elephants and mahouts.
- Commercial dealing in all Schedule-I species including elephants is banned in terms of Sections 44 and 49B. The Act provides that a person can own a captive elephant only on the strength of an ownership certificate issued by the CWLW (Ref. Sections 40, 41 and 42). But an elephant-owner cannot sell his elephant or dispose it off by any other mode of commercial nature because of an amendment carried out in S.43(1) in 2003. Ironically, the said amendment was not specifically meant for elephants. It was intended to prevent trophies of Schedule-I animals like tiger, leopard, rhinoceros, etc., presently in personal collection of various individuals, from entering the market. But, the law-makers overlooked the fact that there were about three thousand captive elephants in private ownership in India which would be affected by the said amendment. The Steering Committee of Project Elephant advised the MoEFCC in December 2003 to amend the WPA-1972 and exempt captive elephants from the restriction imposed under S.43(1). But the proposed amendment has not yet taken place. As stated earlier, owners in the North-East India find it difficult to maintain their elephants. There is a demand for these elephants in other parts of the country for the purpose of eco-tourism, temple duties, and patrol by the forest staff. But the owners cannot sell them legally in view of S.43(1) as it stands now. As a result, even the FDs in need of captive elephants find it difficult to procure them from the legitimate owners. Meanwhile, elephants continue to be sold, albeit illegally, in the North-Eastern India and the famous cattle fair in Sonapur (Bihar).

- In November 2009, the Central Zoo Authority (CZA) issued a directive banning captive elephants from zoos. It has put further restrictions on the use of captive elephants within the country.
- Asian elephant (*Elephas maximus*) is in Appendix-I of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) and, accordingly, international trade in live elephants and all products derived from them is not allowed. Export Policy of Government of India, therefore, does not permit commercial export of elephants. Meanwhile, elephants from India are allegedly exported to Nepal through the land-borders in violation of the Export Policy and the CITES.
- There is a constant lobbying in the country by the animal right activists against keeping elephants in captivity.

6. In the absence of legal ways for disposing off captured elephants, FD has no option but to retain all the elephants captured under Sections 11 and 12. This in itself is a difficult decision in view of the huge financial implications of maintaining captive elephants.

7. As stated earlier, capture of elephants and their retention in captivity has become a necessary evil as far as management of HEC in India is concerned. But the corresponding legal tools cannot be used effectively without creating adequate room for the use of captured elephants. A few points that need to be considered for this purpose are as follows:

- Most of the FDs in the country can increase their intake of captive elephants by using them for patrolling/ monitoring especially during monsoon seasons.
- The Tourism Policy should encourage use of captive elephants in place of polluting vehicles for eco-tourism activities in National Parks and Sanctuaries and other sensitive zones.
- Export Policy should be reviewed for permitting export of elephants to foreign zoos /tourism facilities and also for elephant-rehabilitation programme in other Asian countries.
- S.43(1) may be revisited in the light of the recommendation made by the Steering Committee of Project Elephant in December 2003.

- The recommendations of ETF and KETF for the welfare of captive elephants should be implemented.

Human-Rhino interaction in India

Current population status and distribution of species

The great one-horned rhino (*Rhinoceros unicornis*), the largest rhinoceros of Asia, was once distributed all along the northern part of the Indian subcontinent. Currently the species exists in few small population in North-East India and Nepal. In the early 1900s, the species was on the brink of extinction as only 200 individuals were left in the wild. However, conservation efforts undertaken in India and Nepal helped the recovery of the species. Population estimates made in 2014 indicated a total population size of 2831 individuals, of which in Kaziranga National Park holds a population of 2329 individual, Orang National Park 100, Pabitora Wildlife Sanctuary 93, Manas National Park 31, Jaldapara National Park 186, Gorumara National Park 43 and Dudhwa National Park 31 (B. Talukdar *pers comm*).

Although the overall population size of the species is increasing, considering the increasing threats jeopardizing the future of the Indian rhino, it has been categorized as ‘Vulnerable’ by the IUCN. Legally the species receives the highest degree of protection in India as it has been placed in Schedule-I of the Wildlife (Protection) Act (1972). It has also been included in Appendix-I of CITES, which prohibits international commercial trade of this animal and all its derivatives.

Status of negative interaction

Crop-damage by the rhino is the major reason for the conflict, and sometimes encounter with rhino leads to injury and death of humans. The incidents of rhinos killing / injuring people mostly take place within forests and the victims include either the forest staff or poachers or trespassers or grazers (S.S. Bist *pers comm*). In Pabitora Wildlife Sanctuary, five people were killed by rhinos between 2000 and 2010 (Bhatta, 2012). The number of incidents that resulted in deaths was high in Royal Chitwan National Park between 1977 and 1988. A total of 78 accidents involving rhinos resulted in 23 deaths and 55 injuries to humans (Jnawali, 1989) in Royal Chitwan National Park. Ghosh (1996) mentions that crop-depredation in Jaldapara National Park, West Bengal is increasing. However, the local people are traditionally tolerant of rhinos.

Reasons for negative interaction

Humans had few negative interactions with rhinos in the past, but increasing habitat loss due to encroachment and silting of *beels* is forcing rhino to venture out of the protected area (Talukdar et al. 2014).

A decrease in the availability of fodder biomass due to an invasion of exotic weeds is another factor contributing to the increasing movements of rhinos outside the protected area in search of food (Talukdar et al. 2014). The area under *Desmodium triflorum*, *Cardiospermum halicacabum*, *Ipomea carnea* and *Argemone mexicana* in Pabitora Wildlife Sanctuary (Bhatta, 2012), and that under *Mikania micarantha* and *Eupatorium* sp. in Nepal are rapidly increasing, and these plants are competing with native fodder species. In West Bengal, *Lantana camara*, *Mikania cordata* and *M. scandens* have infested the grassland habitats severely (Ghosh, 1996).

Expansion of woodlands into grasslands is also leading to a decline in fodder and habitats for the rhino (Bhatta, 2012). Since 1977, in Pabitora Wildlife Sanctuary, the area of woodland habitats has increased by 34%, with a parallel decline in grassland habitats by 68% (Talukdar et al. 2014).

Illegal grazing inside rhino habitats is on the rise, leading to decreased availability of fodder for the rhino. Overgrazing has resulted in degradation of 50% of the grasslands in Pabitora Wildlife Sanctuary.

Management of negative interaction

→ Current mitigation measures

- *Machans*, or guarding platforms, are erected at the boundary or in the middle of crop fields. This was found to be an effective strategy of crop-protection but can be really dangerous if an animal is in a rage and attacks a *machan* (Nepal & Weber, 1995).
- Due to high risks of poaching of rhinos, the forest staff in Assam, West Bengal and UP follow a strict regime of patrolling along the forest boundaries and steps are taken to drive rhinos back to forests as soon as they are detected in the croplands. *Kunki* elephants are used for driving the rhinos whenever required.
- Traditional scaring devices such as bundle of burning thatch grass, creating noise (hitting empty tin, fire crackers and whipping noise through a *Eulalopsis* rope etc.,) and scare

crow are being used for a long time in Royal Bardia National Park and Sauraha area in Nepal (Jnawali, 1989; Thapa, 2010).

- Extensive habitat improvement work (e.g. plantation of fodder-grasses, thinning of trees, weed-eradication and digging of wallow-pools) is being carried out in Jaldapara and Gorumara national parks every year to enhance the carrying capacity of the two parks and to prevent rhinos from straying outside for grazing.
- Bio-fences are erected using thorny plant species such as *Ziziphus mauritiana* and *Euphorbia* species in Nepal. Thapa et al. (2010) found that this to be one of the most effective methods of crop protection. Even though it is the cheapest and most effective method of protection, it suffers from two major drawbacks. The first drawback is that *Euphorbia* species take a long to grow into an impenetrable fence. The second is that the roots of aged plants decompose, leading to the collapse of fences.
- In West Bengal (Jaldapara and Gorumara National Parks) and UP (Dudhwa National Park) power fences are used to prevent straying of rhinos outside PAs.
- Deaths caused by rhinos in India are mostly accidental. Jnawali (1989) suggested a few instinctive techniques such as climbing or running around a tree, dropping any personal belongings (piece of cloth or other item) while running away and swimming away to avoid attacks during encounters with rhinos.
- There is a strong Joint Forest Management mechanism in place in Jaldapara and Gorumara National Parks in the form of Eco-development Committees to involve local people in management of human-rhino conflict. West Bengal Forest Department regularly carries out eco-development activities to enhance social-carrying capacity of the fringe-area people.

→ **Mitigation measures suggested**

- Studies conducted by Thapa (2010) and Jnawali (1989) in Nepal focused on the mitigation measures used by farmers to reduce crop damage due to rhinos, and the following suggestions are based largely on these studies. Both studies recommend the use of different combinations of the mitigation measures. Sekhar in India (1998) made similar suggestions for reducing the chances of problem animals getting habituated to the mitigation measures.

- Thapa et al. (2010) suggested the use of electric and mesh-wire fencing to prevent the entry of rhinos into crop-fields. However, the high maintenance costs involved make it less preferred by farmers. Jnawali (1989) suggests that some material could be hung on the fence that creates a noise that alerts the farmer to the animal's presence.
- Digging trenches adjacent to fence walls along crop-fields to restrict the movements of free-roaming rhinos has been suggested by Jnawali (1989). Moreover, this method could reduce fence-damage.
- Limiting the extent of livestock grazing could help reduce the conflict by increasing the food available to rhinos (Jnawali, 1989).
- Cultivation of crops not preferred by rhinos has also been suggested as a mean of reducing crop-damage(Jnawali, 1989; Thapa, 2010). However, the unwillingness of farmers to switch to other crops and a lack of institutional support are the biggest hurdles in the implementation of this technique.
- Wildlife managers should prevent trespass and grazing inside rhino habitats.

→ **Existing policies**

- Rhino is in Schedule I and Human-Rhino Conflict is required to be managed under S.11 (1) (a). It gives rhinos a kind of immunity against crop-raids. In any case, degree of crop-damage by rhinos is seldom severe and local people show great tolerance towards crop damage by rhinos. Rhinos don't indulge in killing livestock. Rhinos are not known to be habitual human-killers. Therefore, in practice, there is no scope for invoking S.11 (1) (a) against rhinos. The main focus of managing human-rhino conflict should, therefore, be on preventing straying of rhinos outside PAs (which is also important as an anti-poaching strategy) and to enhance social carrying capacity of the people (S.S. Bist *pers comm*).

Human-Nilgai interaction in India

Current population status and distribution of species

The nilgai (*Boselaphus tragocamelus*) is endemic to peninsular India. It is widely distributed across the country, from the Himalayan foothills to the southern districts of Andhra Pradesh (Sankar & Goyal, 2004). It inhabits arid areas, scrub and dry deciduous forest but avoids dense forest and desert. Although it has drastically declined in its distribution due to habitat destruction and overhunting, its population size in a few northern and central Indian states ranges between 1,00,000 and 1,50,000 individuals (Sankar & Goyal, 2004). Due to a lack of population studies on the species and its overabundance in a few states, the overall status of the population is assumed to be steady. The IUCN categorized the nilgai as a Least Concern species, and because there is no illegal trade in the species and its parts, CITES does not include it in any of the appendices (www.iucnredlist.org, www.cites.org). The species is listed in Schedule-III of the Wildlife (Protection) Act (1972) in India.

Status of negative interaction

With 60% of the total nilgai population residing in four northern and central states of India (Haryana, Madhya Pradesh, Uttar Pradesh and Rajasthan), the level of conflict is high in these regions (Chauhan, 2011). The reported crop losses due to nilgai are 50% and 73% of the total crop-damage due to wild animals in Sariska and Kumbhalgarh Wildlife Sanctuary, respectively (Chauhan & Singh, 1990; Chhangani et al., 2008; Sekhar, 1998). The nilgai is the top crop-raider in Ranthambore and central Saurashtra and was involved in 70% of the crop-raiding cases (Karanth et al., 2013; Mehta, 2014). Despite of the nilgai being rare in Nepal, it accounted for 8.3% of the total crop-damage caused by wild animals. The number of road mishaps involving vehicular collisions with nilgai are also increasing in states with high densities of the species (Chauhan, 2011).

Reasons for negative interaction

Historical records indicate that the hunting pressure on the species was high during Mughal era (Sankar & Goyal, 2004). However, the present overabundance of the species has been suggested as the proximate reason for the increasing conflict in Indian states. Since the implementation of the Wildlife Protection Act (1972), the overall protection of wildlife has improved. Moreover,

changes in land use practices have resulted in an overabundance of few species such as the nilgai. Hunting of nilgai for crop-protection under Section 11 (1) (b) has been permissible right from the time of the implementation of the Wildlife Protection Act (1972), but few communities (i.e., the Bishnoi) do not allow hunting in their areas. This is another important reason for the increase in the population of the nilgai. The nilgai has a prolonged breeding season, and the loss of potential predators from human-dominated areas has resulted in its overabundance (Chauhan, 2011; Chauhan & Singh, 1990; Sekhar, 1998). Loss of habitat and depletion of food resources as a result of conversion of nilgai habitat to plantations of non-palatable species (*Acacia* sp. and *Prosopis juliflora*) has resulted in increased conflict in Haryana (Chauhan & Singh, 1990). Also, in the cropping season, the animals raid crops in search of richer nutrition compared with what is available in their refuge sites (Mehta, 2014). Nepal had a very small population of nilgai, but the species is still reported to be one of the top crop-raiders due to the depletion of food resources due to livestock grazing (Aryal, 2007).

Management of negative interaction

→ Current mitigation measures

- Crop guarding by humans and physical barriers (stone walls, mud walls and brushwood) are reported to be effective (Mehta, 2014; Sekhar, 1998).
- Night vigils and creating loud noises by beating drums and fire crackers were the most commonly used mitigation methods in central Saurashtra (Mehta, 2014).
- Bio-fencing (thorny bushes and shrubs) and barbed wires (height = 3 m) are being used, but other species involved in conflicts could dig holes to get past these. So they may not be a long-term solution (Sekhar, 1998).

→ Mitigation measures suggested

- Intrusion can be prevented using acoustic (unexpected loud noises, crackers), visual (scarecrows, brightly coloured cloth), olfactory (chilli dung bricks, pepper sprays, tobacco, etc.) and contact deterrents (Chauhan et al., 2010; Kumar, 2012).
- Fencing has proved to be highly effective in reducing the conflict in some protected areas in the country (Karanth et al., 2013). The use of battery-operated electric fencing around farmlands has been proposed a mitigation measure (Mehta, 2014). However, this may interfere with normal animal dispersal and result in shifting the conflict to other, non-

targeted species. Moreover, the associated installation and maintenance costs are generally very high, especially in the case of protected areas with long boundaries (Sekhar, 1998).

- Installing fencing around agricultural areas has also been suggested as a means of reducing the conflict. Farmers of central Saurashtra unanimously perceived government-aided fencing to be one of the top mitigation measures (Mehta, 2014). However, concerns have been raised by a few researchers as this may export the problem to unfenced areas (Chauhan & Singh, 1990).
- Population management and lethal control have been advocated as logical solutions by some researchers. However, Indian law and local communities (especially the Bishnoi and Hindu farmers) do not permures (Chauhan & Singh, 1990).
- Although compensation is provided for crop- losses due to wildlife, there are challenges involved in availing oneself of the funds, and the delays involved often discourage farmers from reporting cases. To reduce the conflict levels, it is imperative to restructure the systems and the compensation schemes (Karanth et al., 2013; Madhusudan, 2003; Sekhar, 1998).
- Improving the habitat in nilgai refuge areas by preventing livestock grazing and by planting various nutritive forage species could reduce the number of crop-raiding cases (Mehta, 2014).

→ Existing policies

- All Indian states hold the power to use the legal option available under Section 11(1) (b) of the Wildlife Protection Act (1972), which empowers the Chief Wildlife Warden or an authorized officer to permit any person to hunt a wild animal or a group of animals (specified within Schedule II to Schedule IV) causing damage to standing crop. So far the state governments of Uttar Pradesh, Uttarakhand, Haryana, Madhya Pradesh and Gujarat have exercised this legal option to manage conflict due to nilgai in agricultural areas (Chauhan et al., 2010). Though there is a provision for lethal control of Nilgai but this policy is not effective due to the religious belief and the carcass of the individuals is not allowed to be taken by hunter.

Human-Wild Pig interaction in India

Current population status and distribution of species

The wild pig (*Sus scrofa*) is one of the most widely distributed terrestrial mammals amongst all Suiformes. This range has been greatly expanded by humans (IUCN 2008). It is common throughout India except Jammu and Kashmir, upper Himalayas and desert, (Chauhan 2004). The wild pig (*Sus scrofa*) is Schedule-III species of Wildlife (Protection) Act, 1972. This species is abundant in many parts of its range, though populations can be depressed in places where hunting intensity is high (for example in eastern and southeastern Asia).

Status of negative interaction

Wild pigs invade human habitations and agricultural and horticultural farms and feed on different crops. Wild pigs were reported to cause 46% of the damage to crops in central Saurashtra (Mehta, 2014). Damage caused by wild pigs to *Triticum vulgare*, *Oryza sativa*, *Zea mays*, *Pennisetum typhoides*, *Saccharum officinarum*, *Arachis hypogea*, *Cicer arietinum*, *Hordeum vulgare*, *Sorghum vulgare* and *Brassica campestris* was 5% to 20% in north and central India (Chauhan, 2011). *Eleusine coracona*, *Vigna radiata*, *Glycine max*, *Sesamum indicum*, *Lens esculenta*, *Ipomoea batatas* and *Lythyrus sativus* showed damage to varying extent (5% to 10%) and in some areas, pulses and vegetables were damaged to an extent of 5% to 25% (Chauhan, 2011b). Dave (2010) reported the damage in terms of percentage of agriculture field area affected near the Little Rann of Kachchh to be between 10% and 25% for cash crops (cotton and cumin), millet and pulses and oil seeds.

Occasionally wild pigs attack people and injure them. Human casualties are caused by wild pigs in different parts of the country (Chauhan, 2004). A survey conducted in Madhya Pradesh revealed that 58 human casualties were caused by wild pigs in and around 12 protected areas and forest divisions between 1989 and 2000 (Chauhan et al., 2009). Most of these cases occurred inside forests and resulted in severe injuries. Seven and five human casualties were recorded in Noradehi Wildlife Sanctuary and Chindwara West Forest Division, respectively. During 1991–1992, two human casualties caused by wild pigs were recorded in Almora Forest Division, Uttaranchal. Sporadic wild pig attacks were reported from different states (Chauhan, 2004).

Reasons for negative interaction

Prater (1971) reported that there is no animal more destructive to crops than the wild pig. It causes extensive damage to agricultural crops and utilizes agro-ecosystems for food resources and shelter. Presently wild pig populations are fragmented and relatively isolated all over the range. Some of these isolated populations have become locally overabundant and depend upon agricultural crops, especially in and around protected areas or managed forests, for a major part of their food requirements. Besides agricultural crops, they cause damage to orchards and forest plantations and possibly act as carriers of some infectious diseases. According to Mackin (1970), Andrzejewski & Jezierski (1978) and Genov (1981), the damage caused to crops by wild pigs increases when there is less natural food available in forests.

Management of negative interaction

→ Current mitigation measures

- Farmers manually guard their farms, create noise, fire crackers and even guns, to scare away wild pigs from farms (Ahmed 1991, Mehta 2104). Wild pigs are killed in many places using local-made guns. At times pig bombs are also employed illegally to eliminate wild pigs.
- The forest department helps with crop protection by deputing crop watch guards in highly impacted areas and providing torches and fire crackers to farmers in a few places to scare away wild animals (Chauhan, 2004).
- Barbed wire fences are also used to contain the damage done to crops by wild pigs. Farms around Bandhavgarh National Park are guarded using electric fencing (Chauhan, 2004).
- Crop protection trenches are reported to be used in Nepal (Thapa, 2010).

→ Mitigation measures suggested

- Contraception and cost-effective barriers have a wide scope and seem to have the potential to develop as effective management tool.

→ **Existing law & policies**

- Almost all states have compensation for loss of crop, damage to property, human and livestock injuries as well as death due to wildlife. Compensation amount vary a lot across states and there is an urgent need to re-structure the schemes as well as the relief amount.

Human-Blackbuck interactions in India

Current population status and distribution of species

The blackbuck (*Antilope cervicapra*) is native to the Indian subcontinent (Lydekker, 1907). It is found in a wide range of habitats, from semi-arid grasslands and scrub to open forest (Isvaran, 2005; Mungall et al., 1981; Prasad, 1981). They reach their highest densities in semi-arid, open and short-grass plains. Blackbuck historically ranged from near Peshawar (in Pakistan), in the northwest, through the Indo-Gangetic plains, up to the plains of western Assam, in the east; centrally, in the Deccan; in open plains areas along the western coast of the peninsula; and along the eastern coastal plains up to southern Tamil Nadu (Lydekker, 1907). Within India, they are found throughout a large part of their former range. However, their populations, previously large and contiguous, are now small, scattered and relatively isolated. The most recent survey of blackbuck populations in the country, based on observations made between 1981 and 1988, arrived at an estimate of 29,000–38,000 individuals (Rahmani, 1991). This estimate includes populations both within and outside protected areas. Rajasthan, Punjab, Gujarat and Maharashtra had the largest state-wise population estimates (Rahmani, 1991). Velavadar, in Gujarat, Tal Chappar, in Rajasthan, Nannaj, in Maharashtra, Rollapadu, in Andhra Pradesh, Ranebennur, in Karnataka, and Point Calimere, in Tamil Nadu, currently hold some of the largest concentrations of blackbuck within protected areas (Isvaran, 2003; Jhala, 1993a; Rahmani, 1991; Ranjitsinh, 1989).

Status of negative interaction

Chauhan & Singh (1990) reported losses incurred by farmers due to crop depredation in Haryana. Blackbuck feed on crops, such as groundnut, wheat, barley, millet, and black gram (Jhala, 1993b; Manakadan & Rahmani, 1998; Prasad, 1981), in areas where croplands are easily accessible (Isvaran, 2004).

Reasons for negative interaction

Blackbuck thrive in protected areas as a result of their high fecundity and their ability to survive well in diverse habitats (Isvaran, 2004). However, this tendency of blackbuck populations to grow rapidly often brings them into conflict with local communities. In most protected areas with healthy populations of blackbuck, individuals regularly feed in adjoining crop fields. Some

factors thought to be responsible for this movement are the relatively small sizes of many protected areas with blackbuck and the greater nutritional value of many crops compared with natural forage, particularly in the dry season (Jhala, 1993b; Manakadan & Rahmani, 1998).

Management of negative interaction

→ Current mitigation measures

- Brushwood fences are used in some places (Chauhan & Singh, 1990)
- The most common protection strategy for farmers in Haryana is to guard their fields by remaining vigilant during the crop season (Chauhan & Singh, 1990) .

→ Mitigation measures suggested

- Selective reduction of the population by translocation in areas with high loss has been suggested (Chauhan & Singh, 1990) .
- Other recommendations include implementing various crop protection measures and compensation schemes and growing non-palatable species in fields close to sanctuaries (Manakadan & Rahmani, 1998). The effectiveness of these various recommendations has not yet been systematically studied.

→ Existing law & policies

- Almost all states have compensation for loss of crop, damage to property, human and livestock injuries as well as death due to wildlife. Compensation amount vary a lot across states and there is an urgent need to re-structure the schemes as well as the relief amount.

Human-Wild Ass interaction in India

Current population status and distribution of species

Two species of wild ass are found in India, the khur (*Equus hemionus khur*) and the kiang (*Equus Kiang*). The range of the khur or Indian wild ass was probably always restricted to the deserts of north-western India. In the 20th century, the Indian wild ass had a fairly wide distribution in the dry regions of north-west India and south Pakistan. It was found as far north as Jaisalmer and Bikaner, in Rajasthan, and westward in Sind and Baluchistan (Gee, 1963). The former distribution of this sub-species was in Baluchistan, around Balgajar, in central Makran, and in Sohtagan, in the extreme western part of Kharan District. A small population survived in the Great Rann of Kutch, on the border between Chacro and Nagar-Parkar tehsils, of Tharparkar District, in Sindh, until the late 1960s (Feh et al 2002). The only remaining population of khur in the world today is in the Wild Ass Sanctuary, the Little Rann of Kutch, and its surrounding landscape in Gujarat (Groves, 1974; Shah, 1993, 2004). An Increasing trend has been observed for the khur population in Rann of Kutch since 1970's. The wild ass population has gradually increased from less than 400 in the late 1960s to about 4000 in 2014 (Shah, 1993, Shah 2015, Moehlman et al 2008).

Kiang is restricted to the high altitude cold desert, on the Tibetan Plateau, between 2700 and 5400. msl. About 90% of kiang distribution is in West China, and 10% population is along borders of Pakistan, India, Nepal and possibly Bhutan (Shah, 2002, Shah et al 2008). Within this broad range, the distribution of the kiang has become increasingly fragmented, and at present, most of the populations are found in protected areas or in areas under army jurisdiction (Shah, 2002). In India, the kiang occurs in the Trans Himalayan areas of Ladakh (Jammu and Kashmir), Uttarakhand and in north Sikkim. The total population of the kiang in India is estimated to be above 3500 to 4000 (Shah & Qureshi 2002, Shah, 2015, shah et al 2008).

Status of negative interaction

The wild ass were found to feed on six species of crops based on village surveys for perception on wildlife conflict (~400 villages) around the Rann. The study indicated that the damage by khur was minimal i.e., ranked lowest in comparison to Wild pig, Cranes and Nilgai, jackals, mynas in the descending order. (Shah 1993, 1999). Wild ass mostly raid crop fields during night,

travelling couple of kilometres, more incidents occurred during summer for food and water (Shah 1993). Damage caused by wild ass was reported between 15 to 25 % of the crop land in the area for all different crop types (Cash crops, millet, pulses & oil seeds) and damage up to 1 km from the fringes of the sanctuary was evident in Northern Little Rann of Kutch (Dave 2010). Almost 80% farmers in Northern part of Little Rann of Kutch believed that the conflict can be avoided if proper mitigation steps are taken (Dave 2010). The attitude toward conflict has changed over time, with people becoming more intolerant with increase in irrigable land and cash crops (Shah 1993, 1999 & 2004).

Reasons for negative interaction

Increases in the wild herbivore populations following better protection with management and changes in land use patterns and intense farming practices because of the water supply from Narmada canal have resulted in severe rise in crop raiding by wild herbivores (nilgai, wild pig, blackbuck) including the khur (Shah, 1999). Agricultural activities have become more intense with better irrigation facilities, thus changing the land use patterns. Prior to the Narmada canal, khur and other herbivores used to move between the PA and the agro-landscapes, with the functioning of the Narmada canal many herds of khur have become resident herds in and around the croplands outside the PA as they could not get back to the Rann. The canal forms the barrier for movement of khur between the sanctuary and the agro-landscapes. In high conflict zones, the agro-systems at the interface of the Rann are the areas most affected (Qureshi & Shah 2013, Shah & Qureshi 2007). Moreover, wild asses are active during the night to maximize the intake of resources at the natural vegetation–agriculture interface (Shah, 1993, 1998, 1999).

Kiang

In the Trans-Himalayan region of Ladakh and Sikkim, the wild equids have been reported by the locals as competitors with the local livestock over the limited resources. The pastoralists tend to maintain large sheep /goat herd sizes in order to compensate over the high incidences of mortality due to harsh environmental conditions. Larger the herd sizes more the resources required; in the high altitude pastures resources are naturally limited with short vegetation growth phase. The kiang-livestock overlap of pasture use therefore would lead to conflicting

situations (Shah et al 2008). In Sikkim despite the kiang population being very small, the local herders perceive that kiang deplete the resources (Shah 1994).

There is an increased pressure on the pastureland due to the increasing population of livestock in Ladakh. The Jammu & Kashmir Government provide incentives to nomads to keep pashmina goats for production of wool (Shah, 1996, 2006; Bhatnagar, 2006). In this context, kiang are increasingly perceived as serious competitors by pastoralists and the local administration (Shah, 1996, 1997). The conflict with kiang has arisen mostly due to a misplaced notion of preserving pastures for livestock grazing. Many pastures are fenced to keep kiang away to maintain resources for pashmina goats (Shah, 1996 & 1997). Temporal use of winter pasture by kiang which were protected for the winter livestock grazing was one of the reasons for the herders' prejudice towards the kiang (Shah & Qureshi 2003). As a consequence, there is a decrease in tolerance towards kiang due to changes in socio-economic conditions.

Overgrazing has reduced the cover in the high land pastures. The complex system of rotational grazing, which has maintained the rangelands, is being modified. Nomad groups now fenced winter pastures and some had built long fences across valleys and hills to keep wildlife out, which will affect the kiang and other wildlife populations (Miller & Schaller 1997, Shah & Huibin 2000, Shah & Gruisen 2000). There are demands from herders to control kiang populations (Miller & Schaller 1997, Shah 1996, Marc Foggin *in litteris*).

Management of negative interaction

The Rann fringe of the Sanctuary and its landscape with a mix of human development experience the major conflict. Human-wildlife conflict often leads to destruction of species and their habitat or political clashes over biodiversity protection which nearly got the Wild Ass Sanctuary on verge of denotification. Outside groups often become involved and proposed solutions multiply and traditional mitigation methods may be forgotten. The risk in such cases is that traditional coping methods are often more understandable, sustainable, and cost-effective for affected communities than are novel solutions advocated by stakeholders who are less directly affected by the conflict. Moreover, the affected communities are sometimes completely marginalized if Sanctuary authorities and outsiders step in to control negative interaction.

→ **Current mitigation measures**

- Efforts to reduce damage has been applied by locals directly or indirectly as follows in the khur and kiang landscapes (Shah & Qureshi 2002):

Direct methods reduce the severity or frequency of wildlife damage:

- Barriers (fences, trenches, walls, buffer zones, etc.)
- Guards (human or animal) Changing the type, timing or location of human activities
- Repellents (Baits, lures, chemical, auditory or visual aversive stimuli)
- Removal of wildlife (illegal killing,) e.g . poisoning

Indirect methods raise people's tolerance for conflicts with wildlife:

- Compensation and incentives (comprehensive crop/livestock insurance policy)
- Participation
- Research and environmental education /Awareness
- In Kutch, farmers manually guard their farms, use ingenious noise-making systems and firecrackers by the night and use various forms of fencing (tape strings, sarees, and plastics) use of *Euphorbia* spp. as a fence to keep herbivores and birds away.
- Some pastures in Ladakh are protected from kiang by fencing. However, it is a bad practice as it prevents other species from using the pastures.
- The khur and kiang landscapes protection of cropland and pastures respectively are done by paid horsemen who chase the wild equid away (Shah & Qureshi 2002, Shah 2015).

→ **Mitigation measures suggested,**

Equus hemionus khur

- A compensation scheme needs to be devised and implemented to address the losses incurred by farmers (Dave 2010).
- The efficacy of various fencing designs against large herbivores must be tested (Dave 2010).

Equus kiang

- There is no practice in vogue for the collection of pasture grass seeds and re-seeding among the changpas. This has to be introduced by offering remunerative price for seeds of promising, time-tested native grasses and reseeded them (Prof. Mir *pers.comm*). Need for a network of fodder producing farms with fodder depots (Prof. Mir *pers.comm*) in Changthang can tide over the unfavorable period and thus benefit the pastoralists and wild species. Any alternative for fodder security for livestock during winter should be linked with summer livestock stocking density in the pastures. By increasing survival rates of livestock without any restrictive policy on livestock holding in a given pasture will prove disastrous in a long run for both wildlife and pastoral economy (Shah&Qureshi 2002, Shah et al 2008).
- Protection of pasture especially by fencing and driving away the kiang on horseback was in high demand by pastoralists. Watchman to be provided by Wildlife Department to protect crop field and pasture was also suggested although the community do elect people to guard the pastures and the crop fields. During harsh winter people demanded that government should increase the quota of food supply and fodder (Shah & Qureshi 2002, Shah et al 2008). Stall feeding for livestock would reduce the pressure on the pastures and also decline the incidences of predation by carnivores.
- Inter-sectoral planning and education of herders are critical for addressing the conflict related to the kiang in Ladakh (Shah & Qureshi 2002, shah et al 2008). Comprehensive pasture management policy should be drafted by involving people, and various governmental bodies like Wildlife Departments, Animal Health Department, Soil Development Board and Ladakh Hill Council.

→ Existing law & policies

- Both the khur and kiang are given the highest level of protection (Schedule-I) by the Wildlife Protection Act (1972). The khur is categorized as Endangered and the kiang as Least Concern by IUCN, and CITES has listed both species in Appendix-II.
- Wild Ass Sanctuary – the name has victimized the species despite the khur attributes to a minimal level of damage in comparison to Nilgai and Wild Pig. The PAs must not be named by a species (N. Shah *pers comm*).

Synthesis of Human-Macaque Interactions



Authors

S.S. Bist, Monica Kaushik, Ninad Mungi, & Qamar Qureshi

Human -Non-human primate interaction in India

Current population status and distribution of species

Non - human primates, whose natural habitats have drastically reduced due to habitat loss and modification (Chapman and Peres 2001), particularly Rhesus macaques (*Macaca mulatta*), Bonnet macaques (*Macaca radiata*) and Hanuman Langur (*Semnopithecus entellus*) utilize anthropogenic environments to their advantage (Priston & McLennan 2012). Rhesus macaque distribution in India extends over much of northern, central (except for northern Kashmir, high altitudes of Himalaya, Great Indian Desert and west-central India) and east whereas, the southern geographical limit has extended beyond river Krishna in the last few decades (Fooden 2000). Estimated population is 500,000, with 50%-60% of the rhesus living in “urban areas” (Soloman 2013). Rhesus macaque population in Himachal Pradesh reported to be 3, 19,168 in July 2004 and 2, 26,086 in June, 2013 (Anon, 2014). The geographic range of the bonnet macaque extends across peninsular India with population estimate around 170,000 individuals (Kurup, 1981), however reduction in population and local extinction is observed within the range (Singh et al, 2011). Hanuman langurs are distributed throughout the parts forests of tropical Indian subcontinent. Its estimated population is approximately 300000 individuals in India (Mukherjee, 2001). India exported 60-70 thousands monkeys per year for biomedical research (Southwick & Siddiqi, 2001), however it was banned in 1978.

Status of negative interaction

In Himachal Pradesh, approximately 53% of all crop damage in the state was attributed to rhesus macaques (Singh & Thakur 2012). In addition, more than 1500 cases of biting are reported by the forest department (HPFD). As informed by the Agriculture Minister in J&K Assembly, monkeys damage 15596 ha of agriculture crops worth ₹ 32.93 Cr and 9426 tonnes of fruits worth ₹ 4.72 Cr annually in Jammu Division (Business line, 4.4.2013). 27 cases of bite and 49 cases of aggressive threats by rhesus macaque were reported from Gauhati University Campus from June 2004 to May 2005 (Devi. S. O & Saikia, P.K., 2008).

Langurs caused annual loss of ₹1.4 lakhs to 1.9 lakhs for studied 12 farms near Kumbhalgarh Wildlife Sanctuary (Changgani et al 2004).

Bonnet macaque enters the houses and hence perceived to be nuisance. The people in the villages bordering the Mollem National Park and Bhagwan Mahaveer Wildlife Sanctuary (Goa) reported it to be the feared, most destructive and most frequent of the crop depredating species (Sengupta & Radhakrishnan 2013).

Reasons for negative interaction

In India, due to agricultural expansion and deforestation resulting in contraction of natural habitats, few primates have colonized rural and urban environments in large numbers (Southwick and Siddiqui 2011).

Their ability of benefitting from human-disposed food is the precursors of conflict with humans (Singh & Thakur 2012). Devotees and animal lovers feel gratified in feeding monkeys in temples, highways or roof tops and consider it a religious deed. As a result, monkeys have become habitual of snatching food from people, attacking them, in extreme cases causing death (Singh & Thakur 2012).

Management of negative interaction

→ Current mitigation measures

- The prevalent management strategy to reduce such conflicts is by translocating macaques to forest patches (Fooden 2000). However, such translocations, if not done carefully, may lead to transfer of conflict to new area or to spread of zoonotic diseases. Also, most of the Forest Departments in India engage professional trappers to capture monkeys from problem areas and release them in remote areas. Animal Right Groups have often blamed the trappers of using cruel methods.
- Capture and translocation of problem monkeys in Delhi has been going on since 1990s. In June 2004, 250 monkeys were translocated from Delhi to Kuno Sanctuary in MP. Monkeys are being released in Asola Bhatti Sanctuary in Delhi in accordance with Delhi High Court's order dated 14.3.2007 and 17138 monkeys had been released till 28.2.2014. Ten million rupees a year are spent on feeding these captured monkeys (Soloman 2013).

- In some instances, Hanuman langurs (*Semnopethicus entellus*) are used to terrorize and displace rhesus macaque (Fooden 2000). However, in areas where these species distributions overlap, agonistic interactions are common, wherein the rhesus macaque has been found to be more aggressive and successful in displacing the Hanuman langur (Fooden 2000). Illegal hiring of langur for chasing away rhesus monkeys from official buildings in Delhi has been prohibited vide WCCB's advisory dated 15.10.2012 (S.S.Bist *pers comm*).
- In other instances, rhesus macaque males have been sterilized to reduce population recruitment and growth (Fooden 2000).
- Tubectomy and vasectomy at large scale was carried in Himachal Pradesh. Till this date more than 84,000 individuals have been sterilized in seven sterilization centers and released back near the capture sites.
- Non-invasive female contraception, can be a viable solution, but not so widely practiced and developed.
- For avoiding the loss by langurs and monkeys in Himachal Pradesh and Uttarakhand, farmers patrol the fields, throw stones with "gophan", keep dogs, fence with thorny twigs, use potash bomb etc. (Chhangani et al, 2004).

→ **Mitigation measures suggested**

- Methods such as oral administration of contraceptives, intra-uterine devices, and blockade of tubal patency following trans-cervical administration of polidocanol foam (Jensen et al.2013) are suggested. However, there is a serious need to carry out field trial to assess the efficacies and impacts on monkey's population, of these different sterilization techniques.
- Risk-potential locations can be reduced by using macaque deterrents like security guards, dogs and/or negative reinforcements on key troop members, alongside management of the critical resources (Soloman 2013). Trained langur can be used as guard animal only after proper permission from the CWLW.

- Solid waste management and proper disposal of rural organic waste as well as prohibition on feeding of monkeys in public places could reduce the conflict cases in long run by stabilizing their population.
- Translocation of problem monkeys from high-conflict zone can be tried provided habitats for translocation are chosen with care and the population to be translocated has been screened against zoonotic diseases.
- Scientists of YS Parmar University of Agriculture, Horticulture and Forestry (HP) have suggested cultivation of Marigold and some varieties of wheat as alternative to crops damaged by monkeys (Amar Ujala, 15.12.2013).

→ **Existing policies**

- All three primates are protected by Schedule II (Part I) of Wildlife Protection Act (1972).
- After the taxonomic revision of Cercopithecidae, some of the populations of common langur (e.g. *Semnopithecus entellus ajax* found in HP) have been categorized as 'Endangered' as per IUCN Red List Criteria. It has been suggested that a differential, species-specific approach should be followed while dealing with non-human primates involved in conflict with humans (Singh et. al. 2005).
- Government of Himachal Pradesh and Uttarakhand declared primates as vermin so that they can be killed by farmers and ordinary citizens (Letter No. 1953/25-28, dated 15th January, 2007 from the Additional PCCF (Wildlife) cum Chief Wildlife Warden, Uttarakhand).
- HPFD has authorized Forest Rangers under S.11 (1) (b) to permit hunting of monkeys (which includes shooting) but HP High Court has stayed shooting of monkeys on 6.1.2011 asking HPFD to try alternative methods.
- HP Government amended the Municipal Corporation Act-1994, in 2004, making feeding of monkeys in public places an offence.
- Despite high incidents of crop damage by non-human primates, HP Government does not give *ex-gratia* relief in such cases.
- Illegal hiring of langur for chasing away rhesus monkeys from official buildings in Delhi has been prohibited vide WCCB's advisory dated 15.10.2012. Considering the usefulness of trained langurs in keeping problem monkeys at bay, particularly in strategic locations

like hospitals, schools, offices, etc. there is need to revisit legal restrictions on ownership and use of langurs.

- Govt of India has banned commercial export of monkeys from India w.e.f 1.4.1978. (Common Langur is also included in Appendix I of CITES while Rhesus Macaque and Bonnet Macaque are in Appendix II of CITES).
- Use of monkeys in circus has also been banned by Govt of India in 1998.

Synthesis of Invasive Species Management



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***Lantana camara* in India**

Current distribution and status of species

Lantana camara (hereafter lantana) is a pan-tropical weed. It occurs in diverse habitats and on a variety of soil types. Is a low erect or sub-scandent, vigorous shrub with stout recurved prickles and a strong odor of black currents; it grows to 1.2-2.4 meters (or even more); its root system is very strong, and it gives out a new flush of shoots even after repeated cuttings; Leaf ovate-oblong, sub-acute, crenate-serrate; flower small, usually varying from white to red in various shades and blooms throughout the year; fruit small, blackish, drupaceous, almost throughout the year, dispersed by birds (Sastry et al., 1990). Lantana also occurs as Liana in many parts where it climbs tall trees and spreads over the canopy. *Lantana* is native to the tropical and sub-tropical regions of Central and South America. In India, it was first introduced in the early eighteenth century as an ornamental plant (Thakur et al., 1992) in Coorg, Dehradun and Kolkata. Since then it has invaded almost all the tropical India and encroaches 13.2 million hectares besides forest and fallow land. Its management cost around US\$ 70 per hectare (Bhagwat et al., 2011).

Reasons for concern

Impacts: Lantana aggressively proliferates and forms a dense mesh of bushes. This happens excessively at the edges of the forests with sparse canopy. It is known to produce allelochemicals that restricts the growth of other species under its canopy (Achhireddy & Singh, 1984). Hence, it replaces native flora, resulting in homogenous vegetation (Lamb 1991). Dense invasion of lantana was reported to related with decline in the diversity of birds (Arvind et al. 2010) and habitat of elephants (Wilson et al. 2013). *Lantana* can alter fire regimes in natural systems (Humphries & Stanton 1992). Consumption of its leaves has caused poisoning to cattle, buffalo, sheep & goats (Sharma et al. 1988). Over consumption of lantana leaves and shoots by wild herbivores has also been reported to be fatal for their health. Malarial mosquitoes have shown to be breeding in its dense thickets (Gujral & Vasudevan 1983). Different varieties of ecosystem services have been altered by *Lantana*.

Success of Invasion: Different populations of lantana were introduced in India, mixing of which, in addition to escape from predators, resulted in enhanced vigorous genotype (Ray & Ray 2014).

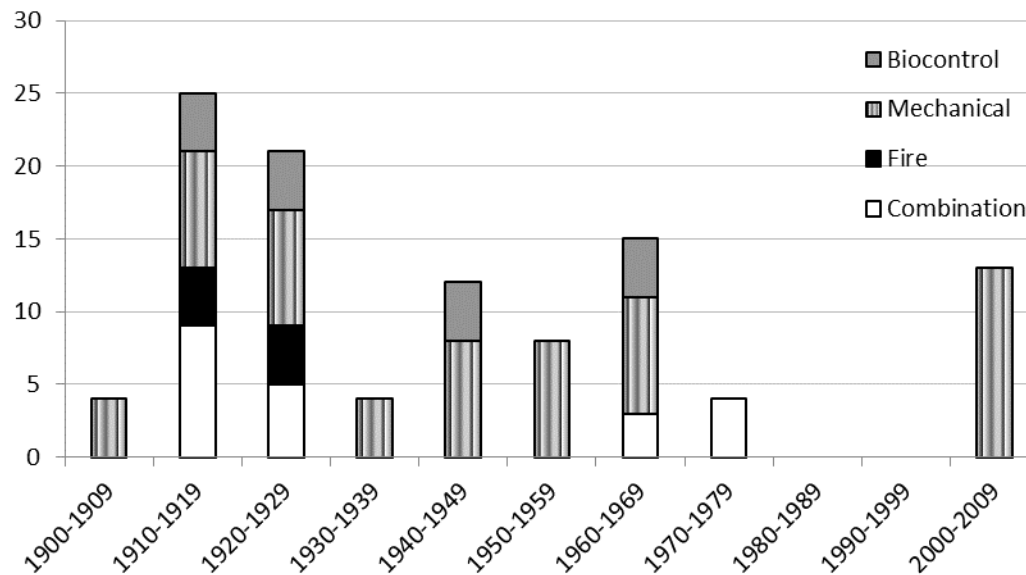
Owing to its high fitness homeostasis and phenotypic plasticity, *Lantana* has invaded in nutrient poor soil, areas with high native cover, and extreme climatic conditions. Allelopathic characters (aromatic, alkaloids and phenolics) present in plant suppress regeneration and growth of other vegetation, thus getting rid of the competitors for resource utilization. *Lantana* also reproduces vegetatively, that makes the eradication complex; as during its removal, nodes of the main stem are dispersed causing dispersal of plant. Moreover fire has been reported to break the seed dormancy of *lantana*, causing high flash of invasion after fire treatment that is commonly used by forest department to restore the grasslands (Sharma et al., 2005). As *lantana* provides green cover and has associated dependencies of species belonging to various taxa, popularly it is perceived as beneficial; thus, impeding the focused restoration of native ecosystem which is already damaged.

Management Interventions

Manual uprooting followed by replanting the native flora is the most preferred technique till now. Though not much success is achieved in the process, resources are spent each year by forest department for *Lantana* management. Bhagwat et. al. (2011) provides an interesting account of techniques so far used for *lantana* management in India (see figure 1). Popular methods are discussed below:

a. Fire. This method is used for burning *Lantana* cover in grasslands and fallow lands. It is the most cost – effective technique in terms of efforts invested. However, many times native flora, nest of birds and shelter of other dependent fauna using the *Lantana* cover and other small animals are lost in the process. Moreover fire induces *Lantana* seed dormancy and hence high invasion *Lantana* is observed post fire (Hiremath and Sunderam, 2005).

Figure 1. History of managing *Lantana* in India (Bhagwat et. al. 2011).



b. Manual uprooting. *Lantana* thickets along the roadside and in understory are manually removed. Presently, it is the only method practiced for clearing the understory invasion. However this method cannot be used at large scale owing to the intensive efforts and repeated treatment needed each year.

c. Chemical. It involves the use of inorganic/organic herbicides. However the usage is limited by high cost of such programs. Moreover a detailed study on effects of such chemicals on components of biodiversity is needed before implementing such studies (Sharma et al.,2005).

d. Bio-control. In India, *Teleonemia scrupulosa* Stal. was introduced for bio-control of *Lantana*. But, control agent could not cope with the vigorous regrowth of *Lantana* at the onset of the monsoon rains; the control agent itself suffered heavy mortality during the winter months. Moreover a detailed study of effects of such agents on other organism is needed before implementing it to other regions (Sharma, 1988).

e. Restoration. Native plants are planted in the invaded patches (mostly after removing the major cover). However, desired result was not achieved. E.g. *Ficus* sp. and castor oil plant was planted to compete with *Lantana*, without much success (Troupe, 1921).

f. Harvesting. Few non-governmental organizations started experimenting with lantana to make furniture, pulp extraction of aromatic oils, etc. However, the scale of such usage is very small compared to the current extensive *Lantana* cover (Troupe, 1921).

g. Adaptive eradication. One of the most preferred technique followed in the recent past was established by Babu et al (2009). The procedure is; 1. cut below the root-stem transition zone 2. burn dried clumps 3. weed out *Lantana* saplings beneath the trees and from the surface of drainage channels originating from the invaded and uprooted area 4. restore grasslands and mixed woodlands.

None of the present methods promises complete spatial or permanent eradication of lantana.

Existing Policies

Lantana colonized variety of habitats and even the protected areas. Every year a considerable amount of overall budget of PA's management have been spent for managing *Lantana* invasion. Recently introduced operational guidelines of the 'intensification of forest management scheme' of the Ministry of Environment Forest and Climate Change (MOEFCC) emphasizes the need for control and eradication of forest invasive species and providing assistance to state-owned or supported research institutions to carry out research for management of invasive like *Lantana*. Kannan et al. (2013) has reviewed the legislative gaps and needs for managing invasive species in India.

***Prosopis juliflora* in India**

Current distribution and status of species

Prosopis juliflora (hereafter ‘Prosopis’), commonly known as *Kabuli Kikar* or Honey Mesquite of Mimosaceae family, is a fast growing shrub, sometimes attaining form of a small evergreen tree in semi-arid and arid tracts (Burkart, 1976). This is the only invasive species amongst many other species of the genus (Pasiiecznik, 1999). The foliage ranges from light to dark green. The spines range in length from 4 mm to 9 mm and form impenetrable barriers for herbivores. All members of the genus *Prosopis* are phreatophytes with deep tap roots (Pasiiecznik, 1999). *Prosopis* flowers are produced in large number on spike-like racemes, and are primarily pollinated by insects. Pods are linear, compressed, 10-15 cm long with 20-25 seeds. Seeds can remain viable up to 20–50 years.

Prosopis has its origins in frost-free *tropical* regions of Central America and Mexico. In many areas within its native range, *Prosopis* sometimes occurs as a noxious weed. Luna (1996) dates the introduction of *Prosopis* to the Sindh part of India to 1857. Lt. Col. R.H. Beddome, the Conservator of Forests of Northern Circle (Madras) introduced this species in Camalpur, Cuddaph district of Andhra Pradesh in 1876 from where it naturalized in other parts of south India (Reddy, 1978). There was a second introduction of material from Mexico in 1912. *Prosopis* was introduced in Rajasthan in 1913 (Muthana & Arora, 1983), and seeds were supplied to neighboring states. In 1915–1916, seeds were introduced at a number of locations (Dubey, 1998). Most of the plantation was done for raising green cover in the arid and semi-arid landscape.

Reasons for concern

Impacts *Prosopis* was originally considered a wonder plant for afforestation in semi-arid tracts especially to meet the fuel wood requirement of the local communities. However, once it invades the grasslands, it leads to rapid loss of wildlife habitat. Many threatened grassland birds and mammals have known to suffer greatly due to invasion by this species. It exacerbates and accelerates soil erosion (Kaur et al., 2012). The United States experiences production losses of US\$200–500 million per year because of *Prosopis* infestations (Pasiiecznik & Felker, 2001).

Success of invasion. This species produces copious amount of flowers and fruits. Each pod may contain 20 – 25 seeds which have very high germination rate. Pods are eaten by cattle and wild ungulates. Seeds that pass through the guts of ungulates germinate even faster and establish very easily. This life-history trait makes this species very successful invader. Extracts from parts of the plant contain various chemicals including tannins, flavonoids, steroids, hydrocarbons, waxes and alkaloids that prevent the germination and growth of almost all plants tested in several studies. The roots are better adapted to an arid climate than native species. It has formed hybrids and complexes with many other congeneric species (Pasiecznik & Felker, 2001).

Management Interventions

Manual removal was the first method used to deal with *Prosopis*. It remains practical only for small land holdings of high value, such as agricultural lands, or where labor is relatively cheap.

Hand clearing can also be used in conjunction with some mechanical or chemical methods, such as chemical stump treatment. Mechanical site clearance involves tractor operations developed for removing trees, in which roots have to be severed below the ground level to ensure that trees are killed. These operations include root ploughing and chaining and are often the most effective mechanical means.

Several biological control programmes have been developed and implemented that use species of seed-feeding bruchid beetles. In their native range, bruchid beetles can destroy substantial amounts of seeds. Twig girdlers and psyllids have also been suggested as possible biological control agents. Psyllids are known to severely affect the growth of *Prosopis* (Hodkinson, 1991) and have been suggested for use in controlling invasions.

In India, Keoladeo Ghana and Ranthambhore National Parks had provided permits for cutting *Prosopis* trees in specified areas for eco-development and management so that *Prosopis* does not spread further, in non-invaded parts of the parks. Local communities are allowed to extract the *Prosopis* for domestic usage under the Mahatma Gandhi Rural Employment Guarantee Scheme (Hiremath & Sundaram, 2013).

In Kachch, the forest department noted that, if scientifically managed, each of the five vehicles falling under *Prosopis* areas in Kachch can yield 10 lakh bags of charcoal each year at an estimated value of Rs.10 crore. The income generated could be used for paying wages for

labourers or could be transferred to government funds. Thus this harvesting could be beneficial for the ecology and economy. However, after the initiation of the programme, native trees were also cut down illegally by people, resulting in a reduction in the green cover to less than 10% in 2004. As a consequence, in 2008 the Gujarat state government stopped the programme.

***Mikania micrantha* in India**

Current distribution and legal status of species

Mikania micrantha (hereafter mikania) is native to tropical and subtropical zones of north, Central and South America. It was introduced to India during the Second World War (1940's) to camouflage airfields and since then is a major weed, especially in north-east and south-west India. The species has drastically spread over the natural and maintained vegetation in the invaded area (Reddy, 2008). It is currently known to occur in the states of Assam, West Bengal, Tripura, Manipur, Kerala, Arunachal Pradesh, Orissa and the Union Territory of Andaman and Nicobar Islands. It is a perennial twining herb with 5-ribbed branches, pubescent or glabrous; internodes are 7.5 - 21.5 cm long. Leaves are opposite, ovate-deltoid, margins are coarsely dentate, crenate or sub-entire, glabrous on both sides; the petiole is 3 - 7 cm long. The inflorescence is axillary paniced corymb. Individual florets are white to greenish-white. The seed is black, linear-oblong and about 2 mm long. Each seed has a terminal pappus of white bristles that facilitates dispersal by wind or on the hair of animals. In south -west India, flowering starts in August and continues up to January. Fruiting season is between September and February, initiates 17 - 21 days after flowering (Sankaran, et.al., 2001).

Reasons for concern

Mikania reduces the growth and productivity of several crop plants, plantations and forest species. Infestation by the weed in the forests of north-eastern India caused habitat homogenization, new microsite formation and a reduction in plant richness (Poudel et al., 2004). The allelopathic chemical affects the native flora. *Mikania* is one of the three worst weeds for tea in India and Indonesia and for rubber in Sri Lanka and Malaysia. Young teak suffers from its infestation. Infestations of *Mikania* make harvesting of non-wood products such as bamboo and reeds an onerous task in the Western Ghats (Sankaran et al, 2001). Crops affected by *Mikania* include banana, coconut, coffee, cocoa, cassava, pineapple, ginger and teak. Intensive weeding of *Mikania* has become necessary to reduce its effect on productivity, and this has resulted in escalation of cost of production of many crop plants (Palit, 1981). *Mikania* infestation in natural moist deciduous forests has affected the livelihood of tribal community in Vazhachal forests in

Kerala. It was possible to collect six bundles of reed (one bundle consisted of 20 numbers) in one day before the infestation of mikania but after infestation they are able to collect only three or four bundles in a day due to twining and creeping habit of the weed on natural growth of reeds.

Success of invasion. A single stalk of *Mikania* can produce 20,000–40,000 mature seeds in one season. The growth of young plants is extremely fast (highest could be 8–9 cm in 24 hours), and using trees as supports, the weed rapidly forms a dense cover. *Mikania* can produce roots from each node and it thus helps easy vegetative propagation. The plant produces phenolic and flavonoids compounds that can kill or retard growth of competitors. The stolons of *Mikania* enable the plant to spread rapidly in young fallows and place it at high levels in the canopy through rapid vertical growth. Since fire is a common phenomenon in slash-and-burn agriculture, it seems that the weeds follow fire-burnt plots because of its tolerance to fire (Murphy et al., 2013; Subedi et.al., 2012).

Management Interventions

The Global Invasive Species Database compiled by the IUCN/SSC Invasive Species Specialist Group provides the following management information on this species,

Biological: A number of very promising (and probably specific) natural enemies are known in Central and South America. Of these, a thrips, *Liothrips mikaniae* appears to be specific and to have considerable potential as a biological control organism (Waterhouse, 1997). *Liothrips mikaniae* was introduced into the Solomon Islands in 1988, but it failed to establish. Fungal pathogens have also been investigated in India for use in potential biological control methods. As part of an integrated approach to controlling *Mikania* in Kerala, a number of fungal pathogens were tried. Only *Myrothecium roridum*, *Corynespora cassiicola*, *Ascochyata* sp. and *Phoma* sp. produced symptoms on both unwounded and wounded leaves. However, none of them caused any serious damage to the host. Their virulence may be low because they have not co-evolved with *Mikania* (Ellison, 2001). A world list of 55 fungal pathogens was prepared based on Barreto and Evans (1995). However, most of the aggressive pathogens are restricted to the native range of the weed (Neotropics). Classical biological control using insects started in 1987 (Cock, 1982) in the Solomon Islands and west Malaysia. In the Western Ghats, none of the insects used for bio-control caused any damage to *Mikania*.

According to Sankaran and Suresh (2013), a rust fungus, *Puccinia spegazzinii*, which attacks the weed in its native range, was imported to India after completing host specificity tests in CABI, U.K. Studies conducted in India showed that the fungus is specific to *Mikania micrantha* and is highly damaging to the plant (infecting leaf, petiole and stem leading to cankering and death) and has a broad environmental tolerance. The pathogen was released in Assam and Kerala in 2005-2006. The releases were successful in the sense that the rust had spread to the large span of mikania distribution at all sites within one week of release. However, the rust could not persist on the field population of mikania beyond 3-4 months especially when the environmental conditions at the release sites became unsuitable (high temperature and low humidity) for disease spread. Low inoculum load and inappropriate time of release are considered to be the main reasons for failure in survival of the rust in the field. However, successful control of mikania using *P. spegazzinii* has been reported from Papua New Guinea and Fiji and trials are underway to release the fungus in Guam and Northern Mariana Islands (Day *et al.*, 2011b; Day *et al.*, 2013; Univ. of Guam, 2012).

Chemical. Controlling *Mikania* is difficult because of its high output of viable seeds and vigorous asexual reproduction. Spraying a combination of the herbicides triclopyr and picloram (1.75 l per hectare) was tried. This yielded good results as the biomass of the weed decreased by 95% in one month. Similarly, application of glyphosate at the rate of 2.5 - 5 liters per hectare is also effective (Sankaran and Pandalai, 2004). These herbicides are relatively less toxic and degrade easily in soil (Ellison, 2001).

Physical removal: In one study, it was found that complete weeding (uprooting and removal) was effective in reed growing areas and forest plantations. As the economics of forest dependent communities was affected by mikania infestation, encouraging local communities in the eradication of *Mikania micrantha* was thought to be considered as an option (Sankaran et al., 2001). Rai and Subedi (2012) have used fire and manual removal at Chitwan National Park, Nepal.

***Parthenium hysterophorus* in India**

Current distribution and status of species

Parthenium hysterophorus (hereafter Parthenium), commonly known as ‘Congress weed’ or Gajar ghas, (Family Compositae) is an erect herb attaining a height of upto 150 cm. Leaves finely lobed. Young plants form a basal rosette of leaves that are up to 30cm in length. An average plant can produce 15,000 seeds and large plants are known to produce 100,000 seeds. Seeds are dispersed by wind, water runoff, transport of grains and vegetables, garden waste etc. Germination temperatures for Parthenium occur between the 8 to 30° C range with the optimum germination temperature being 22 to 25° C. Seed of Parthenium remain viable for 20 years (Parsons & Cuthbertson, 2001).

Parthenium is native to the tropical and sub-tropical regions of Mexico, Central and South America. It probably entered India before 1910 (through contaminated cereal grain), but went unrecorded until 1956. It was first recorded as weed near Pune in Maharashtra State in 1951. By 1972 it had spread into the majority of the western states from Kashmir to Kerala. It is presently distributed almost throughout the subcontinent and occupies over 5 million ha of land in the country. The impact of this weed in the Indian subcontinent has been summarized by Parsons and Cuthbertson (2001). This study highlighted the need of using different bio-control agents for managing Parthenium in the agricultural areas, it also emphasized on early eradication of the seedlings before the species flowers.

Reasons for concern

Impacts: Colonization of stream and ditch banks, open areas and fallow fields by this aggressive species leads to loss of natural habitats, loss in forage production and decline in biodiversity. Once this species takes over in an area, native grass and herbs cannot compete for light and nutrients. Parthenium was reported to cause a yield loss of up to 40% in several crops (Khosla & Sobti, 1980) and a reduction in forage production of up to 90% (Nath, 1981). It is toxic to livestock (Tudor et.al.,1982). It is considered to be one of the greatest source of dermatitis, asthma and nasal, dermal and naso-bronchial diseases. Parthenium toxicity in buffalo calves was

reported to cause the onset of diarrhoea, anorexia, pruritus, alopecia, dermatitis, etc. (Kadhane et. al., 1992).

Success of invasion. This species has ability to flower twice in a year producing enormous quantity of seeds which germinate very fast. Seed dispersal is through wind, water, animals as well as vehicles. These are the primary reasons for its successful invisibility.

Management Interventions

Chemical control. A vast array of herbicides including 2,4-D, glyphosate, MSMA (monosodium methanearsonate), bromacil, atrazine, paraquat, diquat, sodium chloride and many other such chemicals are in use against *Parthenium* especially in agricultural fields (Krishnamurthy et.al., 1977). However, chemical control is not advisable anymore.

Mechanical removal: Ploughing the weed infested fields before the plants reach the flowering stage and then sowing seeds of desired forage / food grain may be effective.

Bio-control The Mexican beetle *Zygogramma bicolorata* Pallister was imported into India after confirming its host-specificity (Jayanth & Nagarkatti, 1987). The beetle has been reported to disperse over more than 2,00,000 km² in Karnataka, Tamil Nadu and Andhra Pradesh and in Jammu, Punjab, Haryana and Madhya Pradesh (Jayanth et al., 1997). This beetle has recently been reported to feed on sunflower (Chakravarthy & Bhat, 1994). Other bio-control insects are *Glomerella cingulata*, *Rhizoctonia solani*, *Sclerotium rolfsii*, *Fusarium pallidoroseum*, *Bremia domingensis*, *Erysiphe cichoracearum* var. *cichocearu*, *A. protenta*, *A. zinnia*, *Cercospora parthenii*, *Entyloma compositarum*. These insects infest parts of *P. hysterophorus* or the entire plant.

STATUS OF AQUATIC INVASIVE SPECIES IN INDIA

Aquatic ecosystems of India have suffered from intense human intervention that resulted in habitat degradation and habitat loss. As a consequence many fresh water fish species have become heavily endangered, particular in inland aquatic systems. This was coupled with irreversible changes in natural population by introduction of invasive species in order to improve aquaculture production. During last 100 years or so, several exotic aquatic species have been brought to India for experimental studies and many of them have been introduced into inland water bodies for improving fisheries production, promote recreational fishing, control pests etc. There were about 324 fish species have been introduced in India, which includes 291 ornamental fishes, 31 cultivable fishes and 2 larvicidal fishes (Mandal 2011). Among these invasive species, brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), Common carp (*Cyprinus carpio*), Mozambique tilapia (*Oreochromis mossambucus*) and Mosquito fish (*Gambusia affinis*) were also listed as worst invasive fish species in the world (Lowe et al. 2000). In addition to that the presence of African cat fish, *Clarias fuscus* and Pacu-Piranha in Indian river systems is another setback for fish conservation in India (Krishnakumar *et al.*, 2011; Johnson *et al.*, 2014). A general plan and guidelines have been developed to regulate fish introduction in India by National Bureau of Fish Genetic Resources (Lakra *et al.*, 2006), but it is not properly implemented by neither by Fisheries Department nor by fish farmers. Similarly several exotic species have been introduced in marine water. In addition to that maritime trade has also been identified as an important factor for spread of marine invasive species through the ballast water. There exists limited understanding on marine invasive species, their distribution, probable impacts on marine ecosystem functioning in India. One of such worst invasive marine species is *Kappaphycus*, a sea alga wildly cultured species in south Indian coast. In this section, we are highlighting the status, issue and different management intervention adopted to manage three important freshwater invasive species (namely, *Clarias fuscus*, *Oreochromis mossambucus* and *Salmo trutta fario* and a major marine invasive species *Kappaphycus*.

***Calarias guirepinus* (African catfish) in India**

Current distribution and legal status of species

Calarias guirepinus is native to Africa, most of Pan-Africa, except the upper and lower Guinea and the Cape Province and widely introduced in other parts of Africa, Europe and Asia, established itself in the wild in many countries, often outcompeting local species and several countries report adverse ecological impact after introduction (fishbase.org; Krishnakumar *et al.*, 2011). Adults mainly live in quite waters, lakes and ponds and prefer shallow and swampy area of the water bodies (Seegers, 2008).

In India, *Calarias guirepinus* was brought from Bangladesh and cultured initially in many parts of the country (Thakur 1998). It is believed that the first consignment of this catfish was brought from Bangladesh through Andhra Pradesh and reached southern India in early 1994 (Middendorp, 1998; Krishnakumar *et al.*, 2011). Throughout India this species has been cultured in Inland waters and it also entered into rivers like Cauvery, Yamuna and Ganga (Singh and Lakra, 2011). Recently, it was reported that the African catfish *Calarias guirepinus*, are spreading rapidly across various drainages in Western Ghats and natural water bodies of Rajasthan (Krishnakumar *et al.*, 2011; Anoop *et al.*, 2009).

Reasons for concern

Impacts. As it is a predatory fish, it preys on many native species. Recent reports indicates, even it prey on small terrestrial birds, aquatic birds and turtles in Bharatpur National Park, Rajasthan (Anoop *et al.*, 2009). Further, it grows very faster than native carps and has high rate of reproductive success. Decline and localized extinction of native fish diversity by predatory behaviour of African catfish have been well reported in many countries, including India (Rabin *et al.*, 1991; Krishnakumar *et al.*, 2011; Anoop *et al.*, 2009). It is also observed that presence of African Catfish in Periyar Lake in Kerala, has drastically reduced many native and endemic fishes (*Lepidopygopsis typus*, *Nemacheilus menoni*, *Crossocheilus periyarensis*, *Hypselobarbus periyarensis*, *Garra periyarensis*, *Nemacheilus periyarensis*) of Periyar Lake (Periyar Foundation, 2006; Sudhi, 2009).

Success of invasion. Highly tolerant to extreme environmental condition, bears an accessory respiratory organ, which enable this species survive in oxygen depleted condition (de Moor and Bruton, 1988). Omnivorous in feeding habits, feeds largely of fish, insects and crustaceans, known to attack healthy animals and also influences distribution and feeding of other fish, even large water birds and terrestrial birds (Teugels, 1986; Anoop *et al.*, 2009). It can easily crawl over ground and reach nearby water bodies, especially during monsoon, this behaviour can lead to escape of culture stock into natural water bodies.

Management Interventions

The National Committee constituted under the chairmanship of the Joint Secretary (Fisheries), Government of India, to oversee and regulate the introduction of exotic aquatic organisms in Indian waters, at its first meeting on December 19, 1997, had directed State governments and Union Territories to ‘take immediate steps to destroy the existing stocks of exotic African catfish and big head fish which had been introduced without official sanction in the country’ (The Hindu, 2014). Though, this species has been banned for aquaculture, culturing of this species is going on every local and corner of the country. So far no management intervention has been implemented for removal and further extension of aquatic invasive species in natural habitat like rivers and lakes. Few attempts have been taken to remove this species manually from Bharatpur National Park in Rajasthan and Periyar Lake in Kerala, but there is no long time solution. The major intervention needed, is to raise public awareness towards the impact of this on native aquatic biodiversity.

***Oreochromis mossambicus* (Mozambique tilapia) in India**

Current distribution and legal status of species

Adult *Oreochromis mossambicus* inhabits reservoirs, river, creeks, swamps, tidal creeks, estuaries and coastal lakes (Blaber, 1997; Allen et al., 2002). This species has origin in East Africa, distributed in Lower Zambezi river and coastal plains from Zambezi delta to Algoa Bay. Occurs southwards to the Brak River and in the Transvaal in the Limpopo system in South Africa (de Moor and Bruton, 1988). Widely introduced for aquaculture, but established itself in the wild in many countries, often outcompeting local species and several countries report adverse ecological impact after introduction (Kottelat and Whitten, 1996).

In India, Mozambique tilapia was introduced in south Indian reservoirs in 1952 to improve reservoir fishery production (De Silva et al. 2004). Now it has been well established in rivers, canals, irrigation tanks and even inside the protected areas like Moyar river in Mudumalai, Periyar lake in Periyar Tiger Reserve, Thenmala river in Senthurani Wildlife Sanctuary, Papikondan National Park (Godavari river) and Coringa Wildlife Sanctuary in southern India.

Reasons for concern

Impacts. Since it is a hardy and well adopted species, it competes with native fishes by occupying their ecological niches. It also interfere feeding and breeding habitat of many native species by making sand nest on the ground. Decline and localized extinction of native fish diversity by competitive nature of Mozambique tilapia have been well reported in South America, Australia, Sri Lanka and India (Starling et al. 2002; Attayde et al. 2011; Dupe & Burrows 2008; Pethiyagoda 1994).

Success of invasion. They can able to survey extreme reduction of dissolved oxygen, adopted to take atmospheric oxygen, tolerate high water temperature and wide range of salinity (de Moor and Bruton, 1988). Omnivorous in feeding habits, feed mostly algae, detritus, worms, insects larvae, shrimps etc., large individuals are reported to prey on small fishes (de Moor and Bruton, 1988; Skelton, 1993). It grows and reproduces in fresh, brackish and even in seawaters. It attains sexual maturity at 15 cm length, but stunted fish may breed at 6-7 cm at an age of over 2 months. Fecundity is high, female deposits 100 – 1700 eggs and well developed parental care mechanism.

Female collect fertilized eggs into mouth and fry catches from the mouth (Allen *et al.*, 2002; Lampoj, 2004).

Management Interventions

So far no management intervention has been implemented for removal and further extension of aquatic invasive species in Indian waters. The major intervention needed, is to raise public awareness towards the impact of *Tilapia* on native aquatic biodiversity. Ground level intervention also requires eradicating this pest fish, especially inside the Protected Areas. It is also necessary to establish a database on the distribution of pest species in the wild.

***Salmo trutta fario* (Brown trout) in India**

Current distribution and legal status of species

Native of Europe, distributed from Spain to Chosha Bay in Russia, Iceland and northernmost rivers of Great Britain and Scandinavia (www.fishbase.org). It was introduced in many parts of the world including India and Pakistan. Although this species is well known for its utility in angling sports, it is now considered as one of worst invasive species in the river wherever it got introduced (Lowe *et al.*, 2000). Brown trout was introduced in head waters of Himalayan rivers and coldwater lakes in Nilgiri from 1899 and 1901 for recreational purpose as well as for food (Talwar and Jhningran, 1991). Well functional trout hatcheries were established by State Fisheries Department of Jammu & Kashmir, Himachal and Uttarakhand to produce seeds for stocking. Currently this species has been established in streams/ rivers of Indus, Yamuna and Ganga (Rajvenshi, 2012)

Reasons for concern

Impacts. Being a carnivore, it is known to survive on fry and juveniles of native fish species. Wherever this species introduced, the native snow trout population in Himalayan water has been declined.

Success of invasion. Thrive well in cold waters, range extension increased in Himalayan rivers. Recent report says, it is recorded in Bhagirathi river till Harsil, Pidar river and Ashi Ganga (Rajvenshi, 2012). It breeds in streams and rivers of Himalayas, even in high altitude lake habitats. In addition to that the State Fisheries Departments have periodically been stocking this species in Himalayan waters as part of promoting Trout fishery.

Management Interventions

So far no management intervention has been made to eradicate or stop the introduction of Brown trout in Indian waters. As Trout fishery and Angling sports are very popular in many Hill states, no active management intervention has been thought.

Marine invasive species: *Kappaphycus alvarezii* in India

Current distribution and status of species

Kappaphycus alvarezii is a marine brown algae (Rhodophyta: Solieriaceae), native of Creagh Reef, Malaysia. Growing attached to calcareous solid materials of detrital origin near the channel west of Karindingan Island on Creagh Reef. It also has distribution records in Philippines, Taiwan and Indonesia (Silva et al., 1996). This alga grows to two meters long and is brown or yellow in color (It is one of many seaweeds being intentionally introduced for the production of kappa carrageenan worldwide. The culture of *Kappaphycus* was initiated in the Philippines during 1960s with local varieties of its wild populations Since then, countries like Japan, Indonesia, Tanzania, Fiji, Kiripati, Hawaii and South Africa have been cultivating this species on a large scale (Johnson and Gopakumar, 2011).

In India, this alga was introduced in open sea in confined condition – employing net bag techniques initially in Gujarat coast and later in Mandapam, Tamil Nadu coast during 1995–1997. Late bamboo raft technique was emerged as most suitable commercial farming. At present, commercial cultivation of *Kappaphycus* is carried out in five coastal districts of Tamil Nadu namely Ramanathapuram, Pudukottai, Thoothukudi, Thanjavur and Kanyakumari (Johnson and Gopakumar, 2011). Now this species has been reported as one of the invasive species in India and other countries (Conklin et al., 2005; Periera and Verlecar, 2005; Anon, 2008; Bagla, 2008; Chandrasekaran et al., 2008; Kamalakannan et al., 2010).

Reasons for concern

Impacts. Being fast growth and vegetative propagation potential, *Kappaphycus* poses major threats to coral reefs. The vegetative part of this species easily attached with coral and start growing on coral reefs. This overgrowing on reef habitats leads to killing corals and bleaching (Conklin et al., 2005).

Success of invasion. It is very fast-growing, known to double its biomass in 15 days (Conklin et al., 2005). *Kappaphycus* is posing sever threat to reefs in Gulf of Mannar, because the vegetative propagules are the primary means of reproduction, which is easily attach and grow

over any hard substratum. As forming of this species has been practiced in Palk Pay region of Ramanathapuram and Tuticorin coasts, during wind and tidal force the vegetative propagules are entering in to the Gulf of Mannar National Park and it started growing on coral reefs. Several studies have confirmed the impact of this species on coral reef ecosystem (Conklin et al., 2005; Anon, 2008; Bagla, 2008; Chandrasekaran et al., 2008; Kamalakannan et al., 2010).

Management Interventions

The commercial cultivation of *Kappaphycus* in India was strongly opposed due to the prediction of its likely invasiveness, as it is exotic to Indian marine environments. However, some environmental impact assessments showed no harmful effects from this alga (Tewari 2006) and thus the cultivation of this species initiated in Indian water by the leading Fisheries Institution in Palk Pay. Later many studies had had found out occurrence of this species in live corals in Kurusadai Island of the Gulf of Mannar National Park and subsequently the invasion of *Kappaphycus* on corals were reported (Anon, 2008; Bagla, 2008; Chandrasekaran et al., 2008; Kamalakannan et al., 2010). Control of *Kappaphycus* in invaded communities has been carried out by either physical method. An underwater vacuuming system, Super Sucker, has been used as a physical method to eradicate *Kappaphycus* in Hawai Bay and also, native collector urchins (*Tripneustes gratilla*) were used to control *Kappaphycus*, which clear them through grazing (Conklin et al., 2005). However, in Kurusadai Island, the Forest Department adopted manual removal method, but the success rate was very less.

Proceedings of
“Human-Wildlife Interactions
and Management of Invasive
Species”

DAY 1

TECHNICAL SESSION

HUMAN-CARNIVORE

Chair: **Sh. Vinod Rishi**

Co-Chair: **Dr. Vinay Sinha**

Sh. Vinod Rishi, Former Additional Director General of Forests, highlighted the need to study the often less-explored human aspect of human- wildlife interaction. Sh. Rishi emphasized the need to estimate the social carrying capacity of a landscape harboring large carnivores. He mentioned the need for dynamic strategies to incorporate temporal changes in the attitude of local people sharing resources with wild animals.

Sh. A.K. Singh, Chief Wildlife Warden from the Jammu and Kashmir Forest Department, shared a news clip about a recent experiment with a metallic suit that can be used by members of rescue team during wildlife rescue operation to prevent injuries to humans. He discussed the efforts of the Jammu and Kashmir Forest Department to bring down the level of the human-bear and human-leopard conflict. Adopted strategies by the Jammu and Kashmir Forest Department such as forming a conflict- control room, working with media and NGOs to create public awareness and providing immediate compensation to victims have resulted in a decline of the number of conflict cases.

Dr. Vidya Athreya, Senior Scientist, Wildlife Conservation Society, indicated that the cultural tolerance of Indian society could be one of the reasons for the country retaining a large proportion of the world's carnivore species despite high human density. She touched upon the serious issue of the presence of wild animals in human use landscapes and increasing conflicts due to ill-informed translocation. According to Dr. Athreya, there exists a huge knowledge gap regarding wildlife in human use areas, and to reduce conflict, it is important to find answers for the following important questions through research and dialogue among stakeholders: (1) requirement to better understand ecology of wildlife outside Protected Areas (2) the role of compensation in increasing human tolerance towards damage caused by wildlife, (3) the role of traditional knowledge, (4) the use of social sciences to understand the human dimension of the problem and (5) adequate information sharing and co-operation among all the stakeholders for resolving conflict

Dr. Vinay Sinha, Additional Principal Chief Conservator of Forests, Maharashtra, commended Dr. Athreya's work and suggested developing site-specific mitigation measures.

Questions and Suggestions:

Dr. R.N. Mehrotra suggested that the capacity of the forest staff be built for handling of conflict situations better and that well-equipped rapid response teams be formed. *Ex-gratia* and other compensations emerged as the important mitigation measures. Dr. R.N. Mehrotra mentioned about the judicious utilization of the CAMPA (Compensatory Afforestation *Fund* Management and Planning Authority) fund for compensation and Dr. R.B.S Rawat proposed an idea of allocating compensation money through centrally sponsored schemes of the MoEFCC. Sh. S.K. Mukharjee emphasized the importance of a fair and transparent compensation process with mandatory validation of damage. Dr. Ruchi Badola mentioned the importance of social and psychological compensation in addition to monetary compensation. Mr. Raisaily expressed his concerns about the carnivore-attack-proof suit, which might injure animals (canine loss), disabling them and preventing them from hunting wild prey.

DAY 2

WORKING GROUP DISCUSSION

Reducing negative interactions while increasing positive interactions with carnivores was identified as the way forward for mitigating the human–carnivore conflict. Considering the urgent need to address the increasing conflict due to a few species, the working group decided to rank the carnivores on the bases of the distribution and magnitude of the conflict. One important suggestion came from the group regarding the criteria for valuation of a conflict's magnitude. According to these criteria, a species involved in human deaths should be given a high conflict value compared with one causing livestock depredation. The group came up with a list of nine species (group of species) for which negative human–wildlife interaction should be minimized: (1) leopard, (2) Asiatic black bear and sloth bear, (3) tiger, (4) lion, (5) wolf, (6) snow leopard, (7) wild dog and hyaena, (8) jackal and (9) other small carnivores. Mitigation strategies adopted to address the conflict due to a particular species could help other cohabiting carnivores as well. Mitigation practices were identified by the group for the top three carnivores (Table 1).

Ex-gratia, an important yet somewhat controversial, management practice was discussed exhaustively during the session. The group had a brainstorming session on two important issues that need to be addressed to strengthen the *ex- gratia* payment process: (1) the inequality in compensation money across various states and (2) the lack of quantification of ‘lost opportunity cost’ (opportunity to earn in the years to come from livestock that had been preyed upon, had these animals not been killed). According to the group, compensation can be strengthened by addressing these two limitations. Research findings of Y. V. Jhala and Kausik Banerjee (WII) also support the economic compensation that could minimize the negative attitude of local communities towards wildlife damage. For further strengthening the compensation, Ruchi Badola (WII) suggested on incorporating the social compensation in addition to economic one. S. S. Bist (WII) elaborated on the alternatives of economic compensation through subsidies for growing alternative crops, insurance for life and property, support for setting up wildlife-proof barriers, categorizing wildlife-depredation as ‘natural calamity’ and compensation by district administration. It was realized that the conflict mitigation guidelines and standard operating procedures (SOPs) formulated should be species- and site-specific to account for the immense diversity in economic status, tolerance levels and attitudes of local inhabitants towards wild animals. Experts in the working group quoted various studies and their personal experiences with the use of simple measures (barrier construction, improvement of infrastructure to safeguard livestock and humans) to effectively reduce negative human–wildlife interactions. The first step of the road map prepared by the group for alleviation of negative interactions was prioritizing sites on the basis of conflict level. The second step is the identification of stakeholders and their involvement at all stages of mitigation and management. Next steps are promotion of inter-agency co-operation and advising the media to play a positive role in educating and sensitizing the public. A special task force should be formed and sustained using appropriate funds (from CAMPA or corpus bodies) to deal with emergency situations. Most importantly, perpetuating thoughts about conservation is an important step for reducing negative interactions.

Table 1. Mitigation strategies for reducing the negative interaction for the selected carnivores

Mitigation measures	Leopard	Bear	Tiger
Awareness (do's and don'ts)	✓	✓	✓
Better livestock husbandry practices and other proactive measures of reducing losses	✓		✓
Using precautionary measures	✓	✓	✓
Research (Identify gaps) in both ecological and human dimensions aspects.	✓	✓	✓
Compensation	✓	✓	✓
Habitat management	✓		✓
Prevention of unnecessary translocation	✓	✓	✓
Management of free ranging dogs	✓		
NTFP collection	✓	✓	✓
Change in cropping patterns	✓		✓

DAY 1

TECHNICAL SESSION

HUMAN-HERBIVORE INTERACTIONS

Chair: Sh. Anmol Kumar

Co-chair: Dr. A. J. T. Johnsingh

Sh. Anmol Kumar, Director General, Forest Survey of India, raised important questions regarding the cause of conflict and strategies of management. He emphasized the importance of wildlife-friendly developmental activities around protected areas and an urgent reconsideration of policies and acts for better management of certain species influenced in conflicts and of the compensation schemes across the country.

Dr. N.V.K. Ashraf, an expert from the Wildlife Trust of India, highlighted the five aspects of mitigation strategies: (1) understanding the dynamics of the conflict, (2) controlling damage, (3) providing *ex gratia* payments and compensation, (4) management of conflict animal and (5) defining the roles of stakeholders. Dr. Ashraf mentioned the differences in the tolerance levels of local communities towards wild animals and the changes in their attitudes with time. He underscored the need to form dedicated conflict management teams and work constantly on building the capacity of forest department personnel to improve the management of conflict cases.

Dr. A. J.T. Johnsingh, an eminent scientist and former Dean of Wildlife Institute of India, provided the species-specific account of the various herbivores involved in conflicts and their current population status. Dr. Johnsingh pointed out towards the degrading quality of the various large herbivore's habitat due to anthropogenic pressure and due to invasion of exotic inedible species such as *Lantana camara* that leading to straying out of wild animals. According to him carrying capacity of an area should be taken into consideration in making decision for maintaining the numbers of mega-herbivores

Dr. S.P. Goyal, senior scientist from Wildlife Institute of India, discussed the need for more specific information on the spatial and temporal locations of human–wildlife interactions to find site-specific solutions. He also mentioned the need to improve and restore habitats in protected areas to minimize the number of conflict cases.

Sh. Qamar Qureshi, senior scientist from Wildlife Institute of India, explained the role of changing land-use patterns and the increases resources in post green revolution period as the casues of increase in the population sizes of a few herbivore species, such as the nilgai, wild ass and blackbuck, in India. He also pointed out the drawbacks associated with the use of translocation as a mitigation tool. This has resulted in mortality of the concerned individual/population and transferred the problem to other areas. Any attempt of translocation should be done with the proper strategy and planning.

Questions and Suggestion:

Suggestion were provided by the experts on the idea of amending the policies and acts, after which the session was opened for discussion. One of the suggestions from Dr. Jhala was to adopt a precautionary approach and use scientific information relating to a species while deciding its placement in Wildlife (Protection) Act schedules. Sh. R.N. Mehrotra cautioned the house about taking any hasty decisions regarding modification of the existing policies. Dr. R.B.S Rawat raised concerns about the issue of crop-depredation by wild animals, which has resulted in farmers abandoning cultivation, especially in the higher Himalaya. He also requested Wildlife Institute of India to develop relevant projects that could help to formulate SOPs and guidelines to address conflict issues. The use of lethal control to curb some overabundant wild animals such as the nilgai and macaque was also discussed. Mr. Satpal Dhiman, DFO, Himachal Forest Department, pointed out that in the absence of any sound ecological backing, such measures have faced strong opposition.

DAY 2

WORKING GROUP SESSION

Using the criteria of distribution, magnitude of conflict and involvement in human mortality, this group identified two sets of species: (1) major conflict species and (2) moderate conflict species. The elephant, wild pig, blackbuck and nilgai were categorized in the first group, and the wild ass, chinkara and gaur were placed in the second group. Experts, researchers and students identified the states facing high levels of conflict due to selected herbivore species and then jointly prepared species-specific mitigation and management strategies. A number of traditional and mitigation measures used to keep the animals away from human habitations and crop lands were

discussed. It was realized that traditional preventive measures such as night vigils, the use of noise (drums, fire crackers, etc.) and erecting barriers (electric fencing, concrete walls, chilli fencing and bee hives near crop lands) could help reduce damage caused by wild animals considerably. Long-term mitigation measures such as habitat restoration, invasive species management and corridor management were also thoroughly discussed. The group also touched upon the important dimension of negative impacts on wild animals due to humans. The increasing elephant mortality due to speeding trains is one example. The group suggested that installing sensor networks to inform train drivers about the presence of elephants near railway tracks or altering the routes of trains near forests or important corridors would bring down the mortality rate. According to the group, crop insurance or providing incentives to farmers, especially in areas with high levels of conflict, could help in increasing the tolerance of local communities towards damage caused by wildlife. Controlling the populations of overabundant species in areas with high levels of conflict as a last resort was also discussed. However, the group advised that the population status of the species in question be ascertained to avoid its local extirpation.

DAY 1

TECHNICAL SESSION

HUMAN-MACAQUE INTERACTIONS

Chair: **Sh. R.N. Mehrotra**

Co-Chair: **Sh. A. K. Wahal**

Sh. R.N. Mehrotra, Former PCCF & Head of Forest Force, Government of Rajasthan, mentioned about the increasing conflict in certain states due to three species of the primates namely, Hanuman langur, Rhesus and Bonnet macaque. These population are no more dependent on forest and are part of urban fauna. He further mentioned about attachment of religious sentiments of the public with primates which makes it difficult to implement population control strategies.

Sh. A.K. Wahal, Former PCCF & Head of Forest Force, Government of Arunachal Pradesh, stressed on finding the long-term solutions (i.e., social forestry) to resolve negative human-macaque interactions. He also mentioned about accounting for human-socio- religious relationship with macaque while dealing with this problem to ensure success of the implemented mitigative strategy.

Sh. S.S. Bist, discussed about the problem of solid waste management in urban areas which is one of the important reasons for increasing macaque population. Sh. Bist provided instances from Uttar Pradesh, Uttarakhand, Delhi, Himachal Pradesh and other states that are facing problems due to increasing damages to crops and attacks on humans by macaques. He gave a detailed account of the preventive and mitigative strategies used by different states as well as their success rate. He emphasized on taking help from research institutes to provide the reliable population estimates and non-governmental agencies for increasing tolerance of local communities by creating awareness about this issue.

Dr. Y. V. Jhala reiterated the availability of superabundant resources in urban areas in the form of food from dumpsters and roosting habitats on buildings and trees leading to increase in macaque population. He opined that instead of complete wipe out macaques should be managed at the levels acceptable by the society. He suggested that while using population control

measures ecological and behavioural aspects of the macaques should be taken into considerations.

Questions and Suggestions:

Sh. Satpal Dhiman shared information about the Himachal Pradesh forest department effort for macaque population control. He provided a detailed account of the sterilization technique used by the department as well as other associated important aspects. Details of the process can be found at the HPFD website (hpforest.nic.in/pages/display/monkey-sterilization-programme). High cost-involvement in establishing sterilization centers, decline in capture rate of macaque at subsequent efforts and post-release monitoring are some important facets of this strategy. Mr. Dhiman suggested that these aspects should be considered well in advance by the states which might use this strategy.

Sh. Suresh shared his observation from North-East India where only the alpha male was removed by the local community to destabilize the social structure of the troops and consequently reduces the conflict.

Participants also suggested about the use of watch dogs to reduce crop-damage by macaques and plantation of fodder trees in the buffer areas of macaque habitats.

DAY 2

WORKING GROUP DISCUSSION

During the early part of the discussion among the group members, concerns were raised about the lack of basic information about three primate species in conflict, namely Rhesus macaque, bonnet macaque and Hanuman Langur. Group members decided that population estimation should be the first step in resolving the increasing human-macaque interaction. Depending on conflict level and dependency on the human habitation primate populations can be categorized in three groups 1) commensal 2) non-commensal and 3) semi-commensal. All these populations in wilderness as well as in human-dominated landscape should be estimated separately. The stakeholders were identified to assist in conflict mitigation based on the population categories of

macaques like highway stakeholder, rural/cropland, urban/semi-urban, temple monuments/tourist spots and forest area

Prevention of crop damages by deterrence (trained dogs, fire cracker, catapults etc.) and revival of traditional knowledge were stressed to be the very important procedure for addressing macaque –human conflict mitigation.

For managing the increasing negative interaction between human and macaques, group discussed about population control method adopted by Himachal Forest Department. For developing standard protocol for management, all the transitional steps such as capturing techniques, transportation and post monitoring of sterilized animal etc. were discussed. Group also emphasized on the efficacy evaluation of anti-fertility drugs for population control (pZP).

Group discussed about the nitty-gritties of the legislation for declaring the species as a vermin and controlling the population growth by legal ban on feeding of macaques.

The research and advisory group was decided to include following agencies: WII - Nodal Agency, Forest department (PCCF & CWLW), National and international NGOs, Experts – scientist/veterinarian/ex forester, ICAR, IVRI and representative of universities and institutes, NEERI. Whereas the implementing agencies were Ministry of Environment, Forest & Climate change, State forest Department, Local bodies (panchayats, municipalities, resident welfare association, etc.), other stakeholders (Temple authority, tourism Deptt.), Veterinary Department and Agriculture & Horticulture. For carrying out the research funding agencies identified were CAMPA, EAPs, Panchayats, Corporate houses (Maharatan etc), Municipality, Government of India (MoRD) and NGOs.

Day 1

TECHNICAL SESSION

MANAGEMENT OF INVASIVE SPECIES

Chair: Dr. Srikant Chandola

Co-chair: Dr. G. S. Goraya

Dr. G.S. Goraya, Deputy Director General, Indian Council for Forestry Research and Education (ICFRE) Dehra Dun, provided details of the invasive species management efforts undertaken by Forest Department in Himachal Pradesh. He appreciated the participatory role of communities in successful management of invasive plants.

Sh. Rajiv Bhartari, Head of Ecotourism Wing, Uttarakhand Forest Department, shared the success story of *Lantana* removal in Corbett National Park under the supervision of Professor C.R. Babu, University of Delhi. He emphasized the need for immediate action for management of *Lantana*. *Lantana* affects the growth and regeneration of native plant species as well as the natural fire cycle. In addition to providing technical details of the removal method, he underscored the necessity of restoration as a subsequent step for preventing further invasion through seed bank germination.

Dr. A.J.T. Johnsingh shared his personal experience with invasive species in Mudumalai Tiger Reserve, southern India, where the present management actions are failing to manage *Lantana* and *Opuntia*. These species have deleterious impacts on the native ecosystem. Dr. Johnsingh added that it is important to understand key biological processes such as animal-mediated seed dispersal to prevent the introduction and spread of invasive plants in novel areas. He emphasized that public participation can make the management of invasive species easy and effective.

Mr. Ninad Mungi, researcher from Wildlife Institute of India, stressed the need for scientific research to answer important questions regarding biological invasions for better management. Mr. Mungi highlighted the opportunity for generating employment for efficient eradication of invasive species such as *Lantana*, which is used for making furniture, water hyacinth, which is used as fodder and a fertilizer, and *Prosopis juliflora*, which is being used for energy production.

Dr. Srikant Chandola, former Principal Chief Conservator of Forests (Wildlife) and Chief Wildlife Warden, Uttarakhand, highlighted the cases of lesser known exotic species in Uttarakhand that need immediate attention from the research community before the problem becomes unmanageable.

Questions and Suggestions:

Prof. Qamar Qureshi expressed his concerns about using bio-control agents in Indian forests without adequate field trials, which could result in invasions of additional species in the ecosystem. He also suggested that precautionary measures be taken during restoration activities to prevent the invasion of weedy and exotic species in protected areas. Dr. R.B.S. Rawat suggested that the huge amount of biomass generated as a result of management of invasive species be used for power generation and for making useful items such as furniture.

DAY 2

WORKING GROUP DISCUSSION

After an initial discussion, the group members agreed unanimously that identification of the invasive species of national concern should be the priority for reducing their spread and subsequent damage to the natural ecosystems. To fill the knowledge gap and disseminate scientific information on the invasive species scientific research, experts' opinions and web portals could be utilized. The group also suggested actions and institutions that could help address the gaps in information through research. It was reiterated that efforts should be invested in identifying invasive species in major ecosystems such as terrestrial, marine, island and freshwater ecosystems. A tentative list of the major invasive species in the above-mentioned four major ecosystems was prepared by the group during the discussion. According to the working group, the Ministry of Environment, Forest and Climate Change should, in the interest of national biosecurity, direct the agencies and departments of all the ministries involved to conduct brainstorming sessions about the issue of invasive species as it is among the objectives of the Aichi targets. The group also suggested that a task force be established for each ecosystem. The roles and potential institutes are listed in table 1. According to the discussion, a task force should be provided with clear and achievable directives. The mandate of a task force should direct it

regarding the prioritized invasive species, sites and pathways of their introduction and their movement. The mandate should direct the authorities to cease the use of management practices such as fire and biological control that are not validated through research. Important responsibilities identified for the task force were education and outreach programmes for stakeholders, training programmes for utilizing eradicated plant material, research and timely meetings with the members and stakeholders. Considering the high cost involved in achieving all the tasks, potential funding agencies were also identified by the working group. The governmental funding agencies identified were CAMPA, Green India Mission, MNREGA and DST. The group suggested that using corporate social responsibility funds could also be explored. A tentative time frame was also chalked out by the group spanning all the stages from the release of an order by the MOEFCC to the formation of task forces, identification of research priorities and other subsequent steps.

The AIS of national concern were decided for different ecosystems based on the experience and research. But further investigations regarding environmental damage caused by them have to be researched.

Terrestrial Ecosystem: *Lantana camara*, *Mikania micrantha*, *Parthenium hysterophorus*, *Prosopis juliflora* (socially important), *Leucaena leucocephala*, *Chromolaena spp.*, *Ageratum spp.*, *Cassia tora* (investigation needed), *Xanthium strumarium* and *Achatina fulica* (Giant African Snail).

Islands Ecosystem (Andaman and Nicobar): *Axis axis* (Spotted deer) and *Hoplobatrachus tigerinus* (Indian Bullfrog) (investigation needed).

Fresh water Ecosystem: *Eichhornia crassipes* (plant), *Ipomea carnea* (plant), *Tilapia* (Fish) and *Clarias gariepinus* (African Magur) (Fish).

Marine Ecosystem: *Kappaphycus alvarezii* (Sea Weed)

Table 2. Institutionalizing the invasive species (IS) management plan for different ecosystem

Targets	Potential Institutions
1. Identifying status of IS of national concern for all the landscapes involved. 2. Experiment with management practices, review the standard operating procedure (SOP) and guidelines for IS management.	Wildlife Institute of India (WII) (PA's); Indian Council of Forestry Research and Education (ICFRE), Fishery Survey of India (FSI) , The Centre for Marine Living Resources & Ecology (CMLRE),
1. Review the practices and status. 2. Developing SOP for every IS of national concern 3. Develop site-specific guidelines for restoration of the native ecosystem. 4. Monitoring the restoration process and producing timely reports	Indian Council of Forestry Research and Education (ICFRE), Forest Research Institute (FRI) , Central Institute of Freshwater Aquaculture (CIFA); ICAR ; Directorate of Weed Science Research (DWSR)
1. Prioritize the areas for managing every IS based on the status developed 2. Implementing the species specific SOP's guidelines for restoring the native ecosystem 3. Allocate the funds and conduct timely audits for implementation. 4. Produce yearly report on the progress in managing IS.	State biodiversity board (SBB), State fishery department & State Agricultural department , Minister of Water Resources, River Development and Ganga Rejuvenation
1. Implement the directed management recommendations. 2. Identify means of involvement of local communities 3. Conduct patrolling to stop the harm caused to native species while managing IS. 4. Submit the report containing information about area targeted, economics, efforts, time and restoration.	State forest department (for area under their responsibility), State revenue department (Revenue land, plantation), Coastal protection and development Advisory Committee (Marin ecosystem), State Agricultural department , State revenue department (Revenue land, plantation)
1. Identify pathways of invasion 2. Make the import and export of biological material stricter and fix the norms for biological transport based on rigorous research	Directorate of Plant Protection, Quarantine and Storage
1. Promote awareness in society through outreach. 2. Workshops for reusing the extracted IS parts and promoting the economic usage of it	NGO's, panchayat, Gram sabhas, Horticulture dept, Animal husbandry.

Chair: Sh. S. K. Mukharjee

Co-Chair: Dr. A. K. Bhardwaj

Sh. S.S. Bist provided an elaborate account of the available acts and sections in Indian legislation to handle conflict situations and problem animals. At the same time, he mentioned the challenges and gaps associated with each act, which make it difficult for the forest department to utilize them for conflict management. Sh. Bist also mentioned several facets of *ex-gratia* payments for mitigation of damages caused by wild animals. He added that subsidies for crops, livestock insurance, designating damage caused by wildlife as natural calamities and providing incentives through developmental funds should be utilized by the government as alternatives to *ex gratia* payments. He emphasized that the available policies (National Livestock Policy, National Mining Policy, National Agriculture Policy National Policy for Farmers, etc.) should be used efficiently and co-operation among the concerned departments should be improved for better management of human–wildlife interactions.

Dr. Dipankar Ghose, Director, Species Landscape Programme, WWF-India, highlighted the high tolerance level of communities and culture of conservation as being responsible for a long co-existence of humans and wildlife. Our constitution provides a right to each and every citizen to have a healthy environment, and it also provides a right to protect and improve the same. Dr. Ghose provided suggestions to be incorporated into the legal framework for improving the management of human–wildlife interactions in the country. Deployment of tracking squads, using camera traps for correctly identifying conflict individuals, providing early warning systems, forming an advisory committee consisting of representatives of all concerned stakeholders, etc. were some of the suggestions provided by Dr. Ghose. According to Dr. Ghose, wildlife conservation in India follows a protected area-centric approach. However, the degraded quality of most of protected areas is the one of the most important causes of the increasing number of conflict cases. Therefore, improving the habitat to ensure that resources are available for wildlife is the first step for ensuring the peaceful co-existence of humans and wildlife. He then mentioned the discrepancies in the *ex gratia* compensation across the country and advised that there should be one country-wide policy.

He stressed the need for conducting long-term scientific research to help policy makers formulate guidelines.

Sh. Samir Sinha, Field Director, Corbett Tiger Reserve, discussed the gaps in policies and law as well as the conflicts among multiple acts.

Sh. S.K. Mukharjee, former Director, Wildlife Institute of India, provided his views on the existing policies and action plans. Differences between the state and central government legal administration serve as a hurdle to the implantation of action plans. Like other experts, Sh. Mukharjee emphasized the role of long-term research in guiding policy makers. He suggested that premier research institutes such as Wildlife institute of India should be given charge of capacity building in the ecological research arena in the country.

Questions and Suggestions:

Dr. Abhijit Das drew the group's attention towards the serious issue of the lack of a law to deal with a Schedule-I species (the elephant) being feral and invasive on the Andaman and Nicobar Islands.

Draft Guidelines for the Management of Human-Wildlife Negative Interactions and Invasive Species

**MODEL OPERATING GUIDELINES (M.O.G.) FOR DEALING
WITH HUMAN-WILDLIFE NEGATIVE INTERACTIONS AND
ALLIED MATTERS**

DRAFT REPORT PREPARED BY

S.S. BIST, IFS (Retd)

EMERITUS SCIENTIST

Section-1

MODEL SETUP FOR MANAGEMENT OF HUMAN-WILDLIFE NEGATIVE INTERACTIONS

As envisaged in the Wildlife (Protection) Act, 1972 (WPA-1972), the Forest Department (FD) in each State* of the country has a Wildlife Wing, headed by the Chief Wildlife Warden (CWLW), for looking after all matters relating to protection and management of wildlife. But considering that Human-Wildlife Conflict (HWC) takes place largely in non-forest (rural, semi-urban and urban) landscapes; affects a large cross-section of stakeholders; involves political, social, financial, technical, legal and administrative issues; and calls for coordinated efforts by a number of agencies—a specially designed setup for effective management and monitoring of HWC is called for. The organisational requirements of a particular State may depend upon the extent and seriousness of conflict and also on the kind of wild animals involved, but by and large, a model setup can be planned on the following lines.

1. SETUP AT THE STATE LEVEL

1.1. Advisory and Monitoring Role

1.1.1. State Board for Wildlife: The existing State Board for Wildlife (SBWL), under the chairmanship of the Chief Minister/Administrator, should take up the advisory and monitoring role on all matters relating to HWC at the State level. The State Government may assign to the SBWL the duty of advising on matters relating to HWC in accordance with Section 8(d).

1.1.2. Sub-Committee: For a much vigorous monitoring of the HWC issues, the SBWL should set up a sub-committee headed by the Minister-in-Charge of the Forests and Wildlife. The sub-committee may invite to its meetings such officers, experts, scientists, representatives of the stakeholders and representatives of the major relief / philanthropic organisations as it may think necessary.

* The term 'State' is also intended to include Union Territory (U.T.) in this document.

1.1.3. The sub-committee should meet as frequently as required. In particular, it must meet before the major HWC season to take stock of the preparations. It must also meet whenever an emergency occurs.

1.1.4. The CWLW should submit an annual report on the status of HWC in the State to the SBWL.

1.2. Executive Role

1.2.1. **State Level Coordinator:** The CWLW should remain overall in-charge of HWC management in the State. But given the multifarious and demanding functions of a CWLW in most of the States, the FD may designate another forest officer of sufficient seniority (say, Additional CWLW) at the headquarters of the Wildlife Wing as the **State Level Coordinator (SLC)** for management of HWC. He should be provided with the requisite office support.

1.2.2. The name and contact address of the SLC should be duly publicised from time to time through the official channels.

1.2.3. Suggested duty-list of the State Level Coordinator

1. To ensure quick and effective communication between the CWLW and the district level forest officials dealing with HWC, particularly in respect of permission sought from the CWLW under Sections 11 and 12.
2. To coordinate with other government departments, researchers, NGOs, media and relief / philanthropic agencies at the State level.
3. To organise training / capacity building programmes relating to HWC within the State.
4. To procure darting guns and drugs for chemical immobilisation of wild animals. Also, to procure the services of chemical immobilization experts, trained elephants, hunters and trappers.
5. To maintain a list of recognised wildlife corridors in the State and ensure their protection and effectiveness.
6. To maintain records and statistics related to HWC and ex-gratia relief in the State and display / update such statistics on the website of the FD.
7. To prepare replies to parliamentary / assembly questions as well as queries from the State Government / Central Government in respect of HWC.
8. To prepare an annual report on the status of HWC in the State for submission to the SBWL (Ref. Para 1.1.4).

2. SETUP AT THE DISTRICT LEVEL

2.1. Advisory and Monitoring Role

2.1.1. District Level Advisory and Monitoring Committee: In all such districts as are sensitive from the point of view of HWC, the FD should set up District Level Advisory and Monitoring Committee (DLAMC). The DLAMC should preferably be chaired by the Minister-in-Charge of the district. It should include the District Level Coordinator (Ref. Para 2.2.1) and other territorial DFOs / PA managers within the district, District Magistrate, District Superintendent of Police, Chairperson (Sabhadhipati) of the District Board (Zila Panchayat Samity), local MPs and MLAs, Chief Medical Officer, District Veterinary Officer, District Agriculture Officer, all Honorary Wildlife Wardens in the district, non-official members of the SBWL from the district, major environmental NGOs in the district, representatives of the major stakeholder groups in the district (e.g. railways, tea / coffee planters, army, mining companies, electricity board, etc.), representatives of Joint Forest Management Committees (JFMCs), representatives of local relief / philanthropic organisations, representatives of local scientific institutes working on HWC issues, etc. The District Level Coordinator may serve as the member-convenor of the DLAMC. The DLAMC should meet as frequently as required. In particular, it must meet before the major HWC season to take stock of the preparations. It must also meet whenever an emergency occurs.

2.1.2. PA Level Advisory and Monitoring Committees: The WPA-1972 envisages establishment of Advisory Committees for Sanctuaries (S.33B) and Management Committees for Conservation Reserves (S.36B) and Community Reserves (S.36D). The Central Government has also notified Eco-sensitive Zones (ESZs) around a number of PAs and set up Monitoring Committees for each ESZ under S.3 of the Environmental (Protection) Act, 1986 (EPA-1986). The FD should actively consult and involve these Committees in all such matters as may impact HWC management in the region.

2.2. Executive Role

2.2.1. District Level Coordinator: Usually the respective territorial DFOs and PA managers manage the HWC in a district in and around their respective jurisdiction. But in districts having more than one DFO / PA manager, there may often be problems of coordination between different forest officers or between forest officers and the civil authorities and public representatives. The FD may, therefore, designate one of the forest officers in a district as the **District Level Coordinator** (DLC) for looking after matters relating to HWC in the district. It

will be advisable to appoint the senior-most forest officer present in the district as the DLC. He should be provided with the requisite office support.

2.2.2. The CWLW may, in accordance with S.5(2), delegate some or all of his powers under S. 11(1)(b) to the DLC with suitable conditions (Ref. Para 3.1).

2.2.3. The FD may authorise the DLC to requisition staff, vehicles, trained elephants, RT sets, equipment and other logistic support from various Forest Divisions (Territorial or Functional), PAs and zoological park within the district or from the adjoining districts **during any emergency relating to HWC.**¹

2.2.4. The name and contact details of the DLC should be duly publicised from time to time through official channels.

2.2.5. Suggested Duty-List of the District Level Coordinator

1. To prepare a conflict management strategy for the district on the basis of the past conflict records, in consultation with the local forest officers and the district administration, and in accordance with the guidelines given by the CWLW and the State Government.
2. To scrutinise and forward all schemes for HWC management under the Centrally Sponsored Schemes or State Plan for the district to the CWLW and oversee the implementation of the sanctioned schemes in the field.
3. To cause inquiry into death of human-beings by wild animals and submit the same to the CWLW promptly.
4. To cause inquiry into death of Schedule-I animals and submit the same to the CWLW promptly.
5. To maintain dossier of problem animals involved in human deaths/injuries in the district (Ref. Sec. 4 /Para 4.3)
6. To forward all proposals relating to translocation/ capture / elimination of problem animals specified in Sch.I to the CWLW for proclamation under S.11 (1)(a) and ensure the implementation of such a proclamation.
7. To forward all proposals relating to translocation/ capture / elimination of problem animals belonging to Sch.II/Sch.III/Sch.IV for permission to the Authorised Officer under S.11(1)(b) [or issue the permission himself if such a power has been delegated to him as suggested in Para 2.2.2. and Para 3.1] and ensure the implementation of such a permission.

¹ The PCCF (West Bengal) issued a directive in 1991 directing the staff of the non-territorial forest divisions in North Bengal to help the Wildlife Divisions in cases relating to HWC.

8. To maintain a list of recognised wildlife corridors in the district; ensure their protection and effectiveness; and submit a report on their status to the SLC on half-yearly basis.
9. To maintain records and statistics related to HWC and ex-gratia relief in the district and share the same with the SLC once in a quarter.
10. To assist the SLC in preparation of replies to parliamentary questions / assembly questions relating to HWC.
11. To prepare an annual report on the status of HWC in the district to the CWLW.
12. To deal with complaints and grievances relating to HWC management including payment of ex-gratia relief in the district.
13. To coordinate with the other government departments, researchers, NGOs, media and relief / philanthropic agencies at the district level.
14. To oversee the performance of the Anti-Depredation Squads (Ref. Para 2.4) and Honorary Wildlife Wardens (Ref. Para 2.3) in the district.
15. To appoint hunter / trapper for dealing with HWC whenever required.
16. To organise training / capacity building programmes relating to HWC within the district.
17. To convene the meetings of the DLAMC.

2.3. Honorary Wildlife Wardens

2.3.1. In all districts sensitive from the viewpoint of HWC, the State Government may, in accordance with S.4(1)(bb), appoint adequate number of Honorary Wildlife Wardens (HWLW). The HWLWs should be selected keeping in view their expertise in dealing with wild animals; their potential to control the crowd (Ref. Sec. 8 /Para 2) and help the forest staff in the field; and their capability to arrange relief for the people affected by HWC. Retired but experienced veterinarians may also be engaged as HWLWs (Ref. Para 3.2.2). It may be advisable in certain cases (e.g. for dealing with conflict with wild animals existing in non-forest areas) to designate authorities of the district administration or local bodies (Panchayat, Municipalities, etc.) as HWLWs (Ref. Paragraph 3.1.5).

2.3.2. In deserving cases, the CWLW may, in accordance with S.5(2), delegate some of his powers under S. 11(1)(b) to the HWLWs with suitable conditions (Ref. Para 3.1).

2.3.3. In deserving cases, the HWLW may be given the responsibility to supervise the Local Wildlife Squads (Ref. Para 2.5); oversee the working and maintenance of barriers, fences and other devices meant for controlling HWC; and help in verification of applications for ex-gratia relief. They will submit their reports to the DLC.

2.3.4. All the HWLWs in a district should be included in the DLAMC.

2.3.5. The name and contact details of the HWLWs should be duly publicised from time to time through official channels.

2.4. Anti-Depredation Squad²

2.4.1. The FD should set up an Anti-Depredation Squad (ADS) in each district having HWC. The ADS should act like fire brigade to rush to the problem spots and help the people. More than one ADS may be set up in a district depending upon its area, geographical distribution of conflict areas and seriousness of conflict. In many cases, it may be sufficient to have one permanent ADS and set up a few temporary ADS during the major conflict seasons (e.g. crop-harvesting season, elephant- migratory season, etc.) or during an emergency by pooling up staff and resources from various forest divisions.

2.4.2. The ADS should be headed by a Forest Ranger / Senior Deputy Ranger and comprise 10-12 permanent / contractual staff with a provision for leave vacancies. The ADS may work under the administrative control of the DLC or one of the local DFOs as may be convenient.

2.4.3. **Jurisdiction:** In case of more than one ADS in a district, their jurisdiction should be fixed as clearly as possible to avoid any confusion. The headquarters of the ADS should be fixed keeping in view the major zones of conflict. The ADS should be geared up to camp within a conflict zone in emergency.

2.4.4. The contact details (address, phone / fax/ mobile number and/or email ID) and jurisdiction of the ADS should be duly publicised from time to time through the official channels.

2.4.5. **Tools and Equipment:** The ADS should be properly equipped keeping in view the kind of wild animals likely to be faced, nature of depredation, and the terrain.

2.4.5.1. The NTCA's SOP (2013) has recommended the following tools / equipment for ADS dealing with tigers and leopards:

² Referred to as '**Emergency Response Team**' in 'Guideline for Human-Leopard Conflict Management' (MoEFCC, 2011) and as '**Rapid Response Team**' in 'Standard Operating Procedure To Deal With Emergency Arising Due To Straying Of Tigers In Human Dominated Landscapes' (NTCA, 2013). The latter deals with tigers and leopards and was issued vide NTCA's Letter No. 15-37/2012-NTCA dated 30.1.2013.

- I. A field van/mini-truck with built in rails for accommodating a trap cage, with space for equipment, attendants and staff.
- II. A tranquilization kit with drugs for chemical immobilization.
- III. Taser gun for instant immobilization of the animal.
- IV. 2 mobile phones for continued communication with the authorities.
- V. 4 wireless handsets.
- VI. 2 GPS sets.
- VII. 1 long ranging night vision for seeing objects in the dark.
- VIII. A digital camera.
- IX. 4 trap cages (2 for tiger and 2 for leopard).
- X. 1 mini-tractor for transporting the cage in rugged terrain.
- XI. 2 search lights.
- XII. 2 radio collars with receiver and antenna.
- XIII. 2 portable tents.
- XIV. Portable hides – which can be set up fast, to be used for persons with tranquilizers
- XV. 2 folding chairs with table.
- XVI. Hand held audio system.
- XVII. Rope and net.
- XVIII. First aid kits

2.4.5.2. In certain areas (e.g. islands, mangroves etc.) or for certain species (e.g. crocodile), the ADS may need motorboat or a suitable watercraft.

2.4.5.3. The ADS should carry a stretcher for moving chemically immobilized animals.

2.4.5.4. The ADS should also carry suitable guns / rifles and sufficient stock of crackers / rocket bombs. Air guns /rubber-bullet guns are useful for dealing with monkeys and small mammals. Flare guns or light-producing bottle-rockets are useful for locating wild animals in the dark. A hooter /siren may often be useful in scaring away wild animals. Camera traps are useful for monitoring / tracking of a problem animal. A portable public address system is useful for warning people.

2.4.6. Uniform and Protective Gear: The ADS staff should be provided with special uniform to make them identifiable during the operation. The ADS staff should also carry special protective gear in case they are likely to deal with big carnivores.³

2.4.7. Insurance Cover: The FD should arrange insurance cover for each member (permanent or contractual) of the ADS against death or injury.

2.4.8. Suggested Duty List of the Anti-Depredation Squad

1. To remove the problem animals from human habitations, croplands and other sensitive areas by managing the local people, or by driving/ scaring the animal away, or by capturing/ trapping/ translocating/ eliminating the animal—in accordance with the merit of the individual case and in keeping with the provisions of law.
2. To rescue wild animals stranded in human habitations.
3. To identify wild animals indulging habitually in human-killing/ crop-raiding/ cattle-killing/ house-breaking; maintain their dossiers; and submit proposals to the DFO / DLC for hunting them under S.11(1).
4. To help the authorised hunter / trapper /chemical immobilization expert in tracking and locating the problem animals proclaimed by the CWLW / AO under S.11(1).
5. To help the victims of wildlife depredation in getting ex-gratia relief from the competent authority.
6. To provide first aid to the persons injured by wild animals and help them in receiving medical care.
7. To conduct inquiry in each case of human-death caused by a wild animal and submit a report to the DFO / DLC.
8. To conduct inquiry in each case of wild animal killed during conflict and submit a report to the DFO / DLC.
9. To supervise fences, trenches and other barriers set up to prevent HWC and inform the appropriate authority about their maintenance.
10. To oversee the status of the recognised wildlife corridors once in a quarter and submit a report to the DLC.
11. To provide training in conflict-management techniques to temporary ADS, Local Wildlife Squads (Ref. Para 2.5) and other stakeholders.

2.4.9. The CWLW may, in accordance with S.5(2), delegate some of his powers under S. 11(1)(b) for animals listed in Sch.II/Sch.III/Sch.IV to the Officer-in-Charge of the ADS with suitable conditions (Ref. Para 3.1).

³The FDs in West Bengal and Jammu & Kashmir have developed protective gears for leopards. The West Bengal FD has also developed 'human-face masks' for use by the field staff and workers entering the tiger- infested forests in the Sundarbans.

2.4.10. Training: All staff of the ADS should be provided with training with due regard to the suggested duty list and the tools and equipment supplied to them. They should be given basic information about the biology, nature and ecological needs of the wild animals that they are likely to handle. They should also be educated about their duties and powers under the WPA-1972 and the Prevention of Cruelty to Animals Act, 1960 (PCA-1960) and rules made thereunder.

2.5. Local Wildlife Squad⁴

2.5.1. The FD should encourage the local community in a conflict area to form Local Wildlife Squad (LWS). The purpose of a LWS is to manage minor cases of HWC (e.g. chasing and driving of wild animals or guarding of crop) or to manage the situation until the arrival of the ADS. LWS may provide necessary support to the ADS, particularly with regard to the crowd control and monitoring of problem animals. The ADS may also take help from LWS in setting up traps for capturing of problem animals and protecting them.

2.5.2. The FD should, in particular, insist upon formation of LWS in a locality before undertaking construction of a barrier (e.g. power-fencing or trench) and entrust the monitoring and maintenance of the barrier to such LWS.

2.5.3. The FD should preferably undertake the distribution of crackers, search-lights and other material in the conflict area for managing HWC through the LWS.

2.5.4. The LWS may take many shapes depending upon the local circumstances. It may consist of volunteers provided by the local JFMCs, Panchayat or a local NGO. The organised stakeholders (e.g. Tea / Coffee Estates, Public Undertakings, Companies, Army Units, Farm Houses, etc.) may be persuaded to set up LWS by engaging their own workers. In emergency situation, the FD may have to set up a LWS for a certain period by paying wages or honorarium to its members.

⁴ Referred to as 'Primary Response Team' in the MoEFCC's Guideline (2011). It finds no mention in the NTCA's SOP (2013) which, however, suggests setting up 'Monitoring Team' consisting of locals'.

2.5.5. In some cases, it may be useful to set up a Joint Wildlife Squad comprising of forest staff and local volunteers. This may, in particular, be needed while dealing with wild animals known to be human-killers—in which case some armed forest staff may be deployed with a LWS.⁵

2.5.6. The ADS should have a list of all LWSs under its jurisdiction and arrange for their training. It may oversee the selection of members of LWS. Old, sick and alcoholic persons should not be included in LWS. The ex-servicemen and the persons possessing licenced guns may be preferred if otherwise fit.

2.5.7. The FD should arrange insurance cover for each member (paid or volunteer) of the LWS against death or injury.

3. ANCILLARY MATTERS

3.1. Authorised Officers:

3.1.1. Most of the tools meant for HWC management, such as killing, capturing, tranquillising, snaring, trapping, driving, baiting etc., come under the definition of hunting and require permission from the CWLW for animals listed in Sch. I [S.11(1)(a)] and from either the CWLW or the Authorised Officer (AO) for animals covered by Sch.II /Sch.III/Sch.IV [S.11(1)(b)]. AOs may be appointed under S.5(2) which empowers the CWLW to delegate his powers under S. 11(1)(b) to any subordinate officer with the approval of the State Government. The State Governments may also appoint AOs under S.4(1)(c).

3.1.2. HWC management usually requires quick decisions in the field and it is not practical to obtain prior permission from the CWLW in each and every case, particularly for routine operations like chasing or scaring wild animal. Therefore, it is necessary to designate adequate number of AOs in the field.

3.1.3. The CWLW cannot designate AOs in respect of the animals covered by Sch.I. He may, however, grant a general permission in favour of the ADS, LWS, HWLWs, and the local forest staff for undertaking simple anti-depredation measures such as chasing and driving wild animals

⁵ The Gujarat FD has set up mixed teams of forest staff and volunteers to manage human-crocodile conflict along Vishwamitri river, Vadodara (August 2014).

from human habitations; and rescuing injured wild animals or abandoned cubs / calves found outside their natural habitats. He may also issue a general permission in favour of the DLC, local DFOs, ADS and some selected HWLWS for capturing (trapping / chemical immobilisation) of wild animals of Sch.I posing threat to human life and releasing them immediately within their home range subject to the condition that all such cases should be immediately reported to him. But no action should be taken for translocating a Sch.I animal outside its home range or putting it under permanent captivity or killing it, without a specific permission of the CWLW in writing. The cases of killing or wounding of Sch.I animal in defence of oneself or of any other persons under the provisions of S.11 (2) should also be reported to the CWLW as soon as possible.

3.1.4. The CWLW should designate adequate number of AOs for exercising powers under S.11 (1)(b) in respect of animals listed in Sch.II/Sch.III/Sch.IV. He may, grant a general permission in favour of the ADS, LWS, HWLWs, and the local forest staff for undertaking simple anti-depredation measures such as chasing and driving wild animals from human habitations; and rescuing injured wild animals or abandoned cubs / calves found outside their natural habitats. He may designate the DLC, local DFOs, Officer-in-Charge of ADS, and some selected HWLWS as AOs for permitting capture (trapping / chemical immobilisation) of problem animals and releasing them immediately within their home range. However, for decisions involving large financial or scientific implications, such as translocating a wild animal outside its home range or putting it under permanent captivity or killing it, should not be left to a junior-level officer and only the DLC or a higher-ranking forest officer should be entrusted with this responsibility. The cases of killing or wounding of animals listed in Sch.II/Sch.III/Sch.IV in defence of oneself or of any other persons under the provisions of S.11 (2) should also be reported to the DLC as soon as possible.

3.1.5. It may be advisable in certain cases (e.g. for wild animals existing in non-forest areas) to designate authorities of the district administration or local bodies (Panchayat, Municipalities, etc.) as AO. S.5(2) stipulates that the CWLW may delegate his powers only to an officer subordinate to him and subject to such conditions as he may specify. In such cases, the State Government should first appoint the authority in question as an HWLW under S.4(1)(bb) and, thereafter, the CWLW should delegate the required powers to him subject to the condition that he will endorse copies of all his orders under S.11(1)(b) to the DLC and also submit a report on the action taken on such orders as soon as possible.⁶ The State Government may also appoint

⁶ As an example, the Government of Gujarat appointed a number of village-heads (Sarpanch) as HWLWs under S. 4(1)(bb) during 2006-07 and permitted the CWLW under S. 5(2) to delegate them with powers under S.11(1)(b) for hunting Blue Bulls involved in crop-raiding.

AOs from outside the FD under S.4(1)(c).⁷ But it is important to ensure that they work under the supervisory control of the CWLW and submit regular reports to him.

3.1.6. The CWLW / SLC should review the working of the AOs from time to time and issue suitable guidelines to them. Training programmes should be organised for the AOs from outside the FD to help them understand the ecology and behaviour of wild animals involved in conflict so that they may take responsible decisions.

3.2. Veterinary Support:

3.2.1. Support from knowledgeable and experienced veterinarians is essential for chemical immobilization and transportation of wild animals; putting radio-collars and identification marks on them; treating sick and injured wild animals in the field and at the Rescue Centres / Transit Facilities; and screening the captured animals for zoonotic diseases before releasing them in the wild. The FD, in collaboration with the Veterinary Department, should identify the veterinarians with experience in dealing with wild animals, particularly those working in the Zoos and PAs, and make the list available to the DLCs. Suitable training programmes and refresher courses in handling wild animals should be organised for the selected veterinarians with the help of the WII, Indian Veterinary Research Institute, Kerala Agricultural University and Assam Agricultural University. Short term orientation programmes for the district veterinarians can also be arranged with the help of the experienced Zoo Veterinarians. The target should be to have at least two trained wildlife veterinarians in each district and equip them with vehicle, necessary instruments and medicines.

3.2.2. In view of the limited number of experienced and trained wildlife veterinarians in the country at present, it will be a good idea to retain the services of such veterinarians even after their superannuation on voluntary or contractual basis. Well-known wildlife veterinarians may also be engaged as HWLWs.

3.2.3. The FD should help the Veterinary Department or a Veterinary College to set up a pathological and diagnostic centre for wild animals.⁸

⁷ As an example, the Government of Uttar Pradesh has appointed District Magistrates under S.4(1)(c) as AO for exercising powers under S.11(1)(b) vide GO No. 736-14-4-94-854/92 dated 9.3.1994. This order is presently also applicable in Uttarakhand.

⁸The FD in West Bengal has established a Wildlife Diseases Investigation & Diagnostic Centre in Kolkata in collaboration with the State Animal Resources Department and the CZA.

3.2.4. The FDs in the States having chronic conflict problems on account of over-abundance of wild animals like rhesus monkeys, blue bulls, axis deer, etc. may also set up Wildlife Sterilization Centres in collaboration with the Veterinary Department or a Veterinary College.⁹

3.3. Chemical Immobilization Team

3.3.1. Chemical immobilisation has now become a *sine qua non* for managing HWC. Chemical immobilisation provides a safe, fast and the least traumatic technique for capturing and transporting problem animals; putting radio-collars and identification marks on them; and treating sick and injured wild animals. Only a few FDs and institutes (e.g. Wildlife Institute of India) in the country at present possess the experts and equipment for chemical immobilisation. These FDs and institutes may not always be in a position to spare their immobilization team for other States, particularly at a short notice. Other FDs should, therefore, also strive to set up their own chemical immobilisation teams as soon as possible. A trained veterinarian should always be a part of the immobilisation team.

3.3.2. The list of trained and experienced immobilisation experts should be available with the SLC and the DLCs. If, however, the FD does not have in-house expertise with chemical immobilisation, it may work out an understanding in advance with other FDs, NGOs or Research Organisations to provide the services of their experts as and when required. The contacts of the identified experts and the terms of their engagements should be made available to the DLCs.

3.3.3. The SLC and DLCs should have a complete list of the darting equipment, drugs and antidotes available with the FD, zoological parks, research organisations and other agencies within their jurisdiction. The equipment should be checked periodically and repaired or replaced. Additional equipment should be procured well in time. Procurement of certain drugs and antidotes is often a tedious and time-consuming exercise. Therefore, the SLC should work out the additional requirement of drugs and antidotes in consultation with the DLCs and initiate the procurement process well in advance. The equipment with drugs and antidotes should be allotted to an ADS if it has an immobilisation expert or kept in a zoo or in the custody of the DLC so that the same is readily available whenever needed. The rules and the guidelines prescribed by the Narcotics Bureau and Controller of Drugs for safety and upkeep of the drugs should be strictly followed.

3.4. Kunki Squad

⁹ The FD in Himachal Pradesh has set up a number of Monkey Sterilization Centres.

3.4.1. Trained elephants (*Kunkis*) and mahouts are very useful in dealing with a number of conflict situations involving wild elephant, tiger, leopard, gaur and rhinoceros. *Kunki* elephants are useful for:

1. Tracking, monitoring, chasing and driving of problem animals.
2. Screening of forests to locate proclaimed wild animals and injured wild animals or their carcasses.
3. Capture of wild elephants by *Mela-shikar*.
4. Training and handling of captured elephants and rescued elephant calves.
5. Assisting experts in chemical immobilisation and translocation of wild animals.
6. Assisting hunter in hunting down the proclaimed wild animal.

3.4.2. FDs of Karnataka, Tamilnadu, Madhya Pradesh, West Bengal and Assam have their own fleets of *kunki* elephants and experienced mahouts.¹⁰ These FDs may not always be in a position to spare their *kunkis* for other States, particularly at a short notice. Some FDs also hire *kunkis* from the private owners in Assam. Depending upon the level of conflict and its past experience, the FD may decide whether or not to set up a permanent *kunki* squad of its own.

3.4.3. The FD may build up a permanent *kunki* squad either by procuring surplus trained elephants from the aforesaid States or by capturing suitable wild elephants from its own forests (under S.11 or S.12 of the WPA-1972) and getting these elephants and prospective mahouts trained with the help of *kunkis* and mahouts from other States.

3.4.4. A squad comprising 4-6 number of *kunki* elephants (including two bulls) of height 8 feet and above should be sufficient for dealing with most of the cases of conflict. *Kunkis* should be trained enough to withstand the sound of gun-fire and ride into a truck so that they can be transported speedily from one problem area to another. They must not be shy of cattle or given to the habit of jerking off their riders.

3.4.5. Selection of mahout and grass-cutter for each *kunki* is very important. They should be physically fit and free from alcoholism; able to handle their elephant in different situations—particularly in the presence of big carnivores and mega-herbivores; skilled in preparing ropes and other accoutrement for their own elephant and the captured elephants; and experienced in providing at least preliminary training to the captured elephants.

¹⁰ FDs of U.P., Odisha and Kerala are presently building up their *kunki* squads. FDs of Uttarakhand and Andaman & Nicobar possess a number of domesticated elephants and mahouts which need training before being used as *kunki* squads.

3.4.6. The *kunki* squad should be camped at a place reasonably close to the potential conflict areas; having plentiful supply of fodder and running water (for bathing and drinking) and accessible to a veterinarian. It's a good idea to plant quick-growing fodder species (e.g. Ficus, Bamboo, hybrid Napier grass, etc.) in the forest offices in and around the conflict areas to take care of the feeding requirements of *kunki* elephants in emergency.

3.5. Trappers, Catchers and Hunters:

3.5.1. The FDs in some States may not have the in-house expertise for trapping and capture of certain species of wild animals (e.g. elephants, monkeys and crocodiles) and may need help from the professional trappers /catchers. The FD may also require skilled hunters having suitable weapons for tracking and killing problem animals proclaimed by the CWLW /AO under S.11(1). A skilled hunter may also be needed to provide a backup to the chemical immobilization team engaged in handling dangerous animals like tigers, leopards, elephants, etc. The SLC should complete the process of selection of trappers, catchers and hunters before the conflict season sets in instead of leaving the matter to be dealt with at the eleventh hour by the district-level officers.

3.5.2. In most of the cases, the trappers /catchers are illiterate / semi-literate and may not respond to the usual system of bidding through tenders and quotations. In such cases, the State Government may appoint and authorise a committee of officials (with representation of the Finance Department) and non-officials with relevant experience to negotiate with the known experts and finalise the deal. It may be useful to prepare a panel of approved experts instead of selecting a single expert so that there is always an alternative when the first one in the panel defaults.

3.5.3. During selection, due weightage should be given to skills, experience and past performance of the expert and his team. Persons with bad reputation should not be selected and a background check should be carried out with the local Police and the local DFO.

3.5.4. It should be ensured that the expert and his team are well-versed with the modern concepts of animal welfare and corresponding legal provisions.

3.5.5. For an operation involving driving, capturing and translocation of wild elephants, the expert may be called upon to provide services of 4-6 number of *kunki* elephants (including two bulls) of height 8 feet and above. The *kunki* elephants should be duly covered by ownership

certificate issued by a CWLW and health certificate issued by a registered veterinarian. The *kunki* elephants and their handlers should meet the requirements indicated in Paragraphs 3.4.4 and 3.4.5 above.

3.5.6. Similarly, for an operation involving driving /scaring of monkeys with the help of trained langurs, it should be ensured that the langurs are healthy and have been procured legally.

3.5.7. The hunters should not be engaged from the open market. The NTCA (2013) recommends that no award / reward should be announced for destruction of human-eating tigers / leopards and some skilled departmental personnel should be engaged for eliminating them. A similar policy may be adopted in respect of other wild animals. But the FDs often lack competent hunters or the appropriate weapons (.375 Magnum and above for tiger and leopard; and .450 and above with hard-nosed ammunition for elephants, rhinos and gaur). It is, therefore, essential to identify expert hunters possessing appropriate gun and ammunition from other sources, particularly the army and police, or from the neighbouring States.

3.5.8. The list of approved trappers, catchers and hunters should be provided to the DLCs so that they may straightway requisition their services without wasting time in formalities.

3.6. Rescue Centres and Transit Facilities:

3.6.1. Rescue Centres are required for sheltering the problem animals captured from the field or the stranded wild animals (including cubs / calves of wild animals) rescued by the ADS and LWS which cannot be released back in their natural habitats due to sickness / injury, or their habit of straying back into human habitations, or their propensity to cause harm to the life or property of the people, or their inability to survive on their own in the wild. In many cases, the captured wild animal needs to be kept temporarily at a Transit Facility temporarily for treatment or investigation, or while awaiting a decision by the competent authority about its disposal.

3.6.2. The number and location of Rescue Centres / Transit Facilities would depend upon the extent and distribution of HWC within the State and experience from the past. Ideally, the Rescue Centre / Transit Facility should be close to a conflict zone as well as a veterinary unit.

3.6.3. A Rescue Centre, by virtue of S.2(39), is a Zoo and, therefore, governed by the provisions of the Chapter IVA of the WPA-1972 and various rules and guidelines issued by the Central Zoo

Authority (CZA) from time to time. An existing Zoo in a district may be used as a Rescue Centre by adding suitable facilities to it.

3.6.4. A Transit Facility does not need any permission from the CZA, though it is advisable to follow the norms and standards prescribed by the CZA for Rescue Centres. A Transit Facility may be set up as an adjunct to an existing Zoo / Rescue Centre or an independent unit near a forest beat office or a veterinary centre. The captured wild animal should not be kept inside the trap cage for more than a week and should be shifted to a larger enclosure as per specifications fixed by the CZA.

3.6.5. Captured elephants and rescued elephant calves need special care of experienced mahouts and trained elephants. Therefore, a Rescue Centre / Transit Facility for them should either be set up close to an existing elephant camp or services of experienced mahouts and trained elephants should be requisitioned at the existing Rescue Centre / Transit Facility.

3.6.6. Some NGOs also run Rescue Centres approved by the CZA in various parts of the country specialising in the care and handling of one or more species of wild animals. The SLC / DLC may tie up with the concerned NGOs for providing help to capture and manage the animals involved in HWC.¹¹

3.6.7. The ADS and LWS should be informed well in advance about the Rescue Centre / Transit Facility where a captured wild animal has to be shifted.

3.7. Inter-State Coordination:

3.7.1. Wild animals know no state boundaries and, as a corollary, people living on two sides of the inter-state border may be suffering on account of the same animal or same group of animals. The FDs of the neighbouring States should, therefore, cooperate with each other and follow uniform policies as regards HWC management.

¹¹ For example, the Wildlife SOS-India runs rescue centres for bears at Agra (U.P.), Bannerghatta (Karnataka), Van Vihar (M.P.) and Purulia (W.B.) and for elephants at Agra (U.P.) and Yamuna Nagar (Haryana). The Wildlife Trust of India runs rescue centres for bears in Pakke Tiger Reserve (Arunachal Pradesh) and for rhinos, elephants and other wild animals in Kaziranga National Park (Assam).

3.7.2. The SLCs and DLCs of the neighbouring States should frequently interact to exchange information and sort out problems, if any. In particular, information about the human-killing animals should be shared and joint efforts should be made to track and capture / kill the same. Information should also be shared in respect of injured animals, translocated animals and those following seasonal pattern of movement (e.g. elephants). Cooperation is also needed for monitoring and protection of inter-state wildlife corridors.

3.7.3. The FDs of the neighbouring States should also organise joint training programmes for their ADS, LWS and JFMC members to boost up mutual trust and cooperation.

3.7.4. As far as possible, the FDs of the neighbouring States should follow similar rates in respect of ex-gratia relief to the victims of HWC.

Section-2

Conflict Management Strategies

1. **General Guidelines:** Strategies for dealing with wild animals in different conflict scenarios should be planned in accordance with the following guidelines:

1.1. In general, a wild animal should either be left undisturbed or permitted to escape to its natural habitat unless there is reason to believe that it has become (or may become) a threat to the safety of humans and their properties (viz. livestock, crop, houses, etc.).

1.2. Intervention, if necessary, should be minimal and commensurate with the level of threat posed by the animal and the level of tolerance exhibited by the stakeholders towards it. So, whereas an animal involved in human-killing just by accident, may be permitted to return to its natural habitat on its own, there should be no hesitation in eliminating an animal indulging habitually in human-killing. Similarly, a distinction needs to be made between the animals involved in crop-raiding and livestock-killing opportunistically and those indulging habitually—the former should be handled through barriers, scaring tactics and precautionary measures, while the latter should be handled through capture, translocation and—if situation so demands—killing.

1.3. The WPA-1972 [S.11(1)(b)] provides no legal strategies for dealing with Sch.I animals posing threat to crops, livestock and other properties. It also puts some riders on the strategies for dealing with Sch.I animals posing threat to human life and limits the choice to the following options:

Option-1: Capture and rehabilitate it in the wild (i.e., release it in its original habitat or translocate it to an alternative habitat).

Option-2: Capture and retain it in captivity, if the CWLW has reasons to believe that Option-1 is not viable.

Option-3: Kill it, if the CWLW has reasons to believe that Options-I and 2 are not viable.

1.4. The WPA-1972 [S.11(1)(b)] does not put any riders on the strategies for dealing with animals belonging to Sch.II/Sch.III/Sch.IV posing threat to human life or indulging in destruction of crops, livestock, houses, etc. It is, however, advisable to follow the options meant for Sch.I animals as cited above.

1.5. The NTCA's SOP (2013) recommends that a tiger/leopard involved in attack on humans (including human-eaters) should not be released in the wild but sent to the nearest recognized zoo. It recommends killing of a human-eating tiger/leopard only after exhausting the option of capturing it alive. The MoEFCC's Guidelines (2011) stipulate that no leopard captured after a deliberate attack on a human (including human-eaters) should be released into the wild. It goes

on to recommend euthanizing a human-eating leopard even when captured. For other animals, the following approach may be considered:

A. No animal involved in deliberate attack on humans (including human-eaters) should be considered for Option-1 (capture and rehabilitate).

B. An animal should be considered for Option-2 (capture and retain) if involved in a single incident of deliberate attack on humans and for Option-3 (kill) if involved in multiple incidents of deliberate attack on humans.

1.6. Option-3 (kill) may be exercised straightway for any wild animal (irrespective of the schedule) in the following cases:

1.6.1. S.11(2) permits killing / injuring of any wild animal in defence of oneself or any other person. This is particularly the case when a wild animal is suspected to be rabid or when it is on a killing-spree and immediate trapping / immobilization of the animal is not possible.

1.6.2. S.11(1) permits killing of any wild animal when it is so disabled or diseased as to be beyond recovery.

1. 7. The wild animals listed under Sch.II /Sch.III /Sch.IV involved in destroying crops or killing livestock should first be considered for Option-1 (capture and rehabilitate) and then for Option-2 (capture and retain). Though S.11(1)(b) also permits Option-3 (kill) in such cases, yet this option should be exercised only sparingly and not until the CWLW /AO has caused an enquiry and come to the conclusion that all reasonable alternative options to protect crops / livestock have been exhausted. The permission in such cases should be given only for killing a limited number of animals for a limited period of time and hunting should be carried out by the hunters engaged by the FD. As far as practicable, only the animals known to be habitual crop-raiders / livestock-killers should be targeted for killing. Option-3 (kill) should not be exercised in respect of wild animals categorised as ‘Threatened’ in the IUCN Red List for involvement in crop-raiding / cattle-killing.

1.8. Before exercising Options-1 (capture and rehabilitate) and 2 (capture and retain), a veterinarian must examine the animal and certify its fitness. The animal should be given treatment for the wounds, if any, suffered during capture. If, however, the animal suffers from zoonotic diseases or wounds which cannot be healed, it should be subjected to Option-3 (kill) through euthanasia. The NTCA’s SOP (2013) stipulates that an injured / incapacitated tiger should not be released back, and the same should be sent to a recognized zoo.

1.9. Abandoned wild cubs /calves which cannot be reunited with their mother should straightway be considered for Option-2 (capture and retain) and sent to a designated Rescue Centre.

1.10. Option-1 (capture and rehabilitate) provides a choice between releasing the animal in its original habitat and translocating it to an alternative habitat. The MoEFCC’s guidelines (2011) recommend that a captured leopard should be released into its home range. A similar policy should normally be followed in respect of all other wild animals.

1.10.1. In some cases (e.g. bull elephants straying long distance from their home range), it may not be possible to ascertain the original habitat of the animal which should, therefore, be translocated to any appropriate habitat.

1.10.2. In some cases, the tolerance level of the local public for an animal may be very low, and there may be no choice but to translocate the animal to a new habitat.

1.10.3. If, after local rehabilitation, the animal does not settle down peacefully in its original habitat and continues to come into conflict with the humans, it should be recaptured and translocated to an alternative habitat—subject to its fitness from veterinary angle.

1.11. If suitable area for translocation is not available (Ref. Para 3.7.6), the animal should be considered for Option-2 (capture and retain).

1.12. If adequate logistics for translocation are not available (for example, translocation of a big groups of elephants and blue bulls), animals may be considered partly for translocation and partly for retention in captivity. However, as far as practicable, entire family groups / social groups should be selected for translocation.

1.13. If, after translocation, the animal does not settle down peacefully in its new habitat, returns to its original habitat, or continues to indulge in conflict with the humans, it should be recaptured and considered for Option-2 (capture and retain).

1.14. Disposal of animals captured under Option-2 (capture and retain) is an important matter and should, preferably be decided by the CWLW in advance.

1.14.1 A captured animal should be kept provisionally in a designated Transit Facility till suitable instructions from the CWLW for its final disposal are received.

1.14.2. In case of an elephant, if it is amenable to training, it should be trained and put to departmental use.

1.14.3. If the animal is in demand by a recognised zoo, it may be sent there with the approval of the CWLW and the CZA. The NTCA's SOP (2013) stipulates that a tiger involved in attack on humans (including human-eaters) should be sent to the nearest recognized zoo.

1.14.4. In other cases, the animal will have to be kept in a designated Rescue Centre for life.

1.14. Along with managing the problem animals, the FD should also try to address the factors which lead to HWC and strive to enhance the tolerance level of the people towards wild animals.

2. Barriers and Watch Towers

2.1. Barriers and watch towers may be constructed either by the FD or by the stakeholders themselves. The DLC and ADS should keep a tab on all barriers being constructed by the FD or any other agencies to ensure that the same do not obstruct a wildlife corridor or divert the conflict to new areas. It may be enough to put a barrier around only the sensitive sectors, labour colonies and hamlets rather than enclosing the entire forests. Moreover, razor-wire fences are harmful to wild animals and should be discouraged.

2.2. All new barriers (trench/ wall /fence/power-fence) and watch towers should be planned with due regard to the seriousness of the conflict; nature of the wild animal; and soil and weather conditions. Power fences should be designed in accordance with the WII's 'Manual on Power Fencing for Wild Animals' (Chauhan, 2010). Guidelines for designing trenches and rubble walls are also available in the WII's 'Manual of Wildlife Techniques for India' [Sale & Berkmuller (eds), 1988]. Designs for construction of Crocodile Exclusion Enclosures are available on the website of the IUCN /SSC Crocodile Specialist Group (<http://www.iucncsg.org>).

2.3. The site and the design of the barrier being constructed departmentally should be approved by an officer not below the rank of a DFO (or an ACF holding post-graduate diploma from the WII). A cost-benefit analysis should be carried out before initiating the construction to ensure that the estimated expenditure on the barrier is commensurate with the financial losses it is meant to curtail. In many cases, regular payment of ex-gratia relief to the victims of conflict may be a cheaper option than to invest heavily on a barrier.

2.4. It is extremely important to protect and maintain the barriers to take their full and sustained advantage for containing HWC.

2.4.1. The concerned stakeholders should be taken into confidence before undertaking the construction of a barrier/watch tower departmentally. They should be encouraged to form a LWS for protection and maintenance of the barrier/watch-tower before the construction starts.

2.4.2. If the financial rules so permit, the construction work (at least the labour component) should be done by engaging the stakeholders. This is to give them a sense of belonging to the barrier /watch tower.

2.4.3. The power fences should preferably be constructed by using local resources and the LWS should be given training and equipment for monitoring the voltage and carrying out minor repairs.

2.4.4. While designing barriers, suitable number of inlets may be provided for meeting the bonafide requirements of the stakeholders.

2.4.5. The ADS and LWS should visit the old barriers and watch towers before the conflict season and get them into working condition. Thereafter, the LWS should look after the barrier / watch tower and try to maintain their efficacy.

2.5. Owners of commercial farms and tea / coffee estates should be persuaded to erect their own power-fences. Wherever possible, small and poor cultivators having adjacent lands should be encouraged to form a co-operative. The FD / district administration should supply energiser and other essential materials to the co-operative and also arrange training for erecting the fence. The co-operative should be asked to provide labour and undertake maintenance works. This will bring down the cost and also encourage the farmers to have a stake in the upkeep of such fences. The fences can be erected before the crop attains maturity and dismantled once the crop has been harvested and removed from the field.

3. Capture of Wild Animals

3.1. General:

3.1.1. Capture of wild animals for the purpose of conflict management by trapping /netting or chemical immobilization should preferably be carried out by the ADS, forest staff or by the experts engaged by the FD. In case, any other agency (e.g. Municipal Corporation, Panchayat, NGO or any other stakeholder) has been permitted by the CWLW /AO to capture problem animals, it must be ensured that the said agency has the experts capable of carrying out capture operations safely and in accordance with the provisions of law.

3.1.2. Whatever be the method selected for capture of a wild animal, all possible care should be taken to ensure the safety and welfare of the animal and avoid all unnecessary cruelty. The term ‘cruelty’ has not been defined in the PCA-1960, but S.11(1) of the said Act describes certain acts of omissions and commissions in respect of animals which are punishable under the Act. These include:

- Subjecting any animal to beating, kicking, and torturing.
- Depriving any animal of sufficient food, water or shelter.

- Confining any animal to a cage which does not permit it a reasonable opportunity of movement.
- Keeping any animal chained or tethered for an unreasonable time or in unreasonable manner.
- Conveying or carrying any animal in such a manner as to subject it to unnecessary suffering.
- Wilfully and unreasonably administering an injurious substance to any animal.

3.1.3. Prevention of Cruelty (Capture of Animals) Rules, 1972 also prohibits capture of animals except by ‘Sack & Loop method’, tranquilliser guns or any other method which renders the animal insensible to pain before capture.

3.1.4. As far as practicable, entire family group / social group of animals should be selected for capture.

3.1.5. To take maximum advantage of capture, the animals known to be indulging habitually in HWC or those playing a major role in HWC (e.g. unattached elephant bulls, alpha-monkeys, etc.) should form the main targets of capture.

3.1.6. Capture of wild animals from an area may often lead to influx of new set of individuals to occupy the vacant territory— thus restoring the conflict level. There should be a supplementary strategy in place to prevent this influx by suitable means (e.g. putting barriers strategically; engaging watchers to keep the intruders away; capturing the animals both from the source and the sink populations, etc.). Help of an experienced wildlife biologist may be taken to address this issue while planning the capture operation.

3.2. Trapping and Netting:

3.2.1. Wild animals (except mega-herbivores like elephants, gaurs and rhinos) can be captured by using traps or nets.

3.2.2. Help of professional trappers may be necessary for capture of certain wild animals (e.g. monkeys, crocodiles, etc.) if in-house expertise is not available.

3.2.3. Trap cages should be properly designed keeping the target animal in mind. Cages should be strong and lightweight so as to cause minimum injury to the animal and facilitate transportation of the captured animal. Fiber-glass cages with holes for ventilation are ideal.

3.2.4. For trapping carnivores, thick chain-links should be preferred to iron rods to minimize the risk of the animal damaging its canines. Cages with rusty iron rods should be avoided. Trap cage should not have any artificial padding made of rubber or any synthetic material which the animal may rip off and eat.

3.2.5. Some allurement may be necessary for trapping wild animals. Baiting in the form of goats, dogs, domestic fowl, etc. is useful for alluring a carnivore to the trap.¹² Similarly, bananas, maize or grams may be used for alluring monkeys to the trap cage.

3.2.6. Cases of local people killing or injuring trapped animals in anger are not uncommon. Therefore, a LWS or ADS or any other reliable agency should take the responsibility of monitoring the trap and protect the trapped animal.

3.3. ***Mela-Shikar***: *Mela-Shikar* method can be used for capturing wild elephants if experienced *phandis* and trained *kunki* elephants are available and the objective is to scare away wild elephants from a given area for a long period. A variant of *Mela-Shikar* involves chasing a herd without any capture. Another variant involves capturing a calf/sub-adult elephant temporarily and releasing it at a safe distance. *Mela-Shikar* can also be used for capturing wild elephants in combination with chemical immobilization when only Xylazine is available as a drug.

3.4. Chemical Immobilization:

3.4.1. Chemical immobilization is a convenient way to capture almost all kinds of wild animals on land and should be preferred whenever a team of experts with appropriate drugs is available. In particular, presence of a qualified veterinarian and availability of the antidotes in adequate quantity must be ensured before undertaking a chemical immobilization exercise. General guidelines for chemical immobilization of wild animals are available in the WII's 'A Guide to

¹²Some forest staff and animal activists wrongly believe that baiting of live animals is prohibited under the PCA-1960. S.11(1)(m) of the PCA-1960 prohibits baiting for the purpose of entertainment and not for managing the HWC.

the Chemical Restraint of Wild Animals [Chowdhury & Malik, 1992]. Specific protocol for chemical immobilization of tigers has been prescribed by the NTCA (2013).

3.4.2. Chemical immobilization may be used along with traps to capture an entire group of monkeys, Chital or Nilgai.

3.4.3. If the *kunki* elephants are available and the terrain is favourable, they should be used for darting of large carnivores (e.g. leopards and tigers) and mega-herbivores (e.g. elephants, gaurs and rhinos). *Kunki* elephants should also be used for restraining and shifting a wild elephant after chemical immobilization.

3.4.4. MoEFCC's guidelines (2011) advise against chemical immobilization of leopards in the open since a darted animal in the open can retaliate and injure people. A similar precaution may be taken in respect of other carnivore species.

3.4.5. While carrying out chemical immobilization of dangerous animals like elephants, tigers, leopards, etc., hunters carrying suitable firearms should be engaged to provide protection and backup support to the immobilization team.

3.4.6. Wherever possible, chemical immobilization should be preferred over shooting to kill a proclaimed wild animal.

3.5. Handling Captured Animals:

3.5.1. The captured animals should not be put on display and no one should be permitted to tease or disturb them. The cage should be covered with tarpaulin with suitable provision for ventilation. The chemically immobilized animal should also be shifted to a cage and covered.

3.5.2. The animal should be treated for injuries in the field itself if a veterinarian is at hand (which must be the case for a chemically immobilized animal) or shifted immediately to a designated Rescue Centre / Transit Facility and examined by a veterinarian. The animal should be photographed. Its morphometric parameters should be recorded and it should be fitted with identity marks (e.g. microchip, ear-tag, colour-coded collars, etc.).

3.5.3. The animal intended to be treated under Option-1 (capture and rehabilitate) should be housed in a designated Transit Facility with minimum exposure to humans. The MoEFCC's guidelines (2011) recommend that if a leopard has been kept in captivity for more than a month, it should not be released back into the wild. A similar policy may be adopted for other carnivore species.

3.5.4. The animal should also be screened for zoonotic diseases. The animal should be released in the wild only if the veterinary doctor is satisfied that it is medically fit and does not suffer from any zoonotic disease. If, however, the animal is found to be suffering from a contagious disease or a disabling wound which cannot be healed, it should be considered for euthanasia in accordance with S.11(1). The animal intended to be treated under Option-3 (kill) should straightway be subjected to euthanasia.

3.5.5. The animal meant to be treated under Option-2 (capture and retain) should be sent to a designated Rescue Centre (or to an elephant camp if the captured animal is an elephant).

3.5.6. The captured animal at the Transit Facility / Rescue Centre should not be kept inside the trap cage for more than a week and should be shifted to a larger enclosure as per specifications fixed by the CZA.

3.6. Transport of Captured Animals:

3.6.1. A captured animal may be transported over a short distance in the trap cage itself. However, for transporting animals over long distances, guidelines given in the CZA's 'Protocols for Transportation of Wild Animals' [Bonai et al (eds), 2012] should be followed. Attention should also be paid to Rules 15-45 of the Transport of Animals Rules, 1978 relating to the transport of monkeys.

3.6.2. The animal should be transported in a stress-free environment without exposure to public. The transport vehicle should be sanitised before and after shipment. The animal should not be exposed to direct sunlight or cold wind during transportation. The persons handling the animal during transit should strictly observe personal hygiene.

3.6.3. A registered veterinarian should accompany the animal being transported over long distance. The animal's health condition should be frequently checked during transit and it should

be immediately treated for sickness or injury, if any. The animal may be sedated during the journey if so advised by the veterinarian.

3.6.4. Safety of the animal and human-beings during transportation should be given utmost importance.

4. Rehabilitation and Translocation:

4.1. Release of a captured wild animal in its original habitat should generally be the rule, but there may be exceptional cases when either the captured animal should not be released at all (Ref. Paragraphs 1.5, 1.8, 1.9, 1.11 and 1.13) or it should be translocated to a new habitat (Ref. Paragraphs 1.10.1, 1.10.2 and 1.10.3).

4.2. As far as practicable, entire family group /social group should be selected for translocation.

4.3. Physical fitness and freedom from zoonotic diseases should be the prerequisite of any rehabilitation programme for any wild animal whether in its original habitat or at a new habitat.

4.4. Rehabilitation of wild animals captured by other agencies (e.g. Municipal Corporation, Panchayat, NGO or any other stakeholder), should only be carried out at a site and in a manner approved by the DLC.

4.5. Photographic / Videographic evidence of the release of the animal should be kept.

4.6. Site selection for Translocation:

4.6.1. Translocation of problem animals often fails inasmuch as the released animals tend to return to their original habitats or add to the conflict at the new site. Selection of site for

translocation of different wildlife species is, therefore, very important and should be carried out by a technical committee comprising experienced forest officers and wildlife biologists with a provision for co-opting representatives of the local stakeholders. The committee should also recommend the maximum number of animals of a particular species that may be released in a potential site.

4.6.2. The following considerations will be helpful in selecting the translocation sites:

- A. The release site must be at a suitable distance from the capture site to minimize the probability of the animal returning to the capture site. In case of elephants, it has been suggested that the relocation site should be ‘3-4 times the Home Range’ distance away from the capture site.¹³
- B. Some assessment of the carrying capacity of the potential site is necessary. Translocation should not lead to overpopulating the site, resource-crunch and intra-specific competition. Some indication of the carrying capacity of the potential site can be had from the current size of the resident population of the animal in question, current level of dispersal (straying), current level of conflict of the animal with humans in the surrounding areas, body condition of the resident animals, and signs of habitat deterioration, if any.
- C. The NTCA (2013) recommends that a healthy tiger in prime or young age without any incapacitation may be released after radio collaring in a ‘suitable habitat with adequate prey base, away from the territory of a resident male tiger (if any) or human settlements’, under intimation to the NTCA. It also recommends release of an encumbered tigress release in ‘low density area of a nearby tiger reserve/PA’. Similar precautions need to be taken in respect of other animals showing territorial behaviour.
- D. The level of threat to the translocated animal at the release site on account of poaching, poisoning, electrocution, train/vehicular traffic, etc. should also be assessed in advance. An area with a previous history of poaching or retaliatory killing of the wild animal in question does not make an ideal site for translocation.
- E. It should be assessed if translocation will lead to significant escalation of HWC in the region, and, if so, whether resources will be available to neutralise this escalation.
- F. It should be ensured that translocation does not lead to spread of communicable diseases among the resident population.
- G. Genetic compatibility between the translocated and the resident population of the animal should be ensured.
- H. It is important to assess the current level of tolerance of the local people towards the animal in question; how the translocation will impact this level; and whether resources will be available to offset any negative impact.
- I. Capacity of the local forest staff to protect, manage and monitor the translocated animal is an important factor.

¹³ Ajay Desai (pers. Comm.)

4.6.3 The potential sites for translocation should be selected much before the conflict season and made known to the DLC and ADS.

4.7. Monitoring:

4.7.1. Monitoring of the translocated animal is very essential to judge the success of rehabilitation. Frequent straying of the animal or increase in the levels of HWC at the rehabilitation site should serve as a notice for the FD to review its translocation strategy.

4.7.2. The animals should be fitted with identity marks (microchips, ear-tags, colour-coded collars, etc.). NTCA (2013) has recommended radio-collaring of tigers before release. MoEFCC (2011) has recommended that radio-collars should be put on a sub-set of the released leopards to monitor post-release movements and survival. It has also recommended involvement of scientists and experts in the radio-tracking of the released leopards. A similar policy should be adopted for all other Sch.I animals.

5. Population Management:

5.1. Overabundance of certain species in some localities may add to the HWC levels. Population management in such areas may be regarded as a tool for HWC management. The WPA-1972 provides two legal tools for population management of a particular species of animal: by declaring it to be vermin (S.62) or by permitting its hunting for the purpose of scientific management (S.12).

5.2. Declaration of the wild animal as vermin: Under S.62, the Central Government may declare a wild animal belonging to Sch.II (Part-I), Sch.III and Sch.IV as vermin (i.e. a species under Sch.V) for a specified area and for a specified period. Declaring a wild animal as vermin is a drastic measure as it withdraws all legal protection to the animal in question (except inside PAs) and gives a blanket permit to the public at large to destroy the animal. Before submitting a proposal to the Central Government under S.62, the CWLW should get the matter examined by a technical committee comprising experienced forest officers and eminent wildlife biologists and also seek approval from the SBWL in accordance with S.8(c). The CWLW should also ensure that all reasonable alternative tools available with the FD for mitigating the HWC have been tried and exhausted before mooted the proposal. An extra care should be taken while submitting a proposal under S.62 for a wild animal categorised as ‘Threatened’ in the IUCN Red List.

5.3. Scientific Management:

5.3.1. Under S.12, CWLW may permit hunting of a wild animal listed in Sch.I (with the previous permission of the Central Government) and Sch.II/Sch.III/Sch.IV (with the previous permission of the State Government) for scientific management. Scientific management includes translocation of any wild animal to an alternative suitable habitat and also population management (without killing or poisoning the wild animals).

5.3.2. S.12 precludes the use of Option-3 (kill) but permits the use of Option-1 (capture and translocate) and Option-2 (capture and retain) for scientific management. It provides the scope for exercising yet another option, viz. fertility control of the wild animal population (Option-4).

5.3.3. S.12 permits the use of Option-1 (capture and translocate), Option-2 (capture and retain) and Option-4 (fertility control) for dealing with Sch.I animals indulging in crop-raiding or cattle-killing which is not possible under S.11(1)(a). S.12 also provides a convenient alternative to S.62 for dealing with Sch.II/Sch.III/Sch.IV animals indulging in depredation inasmuch as the permission of the Central Government is not required and no blank permit for hunting needs to be given to the public at large.

5.3.4. Although S.12 authorises the CWLW to permit hunting for scientific management to any person, yet it is advisable that only the FD or the experts engaged by it carry out the desired operations.

5.3.5. This being an exercise meant for scientific management, the CWLW should get the matter examined by a technical committee comprising experienced forest officers and eminent wildlife biologists. The committee, in particular, should address the following points:

A. It should establish that there is an ‘overabundance’ of the wild animal in question which needs to be managed.

B. It should establish that overabundance is leading to HWC which cannot be addressed only by the existing tools available with the FD.

C. It should provide justification for the number of animals proposed to be captured /translocated/brought under fertility control and the projected impact on the population.

D. It should justify the choice of Options-1, 2 or 4 proposed to be used for scientific management. If Option-1 (capture and translocate) is proposed to be used, the suitability of the alternative habitat should be established (Ref. Para 3.7.6)

5.3.6. Fertility control in free-ranging wild animals is still an evolving subject in India. The FD in Himachal Pradesh has set up Monkey Sterilization Centres for fertility control in rhesus macaque— results of which are not officially known. Zoos usually practise fertility control in captive animals by segregating the male and female populations or by castrating the males. It is advisable to take up a fertility control programme in collaboration with the Veterinary Department and /or a reputed scientific institute.

5.3.7. The FD should have support from the chemical immobilisation team and veterinarians for implementing the programme. Availability of *kunki* elephants and experienced mahouts is necessary if wild elephant is the target animal. Involvement of scientists and experts is advisable for carrying out translocation and subsequent tracking of animals.

5.3.8. The CWLW should take approval from the Central Government / State Government before going ahead with the programme.

Section-3

Dealing with Different Conflict Scenarios

1. Wild Animals Living Within Human Settlements

It is not unusual for some wild animals (e.g. Rhesus Monkeys, Common Langurs, Jackals, Common Civets, Rock Pythons, etc.) to be living within human settlements. The management of these animals would depend upon their potential to cause harm vis-à-vis existing levels of conflict and the threat perceptions of various stakeholders.

1.1. Ordinary Complaints: In ordinary cases (e.g. mere sighting of a wild animal, killing of pets or poultry by a wild animal, etc.) the following action by the FD should be sufficient:

1.1.1. The DLC should take action to monitor the population and distribution of such wild animals from time to time and submit a proposal to the CWLW for population management under S.12 if their overabundance becomes a cause of concern (Ref. Sec. 2, Para-3.8).

1.1.2. The DLC should initiate suitable education and awareness programme based on periodic meetings and publicity material aiming at diluting the threat perception of the stakeholders and also to persuade the concerned authorities and stakeholders for undertaking precautionary measures, particularly in respect of protecting poultry, fruit trees and other assets; and proper disposal of garbage and left-over food.

1.1.3. A Sch.I animal like Rock Python needs to be protected against harm and should be considered for Option-1 (capture and translocate) or Option-2 (capture and retain) depending upon the advice of the veterinarian.

1.2. Wild Animals Causing Nuisance Within Sensitive Locations: Wild animals sometimes cause disruptions within Airport runways, army depots, hospitals, schools, office buildings, ration-shops / food godowns, etc. The following sequence of action may be followed for dealing with such complaints:

A. The DLC should arrange for a safety audit of the location by a team of experts / experienced officers to advise the stakeholders suitably. Quite often the problem can be addressed by advising the stakeholders to adopt either one or a combination of the following measures:

1. Plugging the entry points of the wild animal.¹⁴
2. Using properly designed barrier (trench or wall) or fence (including power fence)¹⁵ or a combination of the two to prevent the incursion of wild animals into a sensitive area.¹⁶

¹⁴For example, use of wire-nets on windows and ventilators of houses for denying entry to civets.

3. Preventing access of wild animals to garbage and other sources of food.
4. Using ultrasonic-sound devices to repel the wild animals.
5. Engaging guards with simple scaring devices (e.g. catapult, crackers, airguns, etc)¹⁷.

B. If, however, the problem persists despite all reasonable steps having been taken by the stakeholders, the ADS should be engaged for removing the problem animals from the scene, by using the following measures:

1. Locating the burrows / dens inhabited by the animals in question and closing them down.
2. Chasing / driving away the group of animals in question aggressively and regularly for some days (say a week) until they are discouraged from coming back.

C. If, however, the ADS is unable to control the problem by the above means, the animals in question should be considered for Option-1 (capture and translocate) or Option-2 (capture and retain) depending upon the advice of a veterinarian and with due permission from the CWLW /AO.

1.3. Wild Animals Causing Physical Harm To Humans: In case of wild animals attacking/injuring / killing human-beings, detailed guidelines given in Section- 4 should be followed.

2. Wild Animals Straying Out From Their Natural Habitats¹⁸

2.1. General Observations:

2.1.1. Wild animals do stray out of their natural habitats for various reasons and often get stranded. Some animals (e.g. leopards and elephants) are known to stray much more than the others. Mere sighting of a wild animal outside forests does not necessarily mean that it should be captured. But straying of wild animals cannot be ignored altogether because it may cause accidental encounters with people and also lead to panic in some areas.

2.1.2. Action in the matter depends on the following factors: whether the animal is involved in attack on humans; whether it can return to its habitat on its own; whether it has a record of straying frequently; the degree of threat to its safety outside its habitat; and degree of threat it poses to humans outside its habitat.

2.1.3. A common element in all the strategies discussed in the following paragraphs to deal with strayed wild animals is the crowd management (Ref.Sec.8, Para 2)) and safety of the local people. The effort of the ADS and LWS should be to keep the people and dogs at a safe distance from the site and to forewarn the people living on the expected escape route of the animal.

¹⁵ Razor-wire fences are harmful to wild animals and should not be recommended. Chain-link fences or woven-wire fences are usually safe and effective.

¹⁶ Suitably designed Crocodile Exclusion Enclosures can be used to keep crocodiles off from bathing/washing ghats along banks of rivers / lakes.

¹⁷Trained langurs may often help in keeping problem monkeys at bay from strategic locations.

¹⁸NTCA's SOP (2013) deals exclusively with straying of tigers and leopards and MoEFCC's Guidelines (2011) deal exclusively with straying of leopards.

Armed Policemen and forest staff should be deployed at strategic points. Nets made of Nylon or Jute should be used as a shield to protect people from sudden bursts from the carnivores. A row of volunteers holding *mashaal* (lighted torches) can provide an effective shield for the people and also prevent the animal from taking a wrong route.

2.2. Wild Animals Stranded in Open Areas

2.2.1. The first priority in respect of wild animals stranded in open areas (e.g. agricultural fields, tea gardens, orchards, open streets, etc.), not far away from their natural range, should be to let them escape on their own. As stated above, the ADS and LWS should keep the people and dogs at a safe distance from the site, prevent all disturbances to the wild animals, and keep a safe passage open for them towards the forests. In most cases, the animals in question would retreat under the cover of darkness. Sometimes, a little prodding from the squad may also be needed.

2.2.2. Services of *kunki* elephants should be used, if available, to drive wild elephants, gaurs and rhinos to safety. Experienced mahouts can also use *kunki* elephants for chasing away tigers and leopards from open areas adjoining forests. In South West Bengal, professional teams of elephant-chasers (locally known as *Hulla*-parties) often help the FD. These teams are also sometimes invited by the FDs of Jharkhand and Odisha.

2.2.3. If, however, local circumstances do not permit safe passage to the wild animal in question, it should be considered for Option-1 (capture and rehabilitate) or Option-2 (capture and retain) depending upon the veterinary advice with due permission from the CWLW /AO.

2.2.4. Some deer /antelopes may stray too far away to return on their own and may also face danger from country dogs and unscrupulous people. Such animals should be considered for Option-1 (capture and relocate) or Option-2 (capture and retain) depending upon the veterinary advice.

2.2.5. Crocodiles are known to stray into village ponds and agricultural fields and pose great threat to humans and livestock. They should be considered for Option-1 (capture and rehabilitate) or Option-2 (capture and retain) depending upon the veterinary advice.

2.3. Wild Animals Stranded in Closed Areas, Wells, Pits etc.

2.3.1. If a wild animal is stranded in closed areas (e.g. house, garage, factory, cattle-pan, etc.) and not likely to escape in the night, it should be considered for Option-1 (capture and rehabilitate) or Option-2 (capture and retain) depending upon the veterinary advice.

2.3.2. Wild animals often fall into wells, pits or ponds and cannot come out. The animals can be rescued and allowed to escape by draining out water and levelling out the walls with the help of JCB machines.

2.3.3. The MoEFCC's guidelines (2011) recommend the use of ladder in dry wells to help leopards climb out. In Gujarat, a trained forest staff is lowered into the dry well inside a cage with equipment to tranquillise the leopard and bring it out.

2.4. Wild Animals On Roads

2.4.1. It is not unusual for wild animals to come on public roads passing through or close to forests. The wild animals are susceptible to being run over by fast moving vehicles. Some of the wild animals (e.g. elephants, gaurs, leopards, tigers, etc.) also pose threat to the safety of pedestrians, cyclists, motor-cycle riders and even the persons travelling by light and heavy vehicles, leading sometimes to a panic situation.

2.4.2. The management of HWC on roads is guided by the principle that 'The wild animals have the first right of way'. The conflict should be managed by identifying the sensitive section of the road and regulating the movement of people and vehicles—the degree of regulation being determined by the kind of wild animals involved, seasonality of conflict and the seriousness of the problem as indicated by the past records. The regulatory measures may include one or more of the following:

1. Putting warning signs at appropriate points.
2. Putting a ban on pedestrians, cyclists and riders of scooters / motor-cycles except during the day time.
3. Putting a speed limit on vehicles.
4. Providing speed-breakers at appropriate points on the road.
5. Prohibiting night-time vehicular movement during certain months of the year.
6. Allowing night-time vehicular movement in convoys only escorted by the armed police/ forest-staff.
7. Prohibiting people from feeding wild animals on the road.

2.4.3. Reducing the height of the lane-dividers and illuminating the sensitive stretch of the road with strong halogen lamp-posts may also be helpful in reducing the level of conflict.

2.4.4. It is necessary to seek permission and cooperation from the district administration and the Police for enforcing the requisite regulations on a public road. It is also necessary to seek public cooperation through educational and awareness programmes.

2.5. Pregnant Animals

2.5.1. Wild animals (e.g. leopards and tigers) sometimes take shelter in tea / coffee estates, sugar-cane fields or some other bushy areas outside forests during their breeding period. Usually there is a past history of such incidents and the concerned stakeholders should be forewarned before the breeding season and advised to exercise due precautions. They should be advised to remove stray dogs and loose livestock and ensure proper disposal of garbage and left-over food to deny easy availability of food to the animal.

2.5.2. Attempts to send a pregnant female animal back to forest may be made by the ADS or *kunki* squad as long as she has not delivered. But a mother animal with cubs / calves should not be disturbed. The LWS should be engaged to secure the area and monitor the animal till she has left the place on her own.

2.6. Abandoned Wild Cubs / Calves

2.6.1. The people / forest staff should be discouraged from 'rescuing' wild cubs / calves found in the vicinity of forests without mother. All such 'rescued cubs / calves' should be released back immediately at the same site from where they were picked up. An elephant calf should be released in the close vicinity of the nearest elephant herd. A reasonable opportunity should be given to the mother to reclaim her cubs / calves. The LWS should be engaged to secure the area and monitor the cubs / calves from a safe distance. A camera trap, if available, should be placed near the release site for conforming the reunion of the mother and her cubs / calves.

2.6.2. If, however, the reunion does not take place within a reasonable period (say, one night), the cubs / calves should be captured and immediately removed to a designated Rescue Centre.

2.7. Injured Wild Animals

Any stranded wild animal found to be carrying serious injuries should be captured (trapped / immobilised) and removed to a designated Transit Facility for treatment. It may be released back in the wild depending upon the veterinary advice. However, carnivores kept in a Transit Facility / Rescue Centre for more than 30 days should not be released. (Ref. Sec. 2, Para 3.5.3)

2.8. Wild animals involved in attack on humans

Guidelines given in Section-4 should be followed in such cases.

2.9. Wild Animals in the Habit of Straying

If the records of the ADS reveal that a particular wild animal released in a nearby habitat has been straying frequently, it should be considered for Option-1 (capture and translocate) or Option-2 (capture and retain) depending upon the veterinary advice.

2.10. Preventing Straying of Wild Animals

2.10.1. Suitably designed barrier (trench/wall) or fence (including power fence) or a combination of the two should be recommended to the stakeholders for preventing the straying of wild animals into strategic locations (e.g. army camps, schools, electric sub-stations, FCI godowns, etc.) situated on the fringe of forests. Strong halogen lamp-posts along the periphery with the forests are also useful to deter most of the wild animals. Arrangement should also be made for suitable disposal of garbage and left-over food

2.10.2. The FD may have to take similar measures as above for preventing the incursion of wild animals into villages suffering high levels of depredation involving loss to human life and livestock. In the Sundarbans, FD has been using Nylon-net fences to prevent straying of tigers into villages.

2.10.3. Guidelines given in Section 2 (Para 2) for barriers and fences should be followed.

Section-4

Dealing with Human Deaths and Injuries

1. **Quick Response:** As soon as information about a wild animal attacking and injuring / killing human-beings is received, the ADS and HWLW should rush to the spot.

2. **Medical Help and Post-Mortem:** The injured persons should be provided with immediate medical help. Arrangements should be made with the help of the Police for post-mortem of the dead.

3. **Relief to the Victims:** Necessary help should be provided to the injured persons / dependents of the dead persons for claiming ex-gratia relief from the competent DFO. Where the rules so permit, part of the ex-gratia relief should be made available to the victims or their dependents immediately without waiting for the official formalities. In deserving cases, additional relief in the form of livelihood support, food-grains, camping material, tools and implements, etc. should be arranged for the victim or his family with the help of the district administration and philanthropic organisations.

4. **Inquiry:** The ADS should conduct an inquiry to establish the identity of the animal in question and to ascertain the circumstances of the conflict.

4.1. **Identification of the Problem Animal:** Since only a few of the locally occurring species of wild animals may be capable of attacking humans, it may not be a problem to find out which species is involved in a particular incident. But pinpointing a particular individual responsible for the attack may not be an easy task and need some investigative skills.

A. The footprints left by the animal at the place of occurrence are usually helpful. It is useful to make plaster-casts / tracings of the pugmarks left by a carnivore in the field and record such parameters as the length and breadth of the pugmark and stride of the animal. The presence of small pugmarks along with large pugmarks may be suggestive of a mother animal with cub. The footprints of an elephant can give an idea about the height of the animal.¹⁹ The eye-witnesses may provide some additional details about the size and shape of the tusks of the elephant and any other peculiarity on its body (e.g. a cut-tail, broken-tusk, injury mark, etc.).

B. Samples of scat / dung, blood, hair or any other body part of the animal, if found in the field, should be sent to a suitable research laboratory for DNA profiling of the animal which is a fairly reliable way of ascertaining the identity of the animal.

C. A comparison of the pugmarks of a tiger / leopard collected from the place of occurrence with the records of the previous census may also give some idea about the identity of the animal.

¹⁹ Double the circumference of the front foot of an elephant will give its approximate height.

D. The NTCA's SOP (2013) has recommended fixing camera traps near the site of incident to get photographs of the tigers active in the area and to compare it with the National Repository of Camera Trap Photographs of Tigers (NRCTPT) or the database of the nearby Tiger Reserve to establish the identity of the tiger and find out the source area of the animal.

4.2. Circumstances of the Conflict: The circumstances of the conflict may be ascertained by recording the evidence of the witnesses, observing the injuries / condition of the corpse, and inspecting the place of occurrence. The objective is to find out whether the alleged attack by the animal in question was accidental or deliberate.

4.2.1. Some Indicators of a Deliberate Attack: Any one of the following actions may be an indicator of a deliberate attack by a wild animal:

- A. The animal (a carnivore) stalked the victim before attacking him.
- B. The animal (a carnivore) lifted and carried away the victim from the place of attack.
- C. The animal (a carnivore) attacked persons sleeping outside their houses.
- D. The animal (a carnivore) ate away a part of the corpse.
- E. The animal (an elephant) chased the victim over a considerable distance before attacking him.
- F. The animal (an elephant) tore apart the corpse and threw the pieces over a large area.
- G. Same animal (a carnivore /an elephant) chased/attacked two or more persons in nearby locations within a short span of time (same day /same week).

4.2.2. Some Examples of Accidental Attack:

- A. A wild animal may attack a person while being chased / driven.
- B. People walking through forests or collecting NTFPs may also have chance encounters with wild animals.
- C. A leopard (usually a pregnant leopardess) often takes shelter in the drains in the tea gardens and may attack a party of labourers plucking tea-leaves and advancing towards it. Similar encounters may take place between farmers and tigers in sugar-cane fields close to forests.
- D. A wild elephant may break into a house in search of food-grains / country-liquor and the residents may be crushed under a wall or roof. People often get injured while running helter-skelter in nervousness when a wild elephant is around. A bull elephant in *musth* may also behave erratically and chase people and cattle.
- E. Photographers often get killed / injured while trying to approach a wild animal close enough to take a good shot.
- F. An intoxicated person is often unable to steer clear of an approaching wild animal and get injured / killed in the process.

4.3. Dossier: ADS/DLC should maintain a dossier of animals involved in attack (both deliberate and accidental) on humans containing all available information about the animal and its victims. Whenever a fresh incident takes place, the information collected about the animal should be compared with that in the dossier to ascertain whether the same animal is involved in more than

one incident and, therefore, a habitual offender. This information can be of great help in deciding whether the animal needs to be proclaimed under S.11(1).

5. Proclamation under S.11 (1):

5.1. If the inquiry hints at deliberate attack by a wild animal, permission should be sought from the CWLW under S.11(1)(a) [for Sch.I animals] or from the AO under S.11(1)(b) [for Sch.II / Sch. III/Sch. IV animals] for exercising Option-2 (capture and retain). If the dossier reveals that the animal in question (other than tigers) is a habitual human-killer, Option-3 (Kill) should be exercised. Wild animals involved in deliberate attack on humans should not be released back in the wild (Ref. Sec.2, Para 1.5).

5.2. If the inquiry hints at an accidental encounter, no proclamation is required. Action should be taken, if necessary, to chase / drive the animal back to its natural habitat. If, however, the dossier reveals that the animal is in the habit of straying out of forests and has been involved in more than one accidental encounter with humans, permission of the CWLW/AO should be sought for exercising Option-1(capture and translocate).

5.3. The proclamation issued by the CWLW/AO should provide as many clues about the identity of the animal and its home range as possible. The proclamation should specify the area over which the animal can be hunted and PAs should be kept out of it. The proclamation should clearly indicate whether the permission for hunting is for Option-1 (capture and translocate), Option-2 (capture and retain) or Option-3 (Kill). It should specify the period (not exceeding three months) after which the proclamation will cease to be in force. The proclamation may be renewed further if there is evidence that the animal in question is still engaged in attacks on humans.

6. Tracking and Monitoring: Adequate number of LWSs comprising of armed forest staff and local volunteers should immediately be deployed over the known range of the animal to locate it and monitor its movements. The NTCA (2013) has recommended laying out a series of ‘Pressure Impression Pads’ in an area where a human-tiger/leopard conflict has taken place to ascertain the daily movement of the animal and plot the same on a map (1:50,000 scale). *Kunki* elephants, if available, should also be pressed into service in tracking and monitoring the proclaimed animal.

7. Engagement of Experts: Adequate number of traps with appropriate baits should be laid out at strategic points. The chemical immobilisation team and approved trappers should also be pressed into service immediately. If the proclamation is for Option-3 (Kill), the approved hunters should also be summoned.

8. Precautionary Measures:

8.1. Adequate publicity should be given in the region about the wild animal posing threat to human life which has been proclaimed under S.11(1) and the people should be informed about the precautions to be taken.

8.2. Information about the proclaimed animal should also be shared with the SLC / DLC of the adjoining State if the range of the animal extends across the inter-state borders.

9. Action after Capture:

9.1. After the animal has been captured (trapped / immobilised), it should be provided with veterinary care as soon as possible. A report should immediately be submitted to the CWLW/AO /SLC/ DLC.

9.2. The animal should be examined by a team of officers (including the local HWLW and a veterinarian) led by the DLC to conform its identity vis-à-vis the order of proclamation.²⁰

9.2.1. If the team is satisfied that the right animal has been captured, further action should be taken as per proclamation.

A. The animal ordered for translocation may be shifted to a designated Transit Facility if it is not possible to translocate it immediately.

B. The animal ordered for retention in captivity may be shifted to a designated Rescue Centre. A captured elephant may be shifted to an elephant camp for training.

C. The animal ordered for killing may be euthanized.

9.2.2. If the team is satisfied that a wrong animal has been captured, it should be immediately released back into its original habitat. If the animal needs further treatment, it should be shifted to a designated Transit Facility. The field operations to capture the right animal should be continued.

9.3. A report should be submitted to the CWLW/AO/SLC immediately.

10. Action after Killing:

10.1. If the animal has been killed by a hunter in accordance with the proclamation, a report should immediately be submitted to the CWLW/AO/SLC/ DLC.

10.2. The carcass should be examined by a team of officers (including the local HWLW and a veterinarian) led by the DLC to conform its identity vis-à-vis the order of proclamation.

10.2.1. If the team is satisfied that the right animal has been killed, a report should be submitted to the CWLW/AO/SLC.

10.2.2. If the team is satisfied that a wrong animal has been captured, it should inform the CWLW/AO/SLC immediately. The field operations to capture / kill the right animal should be continued.

²⁰ The NTCA's SOP (2013) has prescribed a special team for technical guidance and monitoring for dealing with cases involving tigers and leopards.

11. Expiry of the Proclamation:

11.1. If the proclamation issued by the CWLW/AO lapses before the animal is captured / killed, the operation may be stopped and a report submitted to the CWLW/AO/SLC. However, the ADS and LWS should continue to monitor the activities of the animal.

11.2. If, however, there is evidence that the animal in question is still engaged in attacks on humans, a proposal should be submitted to the CWLW/AO for reviving the proclamation.

12. Action in Emergency Situations:

12.1. When the animal is suspected to be rabid or when the animal is on a killing spree and immediate capture (trapping/immobilization) of the animal is not possible, the ADS should take steps for killing it in accordance with S.11(2).

12.2. An inquiry should be conducted by the DLC and a report submitted to the CWLW/AO/SLC.

13. Disposal of Carcass:

13.1. As stipulated in S.39(1), all wild animals killed under the provisions of S.11 are government property. The ADS and LWS should protect the carcass and prevent its misuse by unscrupulous persons.

13.2. As stipulated by the NTCA, carcasses of tigers/leopards should be incinerated in the presence of the Field Director / CF and the whole process should be photographed / videographed.²¹ A similar practice may be followed in respect of other species of wild animals. Special care should be taken to ensure that the parts of the carcass in demand in the illegal market (e.g. tusks of bull elephants, horns of rhinos, gall-bladders of bears, etc.) are destroyed fully.

13.3. There are other bonafide ways of disposing off the carcass or its parts which may be followed with permission from the CWLW. These include:

²¹ SOP for disposal of carcasses of tiger and leopard issued vide NTCA's Notification No. 15-37/2012-NTCA dated 18.3.2013.

1. Handing over the carcass to a recognised zoo / Vulture Conservation & Breeding Centre for consumption by wild animals.
2. Handing over the carcass to a Natural History Museum for display or record.
3. Providing samples to the research institutes / forensic laboratories for legitimate research / studies.

13.4. A report should be submitted to the CWLW/AO/SLC immediately after the disposal of the carcass.

14. A Parallel Strategy for Preventing Accidental Human Deaths and Injuries:

14.1. The fact remains that most of the cases of death or injuries of human-beings are circumstantial or accidental in nature and influenced by local factors including life-styles of the people. These issues can be handled only through awareness and educational programmes targeting the concerned stakeholders and by seeking help from the concerned governmental and non-governmental agencies. For example:

1. Many cases of deaths / injuries of humans are on account of roof / wall crashing on the victim when pushed by an elephant looking for some food-item. Strategies for dealing with the problem of house damage have been discussed in Section 7.
2. Many deaths / injuries take place when the victim is highly intoxicated and unable to protect himself against the wild animal. This is a social problem which needs to be addressed with active support from the community leaders, Panchayat, district administration, JFMCs and NGOs.
3. The villagers entering forests for collecting fodder, firewood, honey and other NTFPs run a great risk of being attacked by wild animals. Suitable restrictions in terms of time and area of collection of NTFPs should be enforced to minimise human-wild animal encounters. If need be, an armed forest staff can be assigned to accompany a group of NTFP collectors. Entry of persons, who are alone, sick, aged or otherwise unable to protect themselves, inside forests also needs to be regulated. The FD should also take strict measures against trespassers.
4. Certain categories of visitors to forests are particularly vulnerable to physical harm by wild animals. These include tourists, pilgrims, news reporters and photographers, researchers, workers of a project within the forest, army personnel carrying out field practice, etc. They should be adequately cautioned; advised to stick to a prescribed route, area, time-schedule

and camping site; or provided with trained guides. In special cases, armed forest staff may be assigned to accompany a group of visitors.

5. Many villagers do not have toilet facilities and visit nearby forests to relieve themselves where they face the risk of running into wild animals. Panchayat and the district administration should be advised to give priority to the villages reporting high levels of HWC for the purpose of setting up community latrines.
6. Street-lighting in the localities adjoining forests can reduce such human-wild animal encounters significantly. In areas where electricity is not available, solar light-posts can be provided. Panchayat and the district administration should be advised to give priority to the villages and tea / coffee estates reporting high levels of HWC under rural electrification schemes.
7. Proper disposal of garbage including left over foods and control over stray dogs and livestock is very essential to keep wild animals away from human localities.
8. Very often, a person gets trampled while chasing away wild animals rather carelessly. Aged and otherwise infirm persons as well as children must not be involved in anti-depredation works. The villages prone to HWC should be encouraged to set up a LWS comprising of volunteers who are physically fit. The LWS should be properly trained and equipped by the FD to deal with wild animals.

14.2. JFMCs and Tea / Coffee Estates should be encouraged to obtain group insurance cover against death / injury of their members / labourers.

Section-5

Dealing with Crop Depredation

1. General:

Wild herbivores have acquired the habit of feeding on a large number of crops ever-since the humans started practicing cultivation. Wild herbivores develop a definite bias towards the agricultural crops in view of their nutritional superiority over the wild fodder and the convenience of feeding. It is, therefore, unrealistic to think that abundance of wild fodder alone can contain wild animals within forests. But conversely, shortage of fodder within forests will definitely induce wild animals to raid the nearby agricultural fields. Thus, the desired strategy should be to take drastic measures for making it inconvenient and un-profitable option for wild herbivores to go after crops and, simultaneously, to make concerted efforts for protecting and improving the habitat within the forests.

2. Action before the conflict:

2.1. ADS should identify the potential conflict areas on the basis of past records and visit them before the conflict season to assess their preparedness. Condition of the equipment (e.g. searchlights) supplied to the farmers / LWS during the previous season as well as old barriers and watch towers built in the area should be checked and action should be taken to get them into working condition.

2.2. ADS should arrange training for the farmers in anti-depredation techniques; help them in setting up a temporary LWS for the ensuing harvesting season and equip it with searchlights and crackers.

3. Action during the conflict:

3.1. ADS should visit the conflict site when the farmers / LWS are unable to manage the situation or when a dangerous animal (e.g. elephant, gaur, black bear/ sloth bear) or an endangered animal (e.g. rhino) is involved. Attempts should be made to scare and drive the animals away from the crop-field.

3.2. Services of *kunki* elephants and / or a professional team of chasers (Ref.Sec.3, Para 2.2.2) should be used, if available, to drive wild elephants, gaurs and rhinos to safe locations.

3.3. ADS, with the help of the LWS, should try to identify the problem animals (individual / groups) which are particularly aggressive or appear to be habitual crop-raiders. This information should be recorded in a dossier.

4. Strong Measures:

4.1. It may sometimes be necessary to create fear within a particularly desperate group of wild animals (e.g. monkeys, wild boars and blue bulls). Permission of the CWLW /AO may be obtained for Option-1 (capture and release) under S.11(1)(b). The objective should be to capture (trap / immobilise) a few animals while in the act of crop-raiding and release them in a nearby habitat after some time (say 12-24 hours). Preference should be given to capture of alpha-males, or animals known to be aggressive, or animals known to be habitual crop-raiders. The operation should be carried out with the help of the ADS and the chemical immobilization team / approved trappers. Option-1 (capture and release) is not permissible for the Sch.I animals indulging in crop-raiding.

4.2. If temporary capture proposed in Para 4.1 does not bring down the levels of crop-damage, permission may be sought from the CWLW/AO for exercising Option-1 (capture and translocate) for the problem animals (except those listed under Sch.I). The guidelines given in Section 2 for capture (Para 3) and translocation (Para 4) should be followed.

4.3. If the translocation proposed in Para 4.2 is either not possible or the translocated animals continue to indulge in serious crop-raiding, Option-2 (capture and retain) should be exercised with permission from the CWLW/AO. Preference should be given to capture of alpha-males, or animals known to be aggressive, or animals known to be habitual crop-raiders. The guidelines given in Section 2 for capture of wild animals (Para 3) should be followed. Option-2 (capture and retain) is not permissible for the Sch.I animals indulging in crop-raiding.

5. Extreme Measures: S.11(1)(b) permits killing of wild animals listed under Sch.II /Sch.III /Sch.IV for destroying crops. But this option should be exercised only sparingly and not until the CWLW/AO has caused an enquiry and come to the conclusion that all reasonable alternative options to protect crops have been exhausted. The permission in such cases should be given only

for killing a limited number of animals for a limited period of time and hunting should be carried out by the hunters engaged by the FD. As far as practicable, only the animals known to be habitual crop-raiders should be targeted for killing. Wild animals categorised as ‘Threatened’ in the IUCN Red List should not be killed for involvement in crop-raiding. Killing of Sch.I animals for destroying crops is not permissible under S.11(1)(a).

6. Relief to the Victims

6.1. Local forest staff, ADS and HWLW should help the victims of crop-depredation in claiming ex-gratia relief from the competent DFO. HWLW and DLC should also pursue the pending applications for ex-gratia relief with the concerned DFO to ensure quick settlement of claims.

6.2 Local forest staff, ADS and HWLW should also identify the poor and destitute among the victims who require support in the form of food grains to sustain themselves or in the form of seeds and implements to re-cultivate their land, and try to arrange help for them with the help of the district administration, NGOs or philanthropic agencies.

7. Barriers and Watch-Towers: The FD may plan for construction of watch-towers, trench, wall or fence (including power fence) for preventing incursion of wild animals in cropland in localities suffering very high levels of crop-depredation and where the beneficiaries are willing to set up LWS for protection and maintenance of watch-tower /barrier. Guidelines given in Section 2 (Para 2) for barriers and watch-towers should be followed.

8. A Parallel Strategy for Preventing Crop Depredation

8.1. Alternative Cropping: The fields located within or adjacent to forests as well as those situated along the known wildlife corridors are particularly vulnerable to depredation. It makes sense to encourage the farmers to change their agricultural practices in such areas and grow such crops as are profitable, but not favoured by wild animals. Help from the agricultural experts and NGOs, and suitable incentives from the government agencies can go a long way in facilitating the change. FD should also try to promote alternative cropping in identified areas through its eco-development schemes as well as awareness and educational programmes.

8.2. Commercial Farms and Plantations:

8.2.1. The DLC should arrange for a safety audit of large agricultural farms, sugar-cane fields, rubber and banana plantations, fodder farms, orchards, tea / coffee estates, etc. situated on the fringe of forests by a team of experts / experienced officers. Quite often the problem can be addressed by advising the stakeholders to adopt the following measures:

1. Engaging crop-guards / LWS equipped with simple scaring devices (e.g. catapult, crackers, search-lights, airguns, etc.).

2. Using properly designed barrier (trench or wall) or fence (including power fence)²² or a combination of the two.
3. Using ultrasonic-sound devices to repel the wild animals.
4. Using strong halogen lamp-posts along the periphery with the forests.
5. Seeking insurance cover.

8.2.2. Usually the wild animals do not harm the tea / coffee bushes except trampling the nursery or young crop. Therefore, it may be enough to put a barrier or fence around only the sensitive sectors and labour colonies rather than enclosing the entire estate. This is particularly important in case of tea / coffee estates being used as a corridor by wild animals.

8.2.3. The FD should, with the help of Panchayat / district administration, discourage the prospective planters from cultivating sugarcane, rubber, banana or any other plant on the fringe of forests which may allure wild animals unless they promise to set up their own barriers.

8.3. **Discourage Illegal Measures:** The farmers sometimes indulge in illegal measures for protecting their crops, such as shooting at the wild animals, using poison or explosives concealed in food items, and setting up electrified fences. The FD should identify such areas on the basis of past records and deal with this problem through awareness and publicity programmes as well as legal action. In particular, farmers should be encouraged to use safe and innocuous power-fences operated by solar-power or rechargeable batteries instead of tapping electricity illegally. Similarly, in case of cultivation over encroached government lands, emphasis of the government agencies should be on removing encroachment and protecting wild animals rather than chasing wild animals.

Section-6

Dealing with Livestock Depredation

1. General:

1.1. It is mainly the wild carnivores who indulge in killing livestock for their food, though reports of wild elephants killing cattle are also sometimes received.

1.2. Wild carnivores have been preying upon the livestock ever-since the humans started practicing animal-husbandry. This may be either due to the shortage of the wild prey or the relative ease of hunting the livestock vis-a-vis the wild prey. Thus, the desired strategy should be to take drastic measures for making it inconvenient and un-profitable option for wild carnivores to go after the livestock, and simultaneously, making concerted efforts for protecting for improving the prey-base within the forests.

²² Razor-wire fences are harmful to wild animals and should not be recommended. Chain-link fences or woven-wire fences are usually safe and effective.

2. Action before the Conflict:

2.1. ADS should identify the potential conflict areas on the basis of past records and visit them before the conflict season to assess their preparedness. Condition of the equipment (e.g. searchlights) supplied to the villagers / LWS during the previous season as well as old barriers and watch towers built in the area should be checked and action should be taken to get them into working condition.

2.2. ADS should arrange training for the livestock-owners and herders in anti-depredation techniques; help them in setting up a LWS and equip it with searchlights and crackers.

3. Action during the Conflict:

3.1. Initial responsibility for managing livestock-killing by wild animals should be taken by the regular forest staff of the PAs / Forest Divisions and the LWS. ADS should visit the conflict site when the villagers / LWS / local staff are unable to manage the situation or when a dangerous animal (e.g. tiger, leopard) is involved. Efforts should be made to remove the animal away from the conflict area by an appropriate strategy described in Section 3.

3.2. ADS, with the help of the LWS /local staff, should try to identify the wild carnivores habitually sneaking into human habitations for killing livestock. This information should be recorded in a dossier.

3.3. The forest staff should monitor the incidents of killing of livestock whether inside forests or in the neighbouring locations. They should particularly keep watch on areas with a past history of retaliatory killing of wild animals and address the problem through awareness and publicity programmes as well as legal action.

3.4. The forest staff should also pay due attention to the disposal of the carcass of the killed livestock so as to prevent its misuse for killing the predator either by poisoning it or using it as a bait. If the kill lies inside forest or very close to it and its safety can be ensured, it should be left to be devoured by wild animals. It may be useful to put up a camera-trap, if available, to photograph the wild animal in question. In all other cases, arrangement should be made to bury / burn the carcass.

4. Strong Measures:

4.1. In case the level of conflict is more than the tolerance level of the stakeholders, permission of the CWLW/AO may be obtained under S.11(1)(b) for exercising Option-1 (capture and translocate) against the habitual livestock-killers. The operation should be carried out with the help of the ADS and the chemical immobilization team / approved trappers. The guidelines given in Section 2 for capture (Para 3) and translocation (Para 4) should be followed. Option-1 (capture and translocate) is not permissible for the Sch.I animals indulging in livestock-killing.

4.2. If the translocation proposed in Para 4.1 is either not possible or the translocated animal returns and indulge in livestock-killing, permission of the CWLW/AO may be obtained under S.11(1)(b) for exercising Option-2 (capture and retain) against the habitual livestock-killer. The guidelines given in Section 2 (Para 3) for capture of wild animals should be followed. Option-2 (capture and retain) is not permissible for the Sch.I animals indulging in livestock-killing.

5. Extreme Measures: S.11(1)(b) permits killing of wild animals listed under Sch.II /Sch.III /Sch.IV indulging in livestock-killing. But this option should be exercised only sparingly and not until the CWLW /AO has caused an enquiry and come to the conclusion that all reasonable alternative options to protect livestock have been exhausted. The permission in such cases should be given only for killing a limited number of animals for a limited period of time and hunting should be carried out by the hunters engaged by the FD. As far as practicable, only the animals known to be habitual livestock-killers should be targeted for killing. Wild animals categorised as ‘Threatened’ in the IUCN Red List should not be killed for involvement in cattle-killing. Killing of Sch.I animals for killing livestock is not permissible under S.11(1)(a) .

6. Relief to the Victims

6.1. Local forest staff, ADS and HWLW should help the victims of livestock-depredation in claiming ex-gratia relief from the competent DFO. HWLW and DLC should also pursue the pending applications for ex-gratia relief with the concerned DFO to ensure quick settlement of claims.

6.2 Local forest staff, ADS and HWLW should also identify the poor and destitute among the victims who require livelihood support or any other relief and try to arrange help for them with the help of the district administration, NGOs or philanthropic agencies.

7. Barriers and Watch-Towers: The FD may plan for construction of watch-towers, trench, wall or fence (including power fence) for preventing incursion of wild animals in localities adjoining forests suffering very high levels of livestock-depredation and where the beneficiaries are willing to set up LWS for protection and maintenance of watch-tower /barrier. In the Sundarbans, FD has been using Nylon-net fences to prevent straying of tigers into villages. Guidelines given in Section 2 (Para 2) for barriers and watch-towers should be followed.

8. A Parallel Strategy for Preventing Livestock-Killing:

4.1. Effective control of livestock depredation is not possible without regulating the animal-husbandry practices like sending the cattle, particularly the unproductive ones, for grazing inside forests without an attendant. In forest areas where grazing is allowed, the FD should impose suitable restrictions in terms of time and area of grazing to minimise livestock-wild animal encounters. Yet another practice that needs to be encouraged among the keepers through awareness programmes is that of stall-feeding of livestock.

4.2. The problem may also be addressed by the FD, where possible, through eco-development schemes for promoting fodder reserves on community lands outside forests— thereby reducing livestock movement inside forests. The FD may also build up community livestock-sheds; set up artificial insemination centres; and undertake vaccination programme in collaboration with the Veterinary Department in the conflict-affected villages to earn the goodwill of the people.

4.3. There is also a need to motivate the livestock-owners through JFMCs, Panchayat and district administration to build strong, robust and properly designed livestock-sheds / poultry farms for keeping the carnivores out.

4.4. The organised and resourceful stakeholders maintaining dairy-farm, poultry, piggery, etc. should be advised to invest in properly designed wildlife-proof cattle sheds. They may also be advised to set up properly designed barriers (trench/wall) or fences (including power fence) or a combination of the two for preventing the straying of wild animals into strategic locations. Designs of such barriers are available with the CZA. Strong halogen lamp-posts along the periphery with the forests are also useful to deter most of the wild animals. Arrangement should also be made for suitable disposal of garbage and left-over food

4.5. JFMCs and Tea / Coffee Estates should be encouraged to obtain insurance cover against loss of livestock by their members / labourers.

Section-7

Dealing with House Damage

1. General:

Almost all cases of house damages in the country can be attributed to elephants. This is quite a serious issue– not only because many poor villagers are put to great hardships, but also because a large number of cases of human deaths and injuries take place in the process.

2. Action before and during the Conflict:

Cases of house damage in many areas usually peak either during or immediately after the harvesting season and measures suggested for dealing with crop-depredation in Section 5 (Paragraphs 2 and 3) are applicable in such cases as well.

3. Strong Measures:

3.1. Some individual elephants may develop a habit of targeting and damaging houses throughout the year. ADS/forest staff should inquire into the cases of house-breaking by elephants and try to identify elephants repeatedly indulging in such incidents (Ref. Sec.4, Para 4). Permission of the CWLW may be obtained for exercising Option-1 (capture and translocate) against the habitual house-breakers under S.11(1)(a) since these elephants do pose threat to human life. The operation should be carried out with the help of the ADS and the chemical immobilization team / *kunki* squad. The guidelines given in Section 2 for capture (Para 3) and translocation (Para 4) of wild animals should be followed.

3.2. If the translocation proposed in Para 3.1 is either not possible or the translocated animal returns and continues to indulge in depredation, permission of the CWLW should be obtained for exercising Option-2 (capture and retain) against the animal under S.11(1)(a). The guidelines given in Section 2 (Para 3) for capture of wild animals should be followed.

4. Relief to the Victims

4.1. Local forest staff, ADS and HWLW should help the victims of house-damage in claiming ex-gratia relief from the competent DFO, if eligible.²³ HWLW and DLC should also pursue the pending applications for ex-gratia relief with the concerned DFO for quick settlement of the claims.

4.2. Local forest staff, ADS and HWLW should also identify the poor and destitute among the victims who require support for the repairs or reconstruction of their huts or any other relief and

²³Only a few state governments provide ex-gratia relief for damage to houses and property by wild animals.

try to arrange help for them with the help of district administration, NGOs or philanthropic agencies.

5. **Barriers:** The FD may plan for construction of Elephant-Proof Trenches (EPTs), walls, or power fences for preventing the incursion of wild elephants in localities adjoining forests suffering very high levels of depredation and where the beneficiaries are willing to set up LWS for protection and maintenance of the barrier / fence. The FD may also take similar measures to protect forest villages/ beat offices /timber depots / rest houses against elephants. Guidelines have been given in Section 2 (Para 2) for trenches and power-fences.

6. **A Parallel Strategy for Preventing House Damage:** Quite often, the house damage may be circumstantial or accidental in nature and influenced by local factors. These issues can be handled only through awareness and educational programmes targeting the concerned stakeholders. For example:

1. Elephants are known to be attracted to a house by the smell of country-liquor. The villagers should be cautioned against storing country-liquor in their houses. The district administration should arrange special drives from time to time in villages situated within or adjacent to forests to discourage brewing of country liquor.
2. An elephant may venture dangerously close to a house lured by a banana plant or a jackfruit tree growing in the compound or pumpkins growing on the wall of the house. The villagers should be cautioned about the dangers of growing all such plants close to their houses as may attract elephants.
3. An elephant may be attracted to a house by the smell of salt or paddy or any other eatable. The villagers should be advised to store salt, paddy and other edibles in a place away from the direction from which an elephant is likely to approach. A useful way to suppress the smell of food-items and to distract elephants is to spray a dilute solution of phenyl or some other foul-smelling (but non-poisonous) substance on the outer walls from time to time.
4. Elephants are also known to target granaries after the crop has been harvested. The villagers should be advised to set up granaries far from the fields and away from the usual routes of elephants. As far as possible, granary should not be a part of the main house. If it is not possible, granary should be set up on the roof of the house at a height beyond the reach of an elephant's trunk.²⁴
5. Observations reveal that the electrified houses are less prone to damage by elephants than those without electricity. District administration / Panchayat should be persuaded to take up electrification projects in the conflict zones on a priority basis.
6. FD should discourage construction of buildings and other structures on known elephant routes and corridors.
7. The organised and resourceful stakeholders (e.g. Tour Operators ,Tea / Coffee Estates, Army, etc.) should be advised to invest in properly designed EPTs, walls, or power fences to protect their residential areas / critical assets located in or around forests. Strong halogen lamp-posts along the periphery with the forests are also useful to deter most of the wild elephants.

²⁴In some parts of Odisha, farmers keep paddy in under-ground storage (known as *khani-dhaan*) to protect it from elephants. The Central Rice Research Institute, Cuttack, has also designed elephant-proof storage bins for protecting paddy against elephant.

8. JFMCs and Tea / Coffee Estates should be encouraged to obtain insurance cover against damage to houses of their members / labourers. Some tea gardens in the Northern West Bengal have insured their labour huts against damage by wild elephants.

Section-8

Managing People

1. Ex-gratia Relief and Other Support:

1.1. The purpose of ex-gratia relief is to help the people overcome the effects of damage inflicted on them by the wild animals and to sustain their sympathy for the wild animals. But it does not serve the desired purpose when the people feel that the relief being paid is unjust and unfair, and get disgusted with the hassles, delays and malpractices in receiving their dues. Ex-gratia relief is an important tool for managing the people and forest officials should strive to take the maximum benefit from it.

1.2. The FDs should review the rules and procedures for payment of ex-gratia relief to make it fast, hassle-free and transparent. It can generally be done by delegating the responsibility of inquiry and disbursement of ex-gratia relief to the JFMCs/panchayat and prescribing a time-limit for the same. FDs in some States have authorised the DFOs to disburse a part of the ex-gratia relief within 24 hours in the event of human deaths / injuries pending final inquiry.

1.3. ADS, LWS and HWLWs should help the victims with the submission of their claims immediately after the incident and also pursue the matter with the appropriate authorities. This is particularly important in conflict situations leading to injury / death when the injured person / dependants of the deceased need immediate financial support. Where the rules so permit, part of the ex-gratia-relief should be made available to the victims or their dependents urgently without waiting for official formalities.

1.4. The DLC should also review the status of settlement of claims periodically and look into complaints and grievances brought to his notice. It is a common experience that the ADS / forest staff face a hostile atmosphere in an area having a multitude of unsettled claims. The DLC should, therefore, ensure that all pending claims from the previous conflict season get settled before the next conflict season sets in.

1.5. The biggest hassle in the payment of ex-gratia relief in many States is often the shortage of funds and delays in budgetary allocations to DFOs. Some FDs have overcome this problem by placing special non-lapsable funds at the disposal of DFOs. Innovative efforts have been made in some States for augmentation of funds from other sources for ex-gratia relief.²⁵

1.6. As far as possible, the FDs of the adjoining States should follow similar rates in respect of ex-gratia relief to the victims of HWC.

1.7. **Supplementary Relief:** It is possible to go beyond what is prescribed in the ex-gratia rules to help the sufferers and earn their goodwill. ADS and HWLW may identify the poor and destitute among the victims who require support in the form of livelihood support, food- grains, seeds, tools and implements, camping material, etc. to recover from their losses and try to arrange help with the help of the district administration, NGOs or philanthropic agencies.

1.8. **Medical Support:**

1.8.1. Care of the persons injured in HWC is an issue that should get serious attention of the FD and the matter should not end with the payment of ex-gratia relief. ADS and HWLW may also arrange transport and medical support for the injured persons. The FD may directly pick up the bill for medical expenses instead of expecting the injured person to make payment and then apply for reimbursement.

1.8.2. Injuries caused by wild animals may often be very serious and need special care. For example, a person trampled by an elephant may need prosthetic limbs or a wheelchair and a woman whose face has been mauled by a bear may need plastic-surgery. The SLC/DLC may make arrangement with the Health Department, Chief Medical Officer, hospitals, NGOs and philanthropic organisations before the conflict season for providing quality medical aid on priority basis to the injured persons.

²⁵ Uttarakhand FD has set up 'Human-Wildlife Conflict Relief Disbursement Fund' vide its GO dated 10.12.2012 with seed money of Rs. 4 Cr from the Uttarakhand CAMPA and Rs. 3 Cr from the Uttarakhand Forest Development Corporation. The funds provided by the State Government, Central Government and other agencies including private donors for the purpose of ex-gratia relief are deposited into this fund. The DFOs get an advance of Rs. 20 lakh into their accounts for payment of ex-gratia relief and the expenditure is refunded within 48 hours of the receipt of sanction orders from the DFO. So, a DFO always has an amount of Rs. 20 Lakh available in his account.

1.9. Insurance Cover:

1.9.1. Insurance as a tool for providing relief to the victims of accidents and unforeseen events has many advantages over ex-gratia which is often inadequate and does not cover all kinds of losses suffered by the people. Attempts should be made to take advantage of the existing insurance schemes.

1.9.2. Insurance companies provide group insurance schemes to cover death and injuries. They also have policies to cover houses and livestock. Insurance companies are generally reluctant to provide cover for crop damage in view of complications of verifying claims and assessing damage, and also because they do not consider it a lucrative venture.

1.9.3. The State Government in Kerala has provided life insurance coverage to the tribal population inhabiting forests. Some JFMCs in the Northern West Bengal are covered by the Janata Personal Accident Insurance Policy of the New India Assurance Company. Some tea gardens in the Northern West Bengal have insured their labour huts against damage by wild elephants.

1.9.4. The Ministry of Agriculture, Government of India, has introduced 'National Crop Insurance Project' in the country during the 12th Plan through Agriculture Insurance Company of India and some public sector insurance companies. This is meant to cover food crops, oil seeds and annual commercial / horticultural crops against pests and natural calamities. The scheme has a well laid out procedure for assessment of crop damage and settlement of claims. The premium is jointly subsidised by the Central Government and the State Government to the tune of 40% to 70%. The Ministry of Agriculture has also been implementing a Livestock Insurance Scheme in 300 districts of the country through the State Livestock Development Boards in which 50% of the premium is paid by Government of India as subsidy. It will be appropriate to bring damage to crops and livestock by wild animals under the ambit of the aforesaid schemes.

1.9.5. Commercial farms, Tea /Coffee Estates and JFMCs should be encouraged to obtain insurance cover for their workers / members against death / injury of humans, damage to crops / houses and loss of livestock caused by wild animals. JFMCs, in particular, should be persuaded to spend a part of their income from NTFPs in buying insurance cover for their members.

2. Crowd management:

2.1. Crowd management is a formidable issue for the managers of HWC all over the country. People often react in an irrational manner when a wild animal strays into their locality. In its simplest form, they may get curious, get dangerously close to the animal, ignore warning issued by the forest staff, and make the escape difficult for the animal. In its worst form, the crowd may get violent, obstruct the forest staff from rescuing the animal, chase the animal indiscriminately and harass it — leading to injuries and even fatalities of humans and / or the animal in question. There have been incidents of the unruly crowd assaulting the forest staff and killing the trapped animal. It is, therefore, necessary for the ADS, chemical immobilisation team, *kunki* squad, trappers/hunters and the general forest staff to anticipate crowd behaviour and prepare for it before executing any capture / driving operation.

2.2. Crowd management essentially means ensuring the safety of the animal, the forest staff, and, of course, the crowd itself. It is basically a law and order situation and involves the district administration and the police. In Kerala, the DGP has issued standing instruction to the district police to provide escort to the forest staff engaged in capture or driving of wild animals. In some States, the District Magistrates invoke Section 144 of the Cr PC to bring the crowd under control. The local politicians sometimes come to the rescue of the forest officers and persuaded the crowd to cooperate.

2.3. The DLC and ADS should make advance preparations for crowd management. They should identify the sensitive areas on the basis of past records and solicit police help before visiting these areas. They should carry out publicity and awareness programmes in these areas and educate the people about the dangers of unruly crowd behaviour. They should identify the influential community leaders and request them to accompany the ADS in the field. A deserving community leader may also be appointed as HWLW and made a part of the HWC management team. Help should also be taken from the local panchayat and NGOs to manage the crowd. Forest staff from the neighbouring forest divisions and members from the local JFMCs may be requisitioned to strengthen the ADS.

2.4. The effort of the ADS and LWS should be to keep the people at a safe distance from the animal and to forewarn the people living on the expected escape route of the animal. Armed Policemen and forest staff should be deployed at strategic points. Nets made of Nylon or Jute should be used as a shield to protect people from sudden bursts from the carnivores. A row of volunteers holding *mashaal* (lighted torches) can provide an effective shield for the people and also prevent the animal from taking a wrong route.

3. Publicity and Awareness Programme:

3.1. FDs routinely conduct Publicity and Awareness Programmes (PAPs) during the Forest Festival (July) and Wildlife Week (October) every year. JFMCs also provide a platform to the forest officers and staff to have regular interactions with the people living on the fringe of forests and PAs. Many NGOs also carry out PAPs relating to wildlife and environment.

3.2. PAPs relating to HWC are expected to be different from the routine programmes inasmuch as these aim at enhancing/sustaining the tolerance level of various stakeholders towards wild animals; addressing the behaviour and life-styles of the people which contribute towards the conflict; and also ensuring their active participation in the management of conflict.

3.3. PAPs can be conducted through meetings, workshops, radio/TV talks, press-releases /advertisement in newspapers, posters, hand-bills, calendars, endorsement by celebrities, etc. But best and lasting results are obtained through personal contacts and one-on-one interactions between the stakeholders and the forest officials.

3.4. ADS and the field staff come into maximum contact with the stakeholders and also serve as unofficial spokespersons of the FD. Therefore, it is extremely important to initiate the PAP with the field level officers and staff to make them aware of the theory and practice of HWC management and help them build a positive and liberal attitude both for the people and the wild animals. Motivated and well-informed forest officers and staff serve as the most effective agents for PAP.

3.5. The next in terms of effectiveness are the enlightened and pragmatic lot from among the local communities who understand the intricacies of the HWC and hold influence over their community. The DLC and ADS should identify these persons; invite them to the PAPs as resource persons; involve them in LWS; use them for crowd-management in the field; and get some of them appointed as HWLWs (Ref. S.1, P.2.3) or members of DLAMC (Ref. S.1, P.2.1.1) or PA Level Advisory and Monitoring Committees (Ref. S.1, P.2.1.2).

3.6. The DLC and ADS should carefully identify various stakeholders and their stakes and also list mutual expectations of each stakeholder with the FD and then plan a PAP for them accordingly. Stakeholders may include district administration, police, municipality / panchayat, JFMCs, politicians / public representatives, army, railways, veterinary department, agriculture department, health department, development agencies, mining industry, tourism industry, big farms / tea estates / coffee estates, small farmers, livestock-herders, fishermen, NTFP collectors, schools / colleges, and many more. The contents and strategy for PAP should be tailor-made for each stakeholder, his stake and tolerance level, and mutual expectation with the FD. For example, stakes of big planters are different from the small farmers and livestock-herders and mutual expectations of each group with the FD are also different. Media, NGOs, research organisations, doctors, and relief/philanthropic organisations are some of the groups which the FD should cultivate in order to get support for HWC management.

3.7. Some suggestions about the issues which should be addressed through PAP are given below.

3.7.1. Enhancing Tolerance Level of the Stakeholders:

1. Educate stakeholders about wild animals — their nature, home-range / territoriality, intra-specific competition, breeding habits, food preference, reasons for straying out into tea gardens / sugarcane fields, reasons for crop-raiding / cattle-killing, etc.
2. Educate stakeholders about the livelihood and development requirements of the people impacting wildlife habitats and consequential conflict with wild animals.
3. Remind stakeholders about the positive ecological, economic and cultural values of the wild animals.
4. Deal with stakeholders' threat-perception of the wild animals by addressing misconceptions and rumours, sharing statistics of conflict level, and highlighting the accidental nature of majority of human deaths / injuries.
5. Motivate the media to report objectively and help in spreading awareness about HWC, and desist from sensational reporting which may lower the tolerance level of the stakeholders.
6. Inform stakeholders about the preparedness of the FD to deal with HWC and action taken against the problem animals in the past.
7. Inform stakeholders about the ex-gratia scheme and other support available for the victims of HWC.
8. Inform stakeholders about the benefits derived by the community through eco-development works and other forestry works vis-à-vis the loss suffered due to HWC.
9. Show appreciation to the stakeholders for their cooperation / good work.
10. Identify the opinion-makers among stakeholders and arrange a separate one-on-one interaction with them.
11. Arrange training for the stakeholders in anti-depredation techniques.
12. Publicise contact details of the ADS, DLC, SLC and CWLW among the stakeholders and inform them about the grievance-redressal system.

3.7.2. Addressing Behaviour and Lifestyles of the Stakeholders:

1. Inform forest-fringe dwellers about the fallout of unregulated grazing and collection of firewood/firewood/NTFPs, forest fires, trespass and encroachment vis-à-vis HWC.
2. Inform livestock owners about the perils of keeping stray dogs and loose cattle, and virtues of stall-feeding of livestock, wildlife-proof livestock-pans and Livestock Insurance Schemes.
3. Educate tourists about the threats associated with feeding of wild animals and throwing garbage and left-over food around.
4. Caution forest-fringe dwellers about the perils of storing country-liquor in their homes and moving around in intoxicated condition.
5. Inform forest-fringe dwellers about the perils of going to the forests for relieving them and about the government schemes to provide them indoor toilets.

6. Inform development agencies about the fall out of blocking wildlife corridors.
7. Educate farmers about alternative cropping for avoiding crop-raiding by wild animals.
8. Inform forest-fringe dwellers about the virtue of having electricity in their houses and streets vis-à-vis HWC.
9. Caution farmers/livestock-herders about shooting at the wild animals; poisoning the livestock-carcass for killing the predators; or setting up electrified fences to protect their crops, and educate them about safe and legal ways of protecting their crops and livestock.
10. Inform forest-fringe dwellers about the futility of 'rescuing' wild cubs /calves seen without mother in the vicinity of forests.
11. Caution big farmers / plantation companies against cultivating sugarcane, rubber, banana or any other plants alluring wild animals without making a provision for a barrier or power fence.

3.7.3. Ensuring Participation of Stakeholders in HWC Management:

1. Motivate villagers / JFMCs to form LWS.
2. Encourage resourceful and privileged stakeholders to set up their own LWS and barriers/fences, and underprivileged stakeholders to help in protecting / maintaining the barriers / fences set up by the FD.
3. Educate stakeholders about precautionary measures to minimise the impact of HWC.
4. Educate stakeholders about the limitations of various anti-depredation measures like capture, translocation, barriers, etc. to help them appreciate the decisions taken by the wildlife authorities.
5. Caution stakeholders about the ensuing breeding season / conflict season of a wild animal and educate them about the precautions to be taken.
6. Caution stakeholders about the wild animals proclaimed under S.11(1) for posing threat to human life and educate them about the precautions to be taken.
7. Motivate resourceful and privileged stakeholders to procure insurance cover for their workers / members against any damage due to HWC.
8. Gather information about effective traditional practices of protecting crops and livestock from wild animals and disseminate the same among other communities..
9. Motivate the residents of a hamlet situated inside a high conflict zone or blocking a wildlife corridor to relocate to a safe area.
10. Persuade district administration, hospitals, NGOs and philanthropic organisations to help the victims of HWC with relief and medical support.
11. Urge stakeholders to help in crowd-management.
12. Seek help from politicians and public representatives to get adequate funds for managing HWC and help in spreading awareness among the stakeholders.
13. Urge Public Sector Undertakings / Companies to support anti-depredation measures and eco-development works under their Corporate Social Responsibility Projects.

4. Joint Forest Management Committees

4.1. A large number of Joint Forest Management Committees (JFMCs)²⁶ have already been set up by FDs for involving local people in the management and protection of forests including PAs. FDs should make a concerted effort to bring all the forest-fringe areas prone to HWC under the ambit of JFMCs and involve them actively in the management of HWC.

4.2. Management of HWC and corresponding duties and obligations of the JFMC members should find a place in the micro-plans of the JFMCs.

4.3. JFMCs should, in particular, be involved in providing volunteers for LWS and ADS; constructing and maintaining barriers and watch-towers; preventing retaliatory killing of wild animals; and verifying applications for ex-gratia relief. Distribution of crackers, search-lights and other materials for conflict management should preferably be done through JFMCs only.

4.4. As an incentive, FDs may reward the JFMCs actively co-operating in the HWC management with liberal financial help for eco-development works. JFMCs may also be brought under group insurance schemes covering human life / injuries, livestock and houses.

4.5. JFMCs having substantial income from forests (e.g. from sale of NTFPs or from eco-tourism) may be encouraged to spend a part of their income on maintenance of barriers, engagement of crop-guards and payment of premium for group-insurance policies.

5. Eco-development

5.1. A number of Centrally Sponsored Schemes in the Wildlife Sector provide financial assistance for carrying out eco-development works in and around PAs. Some schemes including Project Elephant and some Externally-Aided Projects also provide financial assistance for undertaking eco-development works in forest areas other than PAs. Eco-development should be used as a tool for addressing HWC.

5.2. Eco-development activities should be planned for reducing the dependence of the local people on forest resources (e.g. collection of fodder and firewood from forests).

²⁶Also referred to as Forest Protection Committees (FPCs) and Eco-development Committees (EDCs).

5.3. Eco-development activities may also be planned for reducing the impact of HWC (e.g. construction of barriers and watch-towers; promotion of alternative crops; construction of community granaries and livestock-pans, provision of community-latrines; etc.).

5.4. Eco-development activities should also be planned as a means for indirectly compensating the community against damage caused by wild animals and sustaining their tolerance level (e.g. promotion of eco-tourism facilities; construction and repair of community centres, schools and dispensaries; repair of village roads; provision of minor irrigation facilities; provision of solar streetlights; etc.). It should be made clear to the beneficiaries of these activities that they have been receiving various benefits as a reward for their cooperation for protecting wild animals.

5.5. Eco-development works for a particular area should be based on micro-planning of the concerned JFMC if there is one or in detailed consultation with the concerned stakeholders. Eco-development works should not be stereotypes but based on proper assessment of the mutual impact of the people and the wild animals.

5.6. Public Sector Undertakings / Companies should be urged to sponsor eco-development works in high HWC zones under their Corporate Social Responsibility Projects.

6. Relocation of Human Settlements

6.1. Relocation of a human settlement as a strategy for mitigating HWC should be considered as an option in the following cases:

A. When the settlement has been witnessing very high level of conflict on a regular basis and all possible strategies for bringing the conflict under control have been tried and found to be ineffective.

B. When the settlement is known to be obstructing an important and recognised wildlife corridor.

6.2. A relocation proposal should meet the following criteria:

A. It should be based on the willingness of the people involved.

B. It should be compatible with the existing laws, in particular IFA-1927, WPA-1972, EPA-1980, FCA-1980 and the Scheduled Tribes and Other Forest Dwellers (Recognition of Forest Rights) Act, 2006 (FRA-2006), and the National Rehabilitation and Resettlement Policy, 2007.

C. It should be approved by the DLAMC and SBWL.

6.3. A detailed guidelines/protocol for relocation of villages from Tiger Reserves has been prepared by the NTCA (http://www.ntcavillagerelocation.nic.in/about_us.aspx#) which can be suitably adapted for use in other areas as well.

ABBREVIATIONS

ADS	Anti-Depredation Squad
AO	Authorised Officer
Cr PC	Criminal Procedure Code
CWLW	Chief Wildlife Warden
CZA	Central Zoo Authority
DFO	Divisional Forest Officer
DGP	Director General of Police
DLC	District Level Coordinator
DLMAC	District Level Advisory and Monitoring Committees
EPA-1980	Environment (Protection) Act, 1980
EPT	Elephant-Proof Trench
ESZ	Eco-Sensitive Zone
FCA-1980	Forest Conservation Act, 1980
FD	Forest Department
FRA-2006	Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Rights) Act, 2006
HWC	Human Wildlife Conflict
HWLW	Honorary Wildlife Warden
IFA-1927	Indian Forest Act, 1927
LWS	Local Wildlife Squad
MoEFCC	Ministry of Environment, Forests and Climate Change
MLA	Member of Legislative Assembly
MP	Member of Parliament
NGO	Non-Governmental Organisation
NTCA	National Tiger Conservation Authority
PA	Protected Area
PAP	Publicity and Awareness Programme
PCA-1960	Prevention of Cruelty to Animals Act, 1960
S.	Section
SBWL	State Board for Wildlife
Sch.	Schedule
SLC	State Level Coordinator
SOP	Standard Operating Protocol
WII	Wildlife Institute of India
WPA-1972	Wildlife (Protection) Act, 1972

Management of Human-carnivore conflict

On the basis of the expert opinion and discussions during the workshop “Human-wildlife interactions and management of invasive species” conducted by the Wildlife Institute of India, a team of scientists and researcher designed these draft guidelines to manage the human-carnivore conflict in the country. Team also conducted a post-workshop intensive literature survey for preparing these decision making flow-charts. The first flowchart (figure 2) provides a decision-making framework for managers to resolve carnivore conflicts using the existing spatial and temporal information related to conflict cases. The second flowchart (figure 3) provides the steps to be followed in the case of an attack by a carnivore on humans. Subject matter with superscript has been explained in detailed in the following text.

The primary task of the park manager, in case of human-carnivore conflict, is to understand the spatial and temporal distribution of the conflict in the forested area. This understanding can be gained by mapping the existing information relating to the compensation paid to villagers for damage to property, livestock loss and attacks on humans across the years. The method of identifying the present and potential hotspots is described in the following:

IDENTIFY AND CATEGORIZE HOTSPOTS OF CONFLICT

Present hotspots. These are the areas (forest beats, villages, etc.) that have witnessed maximum conflict cases. In the case of a carnivore conflict, villages should be mapped for the frequency and intensity of the conflict (nature of each conflict event-encounter, injury, fatal attacks). All India tiger monitoring guide could be used as a model for required data collection. Frequency and intensity of the conflict can be quantified using the information relating to the compensation offered by the forest department and the number of reported cases. The priority should be; **human injury/attack > Livestock depredation> crop + property damage > property damage > crop damage > perceived conflict**. An area with a high frequency of damage under any of these categories could be further classified on the basis of conflict at the micro-scale (beat or range level). Considering the social attitude when mapping the conflict hotspots is crucial as sometimes even communities with low levels of conflict could react violently to damage caused by wildlife if the tolerance level is low. Regular meetings and discussions are needed to understand the attitudes of different communities (see the section ‘Social Capacity’).

Figure 2. Proposed decision making chart for managing the carnivore-human conflict.

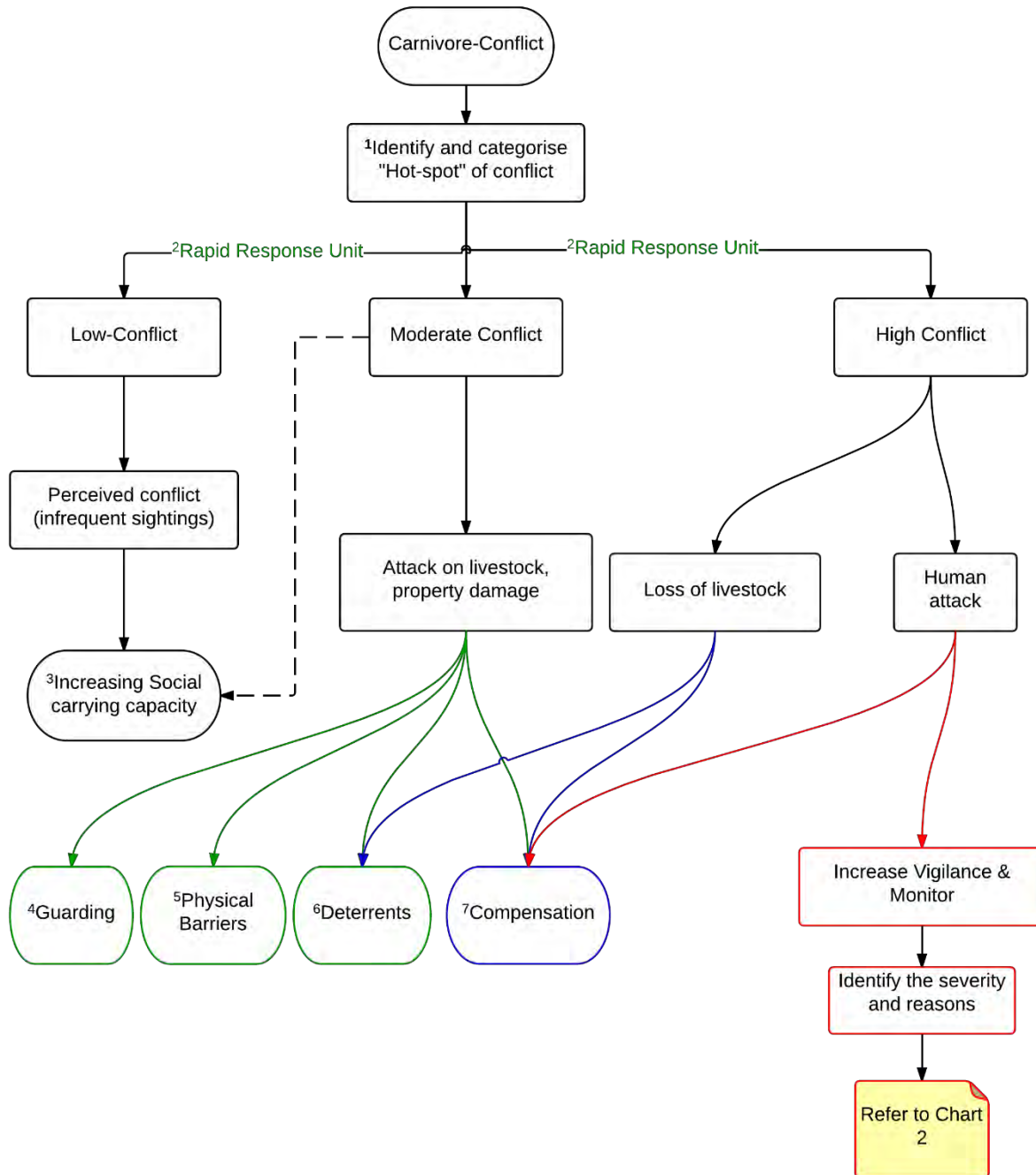
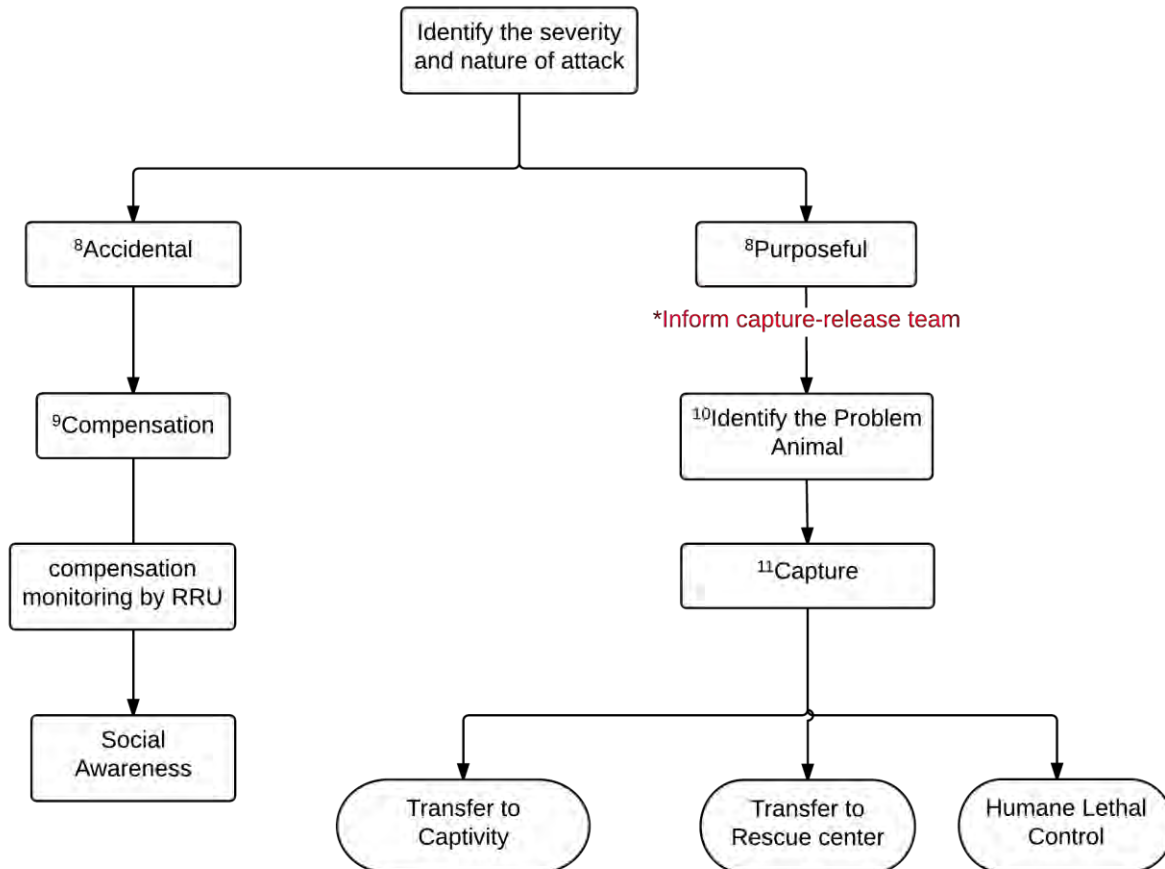


Figure 3. Proposed decision making chart in case of attack on human by carnivore.



Potential hotspots. These are the areas (forest beats, villages, etc.) that could witness an increase in the number of conflict cases in the near future. The hotspots can be in space (village, pasture, forest block) or time (eg. winter season, dawn-dusk period). Spatial hotspots may be so, due to some drivers that make them vulnerable (eg. near forest, near cliffs from where snow leopard can easily attack a corral, remote unattended field where herbivores can damage, etc). Information on the populations of animals and human activity around the forest is required for identifying such hotspots. However, if adequate steps are taken in a timely manner (such as providing fencing, creating social awareness and translocating the increased population to other suitable habitats) potential conflict can be prevented.

UNDERSTAND THE PERCEIVED CONFLICT

After categorizing the surrounding areas into conflict zones broadly, it is essential for the managers to understand the attitude of the villagers towards wildlife. Researchers have started exploring the complex issue of human attitudes towards wildlife (Dickman, 2010; Siex and Struhsaker, 1999; Suryawanshi et al., 2013). In most cases wild species are perceived to be a threat to human life and resources; however, systematic studies have not found a strong basis in support of such perceptions (Siex & Struhsaker, 1999; Suryawanshi et al., 2014). Infrequent sightings of predators and a lack of evidence to prove the involvement of a carnivore in loss of cattle/injury indicates negative human perception. In such situations, it becomes important for authorities to make informed decisions before planning any management.

INCREASE SOCIAL CARRYING CAPACITY

Previously, local communities had more tolerant attitudes towards wild animals because of religious reasons and their long-term attachment with areas (Gadgil & Guha, 1993). However, with the increasing frequency of conflict cases over the years, communities are becoming less tolerant towards wildlife (Dickman, 2010) which might also be exacerbated by the way media reports such incidences in the papers and television. Creating awareness among media, as well as public and policy makers at various scales (local, regional and national) about the unique nature of shared spaces in India which has been part of our history and culture could lead to decreased perception of conflict among people who can change the way public view this issue. Simple

measures adopted by local communities could reduce not only the number instances of in which wild animals are encountered but also the chances of these encounters leading to conflicts. These simple precautionary practices have been described well in various reports and papers. For example, Athreya and Belsare (2007) provide a list of do's and don'ts to avoid being attacked by a leopard, and Charoo et al. (2011) mention precautionary measures for reducing chances of bear attacks on livestock during grazing and at night in pens.

LIVESTOCK GUARDING

Guarding grazing herds can considerably reduce the frequency of attacks on livestock as herdsman with knowledge of carnivore presence in the landscape would avoid the predation hotspots (Karanth et al., 2013). The effectiveness of guarding varies with the number of people involved and the size of the property/herd/farm. There are numerous traditional methods of livestock husbandry in India that takes into account the presence of predators. It is important to study these and use it in for proactive mitigation.

Community guarding. Involving more people in guarding property (farms and livestock corrals) will reduce the number of attacks as well as the number of vigil days per family/individual.

Using livestock guarding animals. In Asia, the use of livestock guarding dogs started some 5000 year ago (Olsen, 1985). It has also been suggested that dogs are the cheapest guarding option both during the day, during grazing, and at night, in livestock corrals. However, the effectiveness of guarding dogs varies according to the breed, terrain of the grazing area, type and density of the predator and the number of guarding dogs (Green et al., 1994). The use of dogs in wilderness as grazing areas should be discouraged as it will affect the wildlife existing in these areas.

Employing local people as guards. In areas where the conflict is very high and unmanageable by the above means, the forest department can employ local people from the villages as night watchmen. This would ensure giving them a source of income and betterment of their livelihoods.

PROVIDE COMPENSATION

Ex-gratia. In the case of the injury or death of a human being as well or livestock, crop-depredation and damage to property due to wildlife, state governments and a few non-governmental organizations provide *ex- gratia* payments in order to reduce the animosity of the

communities cohabiting with the wild animals (Krithivasan et al., 2009; Lenin and Sukumar, 2008; Madhusudan, 2003; Mishra et al., 2003). *Ex-gratia* and compensation in other forms (jobs, subsidies, etc.) have been viewed as an essential mitigation tool in increasing the tolerance of local communities of wild animals (Banerjee et al., 2013).

Innovative insurance schemes. An incentive programme started by the Nature Conservation Foundation (NCF) in Spiti valley to deal with livestock depredation by snow leopards is an excellent example of the use of insurance schemes to reduce human–wildlife conflict. Under this scheme, villagers pay a monthly premium for their livestock, and non-governmental organizations (NCF and International Snow-Leopard Trust) are helping the programme till it becomes self-sustaining. Villagers also receive biannual monetary rewards for better anti-predator herding. The funds generated are used for developmental activities within the village. The villagers have agreed to set aside 500 ha of the area, free of grazing pressure, and thereby provide a chance for the density of the wild prey of the snow leopard to increase.

Similarly, a programme has been started in Pakistan with the help of Project Snow Leopard and a village insurance committee. In this programme, claims are verified by the committee, thereby reducing the chances of fraudulent claims. Unlike the Spiti model, the programme has a two-tier system in which the money is deposited in the insurance fund by the livestock owner as well as the village committee, which receives money through ecotourism activities. In case the loss of a farmer exceeds the money paid by him in the form of premium, the village committee can provide him money from their fund. These could be used in low human density areas, but innovative methods need to be devised for other parts with high density of people.

PHYSICAL BARRIERS

Different physical barriers can be used to prevent entry of carnivore in livestock stocking area, depending upon the situation. In India, barriers are largely prepared to keep the livestock within pens during the night and rarely for providing predator–proof grazing areas. Conventionally fences are made from natural products (thorny bushes, plant poles, rocks, etc.). Different types of physical barriers used in the country are as follows:

Barbed wire fencing. This is a type of steel fencing wire constructed with sharp edges or points arranged at intervals along the strand(s). This form of fencing is used for protecting night pens in India and *bomas* in Africa (Vijayan & Pati, 2002; Sekhar, 1998; Kolowski & Holekamp, 2006).

Chain link fencing. This is a type of woven fence, usually made from galvanized steel wire. It is not used very commonly, mainly owing to its cost. This fencing has been put up on the eastern boundary of Gir National Park to prevent the lions and leopards from straying out as well as to reduce illegal grazing (Vijayan & Pati, 2002). However, considering the cost involved and low effectiveness, this fencing is not used for entire park boundaries (Vijayan & Pati, 2002).

Stone/rubble wall. Construction of rubble walls is limited by the availability of stones. They are expensive to make and elephants can push over unless these are bound with chain-link nets (Sukumar, 2003). Again the height of the wall is an important factor in preventing the entry of animals-

Concrete fencing. This type of fencing involves the use of slabs of concrete or building a wall of sufficient height with a foundation in the ground so that animals do not dig their way in. The efficacy, again, has not been reported, but a few studies mention that this fencing is quite effective (Mehta, 2014).

Nylon mesh. In the Sundarbans, a nylon mesh was erected along the boundary of the park to prevent straying of tigers into villages. This measure has been claimed to be highly effective (Das, 2005).

Physical barriers could restrict natural migratory movement of animal therefore one essential regulation while fencing the forest parts should be done strategically to avoid any resistance to animal movements in corridors.

Rapid Response Units or RRU. These units are currently present only in protected areas and more teams are required all across the country. The unit should have forest department officials, representatives of local NGOs, researchers (environmental science or social science), pradhans/heads of the villages involved and villagers (preferably farmers, teachers). In case of a conflict, the RRU should act to resolve the societal negative attitude by taking adequate

measures as broadly discussed here, but these measures could be tailored to suite the local requirements.

Decision making framework to deal with the situation of attack on humans include two major component 1) confirmation of carnivore involved in attack and 2) strategy to deal with the animal. In case of attack on human being (lethal or non-lethal), situations should be immediately assessed by concerned authorities and cautiously managed. Standard operating procedure and guidelines issued by the MoEFCC and NTCA provide directions to manage human-leopard conflict and situation of carnivores straying in human dominated landscapes (tiger/ leopard). Guidelines to deal with straying bears have also been prepared by the Wildlife Institute of India (see Annexure IV). To differentiate the attack from accidental to purposeful has been described aptly in guidelines issued by Maharashtra forest department to deal with human leopard conflict (Athreya & Belsare 2007). Details about identification, capture and translocation of problem animal have been described in SOPs issued by MoEF & NTCA for tiger ([http://projecttiger.nic.in/Write Read Data/CMS/Final_SOP_11_01_2013.pdf](http://projecttiger.nic.in/Write_Read_Data/CMS/Final_SOP_11_01_2013.pdf)) and human-leopard conflict management (<http://envfor.nic.in/sites/default/files/moef-guidelines-2011-human-leopard-conflict-management.pdf>) & (<http://environmentportal.in/files/Conflict%20management%20manual.pdf>).

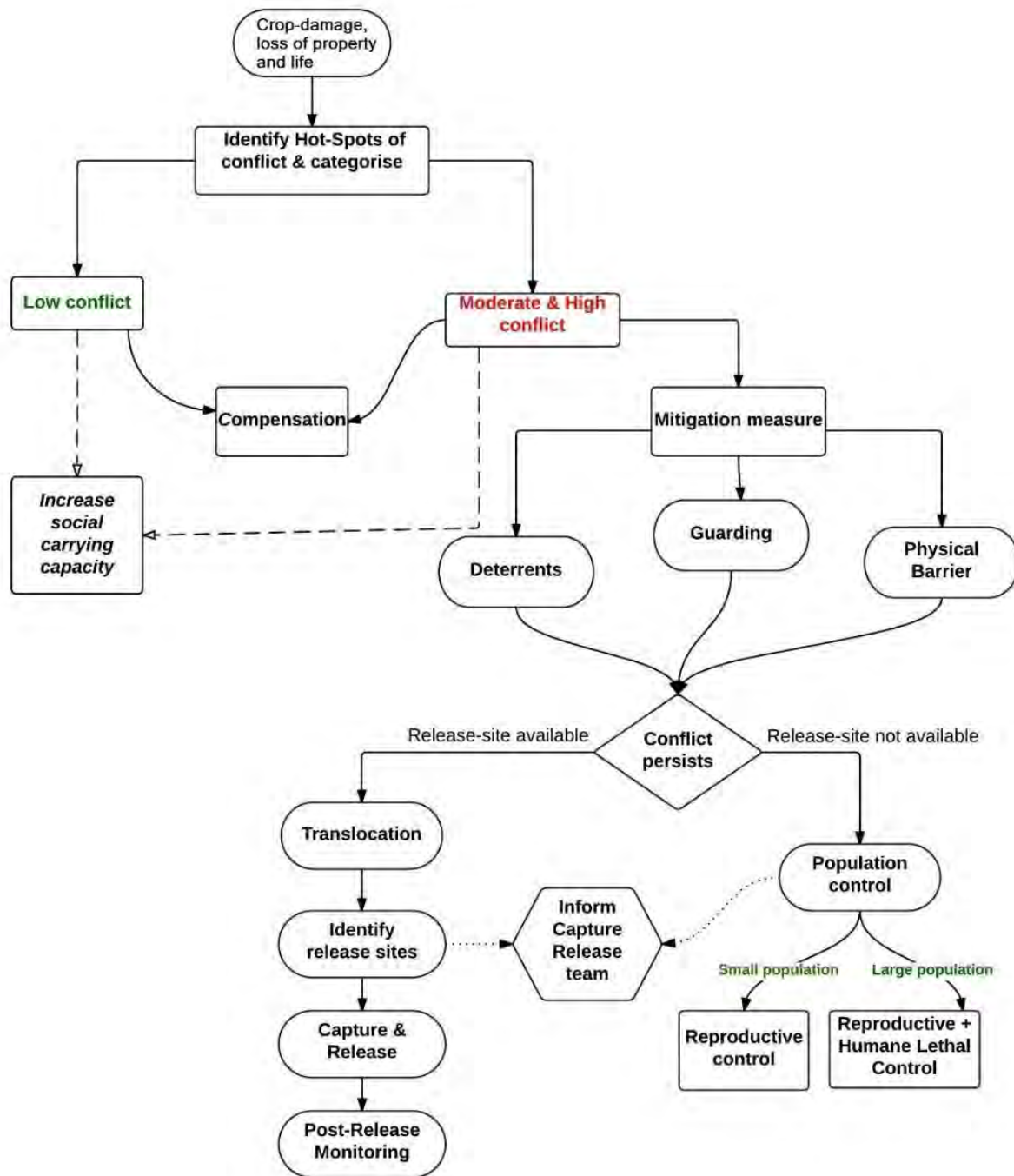
Management of Human-Herbivore Interactions

On the basis of the expert opinion and discussions during the workshop “Human-wildlife interactions and management of invasive species” conducted by the Wildlife Institute of India, a team of scientists and researchers drafted guidelines to manage the human-herbivore conflict in the country. The team also conducted a post-workshop intensive literature survey for preparing decision making flow-charts. The first flowchart (figure 4) provides a decision-making framework for managers to resolve conflict cases using the existing spatial and temporal information related to conflict cases. The second flowchart (figure 5) provides structure of capture and release team for translocation of animals.

Present hotspots. These are the areas (forest beat, village, etc.) that witness relatively high numbers of conflict cases. These hotspots could be different for different types of conflict. Hence in the case of an herbivore interaction, the hotspot could be ranked on the basis of human injury (lethal and non-lethal), crop damage, property damage, loss of life and perceived conflict. Hotspots should be mapped for every conflict on the basis of the frequency of damage and the compensation offered by the forest department. The priority should be: Human death > Human injury + crop/property damage > human injury > property damage > crop damage > perceived conflict. The areas with high frequencies of damage could be further classified for conflict at the micro-scale. Consideration of the social attitudes while mapping the conflict hotspots is crucial as some times areas with the least conflict could react violently and threaten animals and society. This can only be achieved by understanding the attitudes of different villages through regular meetings and campaigns (see section ‘Social Carrying Capacity). The forest department needs to carry out mapping of conflict cases on a yearly basis.

Potential hotspots. These are the areas (forest beat, village, etc.) that could witness increases in the numbers of conflict cases in the near future. This could be due to human encroachment into the forest, increases in the populations of conflict species, etc. To identify such hotspots, precise information about the population of animals and human activity around the forest is required (quantification of these variables could be done according to the scheme of the All India Tiger Monitoring Project 2014).

Figure 4. Decision Making Chart for managing Human-Herbivore Conflict



MANAGING CONFLICTS

If adequate steps are taken (like fencing, social awareness, diverging the increased population to other suitable habitats) in a timely manner, conflict could be mitigated most successfully.

After collecting information on the different criteria (intensity, frequency, tolerance of human communities) related to the conflict, these criteria could be grouped into a single index and partitioned into a scale of ‘**high**’, ‘**moderate**’ and ‘**low**’. In the meanwhile, any conflict case should be addressed immediately to reduce animosity as well as the grief of the victim.

COMPENSATION

Appropriate and timely compensation could reduce the tension between the forest department and the community. The following are the existing and potential compensation schemes:

Ex gratia payments. In the case of injury or death of human beings as well as of livestock, crop-depredation and property damage due to wildlife, state governments and a few non-governmental organizations provide *ex gratia* payments in order to reduce the animosity of the communities towards wildlife (Madhusudan, 2003; Mishra et al., 2003; Krithivasan et al., 2009; Lenin & Sukumar, 2008). Compensation has been viewed as an essential mitigation tool in increasing the tolerance of local communities of dangerous and endangered animals (Banerjee et al., 2013).

Sharing benefits of ecosystem services. An alternative approach of increasing tolerance among communities living close to forested areas is by allowing them to reap the benefits of ecosystem services. Sharing profits generated through ecotourism and economic evaluation of the forest products extracted by communities will instill a sense of ownership among them (Sekhar, 1998). This way, wildlife becomes a valuable resource rather than a liability.

Innovative insurance schemes. A few innovative insurance schemes have been started in India by non-governmental organizations to provide insurance cover to livestock against carnivore attacks. These schemes work well to conserve these predators as well (Mishra et al., 2003). However, so far there have been no such schemes for crop-depredation by wildlife in India.

Challenges. *Ex gratia* payment schemes have loopholes at every level, from verification and estimation of loss due to wildlife to the time of payment (Nyhus et al., 2005).

Precautionary mitigative measures can be adopted by local communities to reduce the chances of conflict. Using deterrents, guarding and installing physical barriers are three major mitigation measures used for preventing entry of herbivores into properties and crop lands. All these methods are discussed in the following.

DETERRENTS

Deterrents are harmless precautionary measures used to prevent animals from gaining access to any kind of targeted source or repelling them from it. Deterrents can be classified into four categories, depending upon the sense organ they target: acoustic (hearing), visual (vision), olfactory (smell) and tactile (touch).

Acoustic deterrents. These deterrents target the hearing sense of the intruding wild animal. Traditional acoustic deterrents used by the farmers against crop-raiding animals were shouting, beating drums, bursting firecrackers, tin-hitting and noise from the whipping rope made from *Eulalopsis* grass. In some parts of the country, guns are also used for creating a sudden noise and scaring away the individual or the group. Playing audio recordings of the predators such as tiger have been used as a deterrent for elephant in southern India but its efficacy is not been reported yet.

Visual deterrents. Scarecrows, coloured cloth strung on fences along fields and fires maintained at corners of crop-fields are age-old visual deterrents used by farmers.

Chemical deterrents. One commonly used olfactory deterrent is chilli. This is mixed with engine oil or grease and applied on fences or ropes all along the perimeters of crop-fields or properties. Chilli smoke and sprays are also used as deterrents. In north-east India, the Assam Haathi Project is experimenting with chilli-based deterrents, especially using the Tezpur chilli (*bhut jholakia*). Tobacco is also efficient as a deterrent, either in conjunction with chilli or alone. These fences have been shown to be more effective in areas with low rainfall in a comparative study conducted in southern India. Pesticides (forite and furadon) have also been shown to deter small animals. In southern India, kerosene and waste oil are poured on potential entry routes for deterring small-bodied animals such as of black-naped hares, mouse deer and porcupines.

Tactile deterrents. Burning sticks and rocks are tactile deterrents used against crop-raiding individuals or groups. Placing of beehives all along crop-fields to prevent the entry of elephants in Nepal and Maharashtra, India has been reported. This method is also claimed to be effective against small herbivores. However, the efficacy of this method needs to be tested. Some deterrents (burning sticks and rocks) could injure the animals and consequently increase the chances of more damage to crop and human life by furious animals. Therefore the use of such deterrents should be discouraged.

Challenges. The major limitation of all these deterrents is their short-term effectiveness against the target animals as most of the animals soon get habituated and start ignoring the deterrents. Another major problem associated with all the deterrents is that they do not really solve the problem and merely shift it from one location to another.

GUARDING

Guarding is the most common form of preventing wildlife from entering farms. Night vigils are kept by almost all the farmers in the country. However, the effectiveness varies with the number of people deployed and the size of the farm. Also, fatigue plays an important role as people have to stay up all night to ensure that wild animals does not enter the farm. The economics of this activity is also seldom understood—the people engaged in night guarding lose a lot of opportunities that they would otherwise have during the daytime. Many of the problems of guarding (e.g. fatigue and scarcity of manpower) can be addressed by combining guarding with other measures such as barriers and deterrents.

Community guarding. Farms are usually situated in a continuous stretch of land and are not very scattered. The owners of all the farmlands and the community can collectively guard all the farms, irrespective of ownership. This can develop unity among the farming community and local villagers as they participate in the same activity and this will lead to better protection in a selfless manner.

Using dogs. Dogs are great pets to keep and are successful most often in keeping ungulates at bay. The number of dogs on a farm depends on its size. Dogs can be kept at all strategic locations in a farm, and being nocturnal, they can easily patrol the farm and deter wildlife.

However, the use of dogs in forests as grazing areas should be discouraged as it will affect the wildlife existing in these areas.

Employing locals as guards. In areas where the level of conflict is very high and is not manageable using the previously described methods, the forest department can employ some unemployed locals from the villages as night watchmen. This will give them a source of income and improve their livelihoods.

PHYSICAL BARRIERS

Barriers are popular wherever conflict is severe as they separate people and animals. The efficacy of these barriers also varies.

Barbed wire fencing. This is a type of intertwined galvanized steel wire fencing has pieces of wires with sharp edges or points arranged at regular intervals along strand(s). Any animal trying to pass through or over the barbed wire will suffer discomfort and possibly get injured. This form of fencing is commonly used all over the country. However, its efficacy and cost effectiveness are questionable. Animals such as wild pigs dig below them, making passages to enter fields. Sturdy animals such as the nilgai have been known to break this fencing by damaging the posts that hold the fence or even jump above the fences if the height is not adequate.

Chain link fencing. This type of woven fence is usually made from galvanized steel wire. Its use is not common mainly due to its cost. The efficacy of this type of fence is seldom reported. Also, it has the similar limitations as those of barbed wire fencing.

Stone/rubble wall. Construction of rubble walls is limited by the availability of stones. They are expensive to make and can be easily pushed over by elephants unless they are cemented or are bound with chain link nets (Sukumar, 2003). Again, the height of the wall is an important factor in preventing animals from entering

Concrete fencing. This type of fencing involves using slabs of concrete to create a wall of sufficient height that has a foundation in the ground so that the animals do not dig their way in. The efficacy of concrete fencing, again, has not been reported yet, but a few studies mention that they are quite successful (Mehta, 2014).

Bio-fencing. This form of fencing involves planting non-palatable and hardy species to hold back intruding herbivores. Plants commonly planted along the boundaries are thorny plants such as Euphorbia (cactii) and *Agave*. At times, non-preferred crop species such as chilli are grown along the boundaries of farms. Currently this technique is under experimentation, and its effectiveness needs to be assessed.

Electric fencing. This form of fencing uses an electric shock to prevent animals from entering farms. The shock is mild and keeps the animals at bay. It is advocated frequently, but has issues related to cost-effectiveness and maintenance.

Trenches. Trenches are used in areas where there is human–elephant conflict. Also, tea garden owners and farmers with large land areas often dig cattle-proof trenches to keep cattle/deer away from their plantations. The trenches should be wide and deep enough to prevent animals from crossing over (Fernando et al., 2008). The trenches work well in combination with electric fences (Desai, 2002; Kulkarni et al., 2007; Parker et al., 2007). The problem with trenches is that animals such as elephants are known to kick the earth into the trenches they can cross. This also leads to gully-erosion in high-rainfall areas.

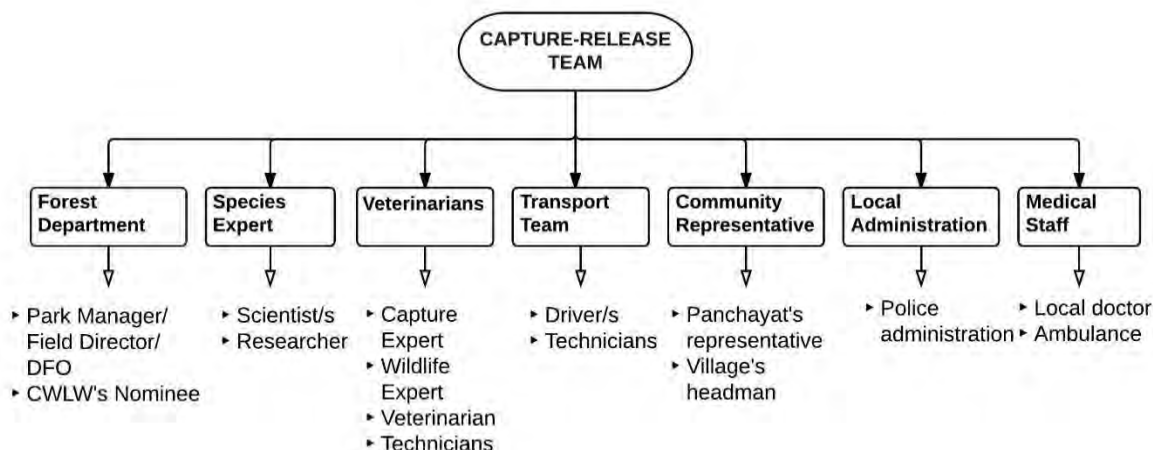
Construction and maintenance of fences by the government is unsustainable. Therefore, fencing should be done on a participatory basis. When the community is involved in either erecting or maintaining a fence, there is a better chance of success. The other option is subsidizing construction of fences for farmers. This way they maintain the fences as their own, and hence these will be more effective as barriers.

MEASURES INVOLVING TRANSLOCATION/POPULATION CONTROL OF WILDLIFE

In case mitigative measures fail to reduce the number of conflicts the options to control the population of the wildlife in a scientific manner need to be used. This will reduce the antagonism of the community towards the animals as well as against the authorities. Translocation and population control are the two methods used to reduce the number of individuals in a given area. Translocation of animals can be done depending on the availability of free and/or less populated potential habitats. In case potential habitats are available, the authorities can translocate animals. It has been observed that animals translocated to new areas become disturbed due to new territory and therefore come in conflicting situations again (A. Desai *pers comm*). The methods

of translocation are species-specific. If translocation is selected, a capture–release team should be prepared for execution of the process (see figure 5).

Figure 5. Members of *Capture-Release* team for capture, translocation and release.



If habitats are not available, population control remains the only viable solution for conflict management. In case of non-availability of potential habitat/s, managers could decide to control population through either reproductive control, humane lethal control or a combination of both.

REPRODUCTIVE CONTROL

According to Garrott (1995), most ungulate species that present problems of local overabundance are medium-to-large mammals with polygamous mating systems where dominant males mate with many females and limit breeding opportunities of subordinate males. In polygamous system reproductive control is most important as even few males can potentially serve the reproductive needs. Any management program designed to control population growth by inhibiting reproduction must evaluate the proportion of the population that must be treated to obtain a desired effect (Garrott 1995). The success of many contraceptive programs depends on costs and ease with which animals can be effectively treated. Three factors limit the level of treatment attainable in the field: (1) the proportion of animals that can be detected, (2) the proportion of animals detected that can be successfully treated, and (3) the efficacy of the contraceptive agent (Garrott 1995).

A relatively high proportion of animals must be treated to significantly reduce reproduction in most situations (Garrott 1995). A highly optimistic scenario would be that if from 90% of the target, 90% animals are treated successfully, and the contraceptive has a 95% efficacy. In such scenario, the level of treatment realized would be $0.95 \times 0.90 \times 0.90 = 0.77$. Thus, under a best-case scenario, nearly 25% of the population remains reproductively active after initial treatment. A more realistic scenario for many wildlife populations may be treated 75% to 80% with a contraceptive 90% effect. This would result in an effective treatment of more than 60% of the targeted population. Several studies suggest that rapidly growing populations may not be stabilized or reduced unless 60-80% of the animals in the population are effectively treated (Garrott 1991, Garrott *et al.* 1992, Hone 1992). In the U.S., feral horse mares and female white tailed deer were injected with contraceptives in a non-operative manner and these contraceptives were recorded to have an efficacy as high as 90% (Kirkpatrick *et al.* 1990, 1992, 1995; Turner and Kirkpatrick 2002, Kirkpatrick and Turner 2008). And these vaccines can produce the desired effects on a wide range of species, especially ungulates.

SOCIAL CARRYING CAPACITY

Understanding and addressing the human-wildlife conflict is incomplete without addressing an aspect -the social component. Human-wildlife conflict cases have increased globally and expected to rise further in future. In such situation it becomes important for the authorities to use not only the biological tools for deterring, restricting and controlling wild animals but also the social tools for increasing the social carrying capacity of the humans sharing space with wildlife. Following text incorporates few methods of raising the social capacity of local community

Social carrying capacity forms an integral part of every aspect of the decision making in managing conflicts. The economic loss of a conflict can be resolved through economic compensation. However, the stigma attached to the wildlife remains in society after every conflict case. Social mitigation needs to be focused on by mitigating the negativity of interactions. The societal attitude that animals are the property of the forest department needs to be changed. This can only be achieved through experiments with social capacity and the involvement of the public in solving the conflict. Hence we propose that the formation of more rapid response units (RRUs) is essential for all protected areas as well as other conflict areas.

RRUs are currently present only in protected areas and more teams are required all across the country.

Team: The team should have forest department officials, representatives of local NGOs, researchers (environmental science or social science), pradhans/heads of the villages involved and villagers (preferably farmers, teachers). In case of a conflict, the team should act to resolve the societal negative attitude by taking adequate measures as broadly discussed here, but these measures could be tailored to suite the local requirements.

If any villager is lost due to an attack by a wild animal

1. Appropriate economic compensation in accordance to the state rules should be provided as soon as possible.

If any villager is injured due to attack of wild animal.

1. He should be moved to the closest hospital by the RRU ambulance while providing first aid treatment.
2. Creative insurance policies should be encouraged that considers the medical necessity of such victims.

In case of damage to property.

1. In case the only available house to the family is lost, they should be provided with alternative shelter in the same village.
2. In case, a commercial property was damaged, innovative subsidies should be encouraged that guarantees the economic compensation of such loss.

In case of damage to crop.

1. The owner should be compensated as per the clause of state.
2. In case of conflict prone areas, the villages should be recommended for common big fencing on basis of innovative subsidies as it reduced per head cost and is comparatively cheaper.

3. For high conflict zone, a chowkidar should be provided for surveillance. The guard needs to regularly interact with the villagers to form a team of volunteer who in the time of conflict could be called for channelizing the animals back to the forest.

The team should possibly undertake following measures to increase social capacity.

1. The team has to hold timely meetings with villagers of the area that suffers conflict. The team needs to learn the problems of villagers regarding any conflict and needs to ask for the legal solution.
2. Primary health center should be made available and equipped with the kind of injuries expected in the park area. RRU should also have an ambulance to be used in case of any emergency, and toll free number for calling ambulance should be displayed on the important areas of the village.
3. The team should also hold timely discussions and lectures in the schools of conflict areas. In case of colleges and university, the team needs to conduct for workshops for skill development of youth who could provide innovative ideas to manage the conflict case.
4. The display board of 'do's and don'ts' should be placed at all important places in village that illustrates about avoiding conflict and acting smartly in the time of conflict.

Management of Human-Macaque Interaction

On the basis of the expert opinion and discussions during the workshop “Human-wildlife interactions and management of invasive species” conducted by the Wildlife Institute of India, a team of scientists and researcher designed these draft guidelines to manage the human-macaque conflict in the country. Team also conducted a post-workshop intensive literature survey for preparing these decision making flow-chart. The following flowchart (figure 6) provides a decision-making framework for managers to resolve conflict cases using the existing spatial and temporal information related to conflict cases.

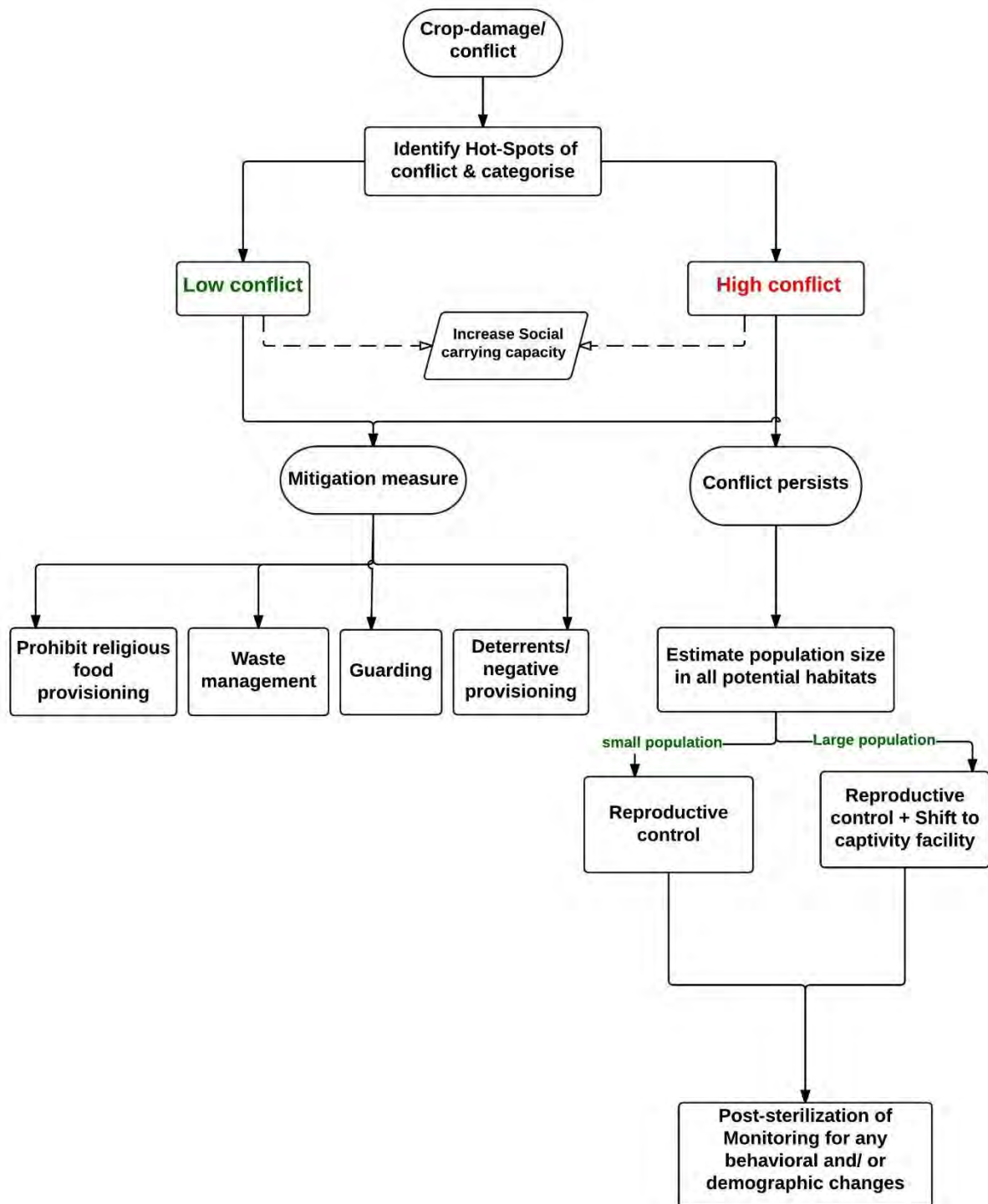
IDENTIFY CONFLICT HOTSPOT

Based on the loss caused by crop damage and direct attacks by non – human primates, the conflict may be classified into low conflict and high conflict zone. Mean a daily range of rhesus macaque is ~1.2 km in human habitats and ~1.9 km in forest habitats (Wada 1984), which implies that managing habitat at the level of village is not sufficient to curb conflict. Accurate information on ranging scale of macaque and spatial interaction between troops can inform us on the zone of influence, where management actions has to be targeted. Understanding ranging patterns of macaques in relation to resource availability can be applied to map the areas with high probability of human macaque interaction (human–macaque interfaces).

INCREASE SOCIAL CARRYING CAPACITY

In the conflict area, awareness programs that intend to increase the social carrying capacity should be stressed. Such programs can highlight the need of proper waste management, prohibiting animal feeding and use of deterrents in case of attacks by the animals. Particularly around the religious constructions where many macaques are fed, it is essential to put a notice board pointing the prohibition on feeding animals. In case of areas with moderate to high conflict, one needs to use combination of action and prevention. Social carrying capacity can also be increased by strengthening JFM, initiating eco-development programmes and ensuring an efficient system for payment of *ex-gratia* relief to the victims.

Figure 6. Decision support chart for managing non-human primate conflict in India



SOLID WASTE MANAGEMENT

It is one of the main reasons for increasing the negative interaction with these species. In the areas with high to moderate conflict, large scale solid waste management should be addressed for which the involvement of communities, panchayats/municipal corporations, forest department and NGO's is essential. An awareness campaign should be held in such areas for proper waste management, the dump yards should be covered and regularly cleared. Food waste from the sub urban areas and villages contribute to the large portion of the diet of these species. Hence, it should be converted to compost by filling in the compost dig and covering it with layer of cattle dung and mud.

GUARDING

People are often charged and food is snatch relatively more in few hotspots of the village or settlement. Such places need a guard who could drive away such problem individual and rescue the victim. The guard may keep dogs that help to drive away the problem individual. Considering their usefulness in keeping problem monkeys at bay, particularly in strategic locations like hospitals, schools, offices, etc. trained langurs may also be used as guard animals with due permission from the CWLW.

DETERRENTS AND NEGATIVE PROVISIONING

Catapults are used by people to scare the macaque that induce negative provisioning. Electronic sound modulator that makes ultrasonic sounds causing discomfort to monkeys present there in residential areas are suggested particularly for the agricultural store houses and poultry safeguards. These high intensity ultrasonic sound waves (10-65 KHz) are out of the range of hearing of humans and most household pets. Barbed wires, monkey snares and metal spokes are often used for repelling the macaque menace around the settlements. However there is no scientific study on the efficiency and long-term consequences of such product on macaque behavior.

POPULATION STATUS ESTIMATE

Before investing the efforts for controlling the population of macaque it is essential to know their population status. For estimating the population, one may stratify the area into equal sized grids. In each of these grids, total count using area search method and mark resight sampling should be conducted. The number of individuals, their age sex composition and habitat covariates should be recorded. From this information, age sex specific and overall macaque densities can be estimated and their population trend and growth rates can be monitored to assess management effectiveness.

Based on the population size and conflict cases one may opt for: Reproductive control (in case of small population, less frequent conflict) and Removal of individual combined with reproductive control (in case of large population and frequent conflict).

REPRODUCTIVE CONTROL

Rhesus macaque males have been sterilized to reduce population recruitment and growth (Fooden 2000). But with a promiscuous mating system (45% of offspring sired by sneak mating) (Berardet *al.* 1994), few fertile males can still sire offsprings of multiple females. Therefore, male sterilization may reduce but not stop population growth. Female contraception, on the other hand, can be a viable solution, but not so widely practiced and developed. Hence, female rhesus macaques should be sterilized preferably with non-surgical techniques used for primates. Methods such as oral administrative contraceptives, intra-uterine devices, and blockade of tubal patency following transcervical administration of polidocanol foam (Jensen *et al.* 2013) should be used. The sterilization should be done in such a manner that the population reduces but remains at a stable size so that troops from outside will have minimum chance of displacing the resident troops. Scientific expertise and facilities for this program need to be developed in consultation with organizations having similar experience, expertise and agenda (Indian Veterinary Research Institute, Institute of Animal Health and Veterinary Biologicals, Uttarakhand Forest Department etc.).

REMOVAL OF PROBLEM INDIVIDUAL

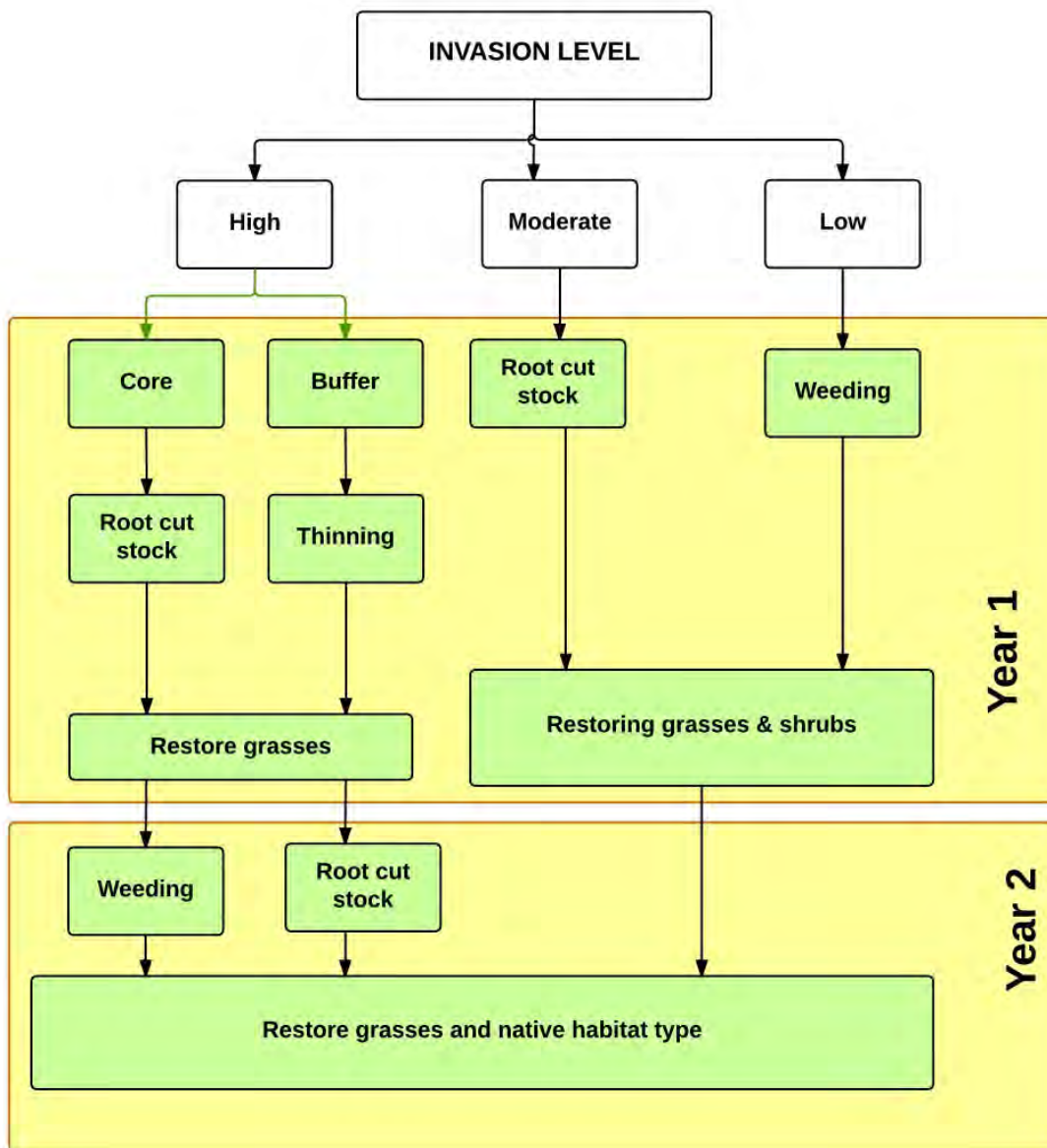
Removal of specific macaque individuals that show persistent aggressive behavior or learnt raiding behavior should be implemented. These few individuals are responsible for most of the

negative interactions with humans. Their targeted removal to rehabilitation centres (captive enclosures) or reducing aggressive behavior by hormonal control/ therapy should be resorted. The cost of rearing such captured individual is high, however as the society bears an emotional attachment with the species, keeping such individuals in captivity is the only solution.

The reproductive control and capturing of animal should always accompany pre – action and post – action population status and the behavioral response of the animals. Rigorous ecological surveys are hence continuously needed during the proper management of this negative interaction.

The current guidelines (Figure 7) have been formulated for lantana management in forested areas on the basis of experts' knowledge and published information. The present strategy is adapted from Ramaswami et al. (2014) and Love et al. (2009).

Figure 7. Decision support chart for *lantana* management in forested areas.



1. Invasion level

Before proceeding with any management plan, the manager needs to understand the distribution of lantana and the level of invasion in and around the park. This assessment of the invasion level could be carried out using the vegetation sampling protocol of the All India Tiger Monitoring Project (Jhala et.al., 2013). According to this protocol, a 2 km transect is to be laid in every beat (an area of 25 km² should have at least three transects). On each transect, circular plots of radius 15 m are to be established at every 400 m to quantify the abundance of native and invasive plants. After collecting data from these transects, the manager needs to map the abundance of lantana within that area. Such monitoring provides baseline data on the level and stage of invasion. It also helps identify other problematic invasive or exotic species that may turn invasive in the future.

2. Conservation prioritization

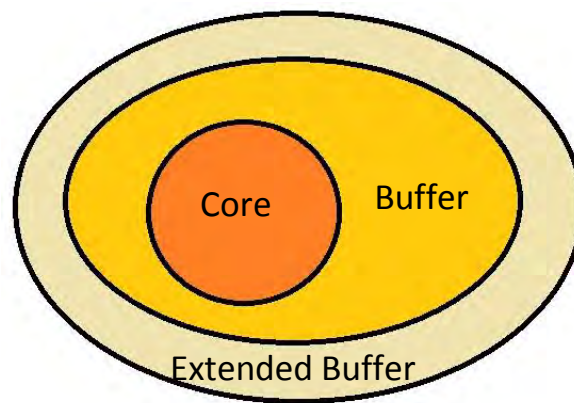
The management strategy needs to be shifted from complete eradication of lantana to restoration of key habitats. These key habitats should be identified on the basis of the ecological value of the patch. In general, lantana should not be allowed to establish itself inside protected areas. In buffer and revenue forests, the invasion level should be kept low until and unless a complete restoration plan is prepared. Grasslands (e.g., *bhabhar*), savannas (e.g., Kachch, Keladevi), sparse canopies, grass-dominated understory vegetation and riverine patches are highly susceptible to dense lantana invasions (Ramaswami & Sukumar, 2013). All such areas should be priority areas for yearly management and should be mapped for prioritization. Sometimes even a small sparsely invaded patch or a few plants in a grassland or meadow (e.g., Kanha meadows) that serves ungulates in a forest or rare habitat (e.g., shola grassland) could result in ecological damage if left untreated and hence should be given similar priority.

3. High-priority highly invaded areas

Once priority areas are identified and assessed, a systematic removal programme should be undertaken for different levels of invasion and conservation priority. As mentioned in Ramaswami et.al. (2014) most of the highly invaded patches have dense thickets of lantana which are surrounded by the buffer of sparsely distributed lantana. In the first management effort

(Year 1), the dense thicket core (core, figure 6) is cleared using root cutstock method (section 4). Simultaneously areas surrounding the first effort are thinned (section 5) (buffer, figure 1). Active grassland restoration is done in the core while grasses and shrubs are restored in the buffer. In the second year, weeding is carried out in the core, and active management can be undertaken for the buffer using the root cut stock method or weeding, depending upon the density of the lantana. The treated area is actively restored and a further, extended buffer is identified that can be managed in the next year. Gradually increasing the size of the buffer in subsequent managements will reduce the dispersal of lantana seeds into the priority area.

Figure 8. Phased management plan for “High-Priority” and highly invaded area. The central core represent high density patch of lantana which is managed in the 1st year followed by buffer in the 2nd year which is later followed by extended buffer.



4. Thinning

In a moderately dense patch of lantana, few plants should be removed to reduce the overall density and make the plants highly separated so that they can be manually removed in the next season. A mechanical crane could be used if the patch is large and approachable; else an axe can be used. The rest of the standing plants in the plot are usually thinned by cutting their branches and shoots.

5. Weeding

Sparse lantana plants or young plants should be manually uprooted by laborers. Usually an axe is used by people cutting the plant. The plant should be removed in the same way as in the root cutstock method.

6. Restoration

For any active restoration programme, native grasses should be planted in the first year as they can provide competition to the invasive species in recolonizing the site. Seedlings and seeds of grasses from nurseries should be planted in the first year. While purchasing the seedlings and seeds, one needs to ensure the quality of seeds so that no plant (native or exotic) is introduced other than the desired one. In case the area is heavily used by ungulates/livestock, it needs to be fenced. Though fencing bigger areas is costly affair, it is crucial as browsing by ungulates can nullify all the efforts undertaken for restoration. However, portable fences, biological fences, etc. could be useful in reducing the costs and hence should be given due priority in the management plan. In the subsequent years, if needed, active restoration can be undertaken by planting species belonging to the native habitat. For example, in case the native habitat type is sal forest, sal saplings should be planted. For passive restoration, see section 5.

7. Utilization of removed plant material

The eradicated plant material should be used rather than being burnt or abandoned in the forest as burning may contribute to liberation of fixed carbon. The eradicated lantana can be utilized for furniture production, paper production, etc. it is recommended that the communities around the forest be involved in this production as it can uplift the economic status of the communities and gradually lessen their dependence on the forest. The potential utility is described by Thekaekara et al. (2013) and Patel (2011). Training for furniture production is provided by the Women Empowerment through Lantana Furniture and Artefacts and Restoration of Environment (WELFARE) project in Corbett, Lantana Craft Centre, Ashoka Trust for Research in Ecology and the Environment (ATREE) in Bangalore and a Dehradun-based NGO named Himalayan Environmental Studies & Conservation Organization (HESCO).

8. Post-management monitoring and follow-up management

In case the habitat is moderately or less prioritized, i.e. it is out of the protected area and has low ecological value, and the invasion level is less, active restoration may be monetarily challenging. Hence, continuous monitoring of the site is advised for quick removal of any regenerating individuals. Weeding should be continued as soon as any young plants are detected. Managed patches should be monitored for at least 5–10 years as Ramaswamy et al. (2014) found that plants regenerate even after 2 years of continuous management. The reinvasion of that site can be prevented by managing the nearby sites, thus increasing the buffer of all the managed areas. A manager must keep in mind that none of these methods is likely to result in complete eradication as seed sources are often located in the surrounding agricultural, urban and forest areas as well. Therefore, subsequent monitoring will help with early detection and reduce the probability of reinvasion.

***Prosopis juliflora* (Prosopis) management**

The management strategy for Prosopis is similar to that of lantana management. However, the root cutstock method is applicable for Prosopis shrubs and not for trees. In the case of trees, it has to be manually cut, which can be achieved by involving local communities. As it was found in Kachch, where the native flora was illegally disturbed and the public participated in management, a team of guards should patrol the ongoing management site for safeguarding the native flora. This management should be done before the monsoon, and the native grasses should be planted with the first shower of the season. The utility of eradicated prosopis is attached in the appendix 6. Continuous monitoring of the area should be done and any regenerating Prosopis plant should be uprooted.

'Prosopis society (of India)' was established at CAZRI in 1993 that intended harvesting prosopis for sustenance of natural systems, grazing pastures and community economics. It developed a detail technical manual regarding the Prosopis management; partially for Rajasthan, Gujarat, Madhya Pradesh and Tamil Nadu (2000).

- State Governments to purchase prosopis pod flour as subsidized livestock fodder in drought; prosopis is cheaper and more nutritious than the alternatives, and is locally available thus improving rural economy and employment generation.
- Joint management of roadside trees, Forestry Department paying villagers day rates to thin, single and prune, generating employment and training villagers.
- Encourage State Forestry Departments and State Forest Development Corporations (SFDC) to promote and market prosopis tree products, and establish a SFDC for Rajasthan.
- Establish independent funds for commercial processing, as lending institutions appear unwilling to provide credit to prosopis -based business.
- Promote assured markets for prosopis products through government intervention, positive 'press' and pressure on private enterprise to establish industries for tree product processing.
- Guarantee a market price for an initial period to stimulate management, production and processing of new products such as prosopis timber or pods.
- Record the area under prosopis, available from village accounts and annual seasons and crop reports.

- Detail the quantities of charcoal exported from state to state, derived from ‘certificate of origin’ issued by State Forest Departments and also for pods and other tree products.
- Demonstrate cheap, simple improved kilns for charcoal production and small scale pod processors, and prosopis for furniture making.

***Mikania micrantha* (Mikania) management**

Presently experimentation is required for managing Mikania. However in case of managing the priority area one can use the traditional method in which Mikania is mechanically removed and the shoots are burnt. Mikania vines should be cut near the ground once a month for three consecutive months in summer and autumn and then in winter and spring. This method was tried in china and 90% of the plants can be eliminated (Zhang et.al., 2004). Manual control in newly infested crop areas have been carried out by rolling, drying and burning the plants but this proved to be unsustainable.

***Parthenium hysterophorus* (Parthenium) management**

Ploughing the weed before the plants reach the flowering stage and then establishing pastures may be effective in the agricultural areas and other approachable areas. In the case of a forest, the soils should be loosened by ploughing and then the plant should be uprooted. However, *Parthenium* has been reported to cause respiratory and skin problems in humans (Sharma, Verma, & others, 2012; Towers & Mitchell, 1983). Hence the labourers involved should be provided with masks and safety costumes. Management should be followed by active restoration of grasses.

Chemical and biological control strategies have been provided in the following. However, all these strategies have not been tested for their effects on the environment and hence have no utility in Indian forests. Their effects on all the environmental cycles and different trophic levels should be determined through experimentation. These experiments will require a scientific advisory. Moreover, the use of any pesticide or herbicide is prohibited in any protected area.

Bio-control by introducing a foreign agent should be avoided as it can have detrimental effects on the native flora and fauna as testing sensitivity of every native species is not feasible.

Review of Policy and Legal Instruments for Management of Invasive Species (IS) in India

1. Policy documents having implications for management of IS

1.1. Forest and Wildlife

1.1.1. Forest Policies:

- I. Forests under the control of the Government in India are required to be managed on the basis of silvicultural principles which stress upon control of weeds and pests. IS have been engaging the attention of the foresters for over 120 years now²⁷. But, neither the National Forest Policy-1988 nor most of the existing State Forest Policies make a direct reference to IS. An exception is made by the Jammu & Kashmir State Forest Policy-2010 which admits that invasive weeds contribute toward failure of regeneration (Para 2.3). It stipulates that forest areas heavily infested with invasive weeds will be systematically treated to restore the natural mix of vegetation in order to augment the supply of fodder, firewood, timber and other forest produce [Para 4.3 (g)]. The Madhya Pradesh State Forest Policy-2005 makes an indirect reference to IS while stating that an appropriate system of forest management shall be developed for protection from various kinds of diseases and destructive forest- pests (Para 3.3.6).
- II. Most of the Forest Policies caution against introduction of exotic species. The National Forest Policy-1988 stipulates that exotic species should not be introduced in forests through public or private sources, unless long-term scientific trials undertaken by specialists in ecology, forestry and agriculture have established that they are suitable and have no adverse impact on native vegetation and environment (Para 4.3.3). This point is reiterated by the Chattisgarh State Forest Policy-2001 (Para 4.2.3), Assam State Forest Policy-2004 (Para 4.2.4) and Maharashtra State Forest Policy-2008 (Para 3.3.9).
- III. Some State Governments show reservations about prohibiting exotic species and IS:
 - a) The Haryana State Forest Policy-2006 stipulates that only the suitable indigenous species should be used for plantation in wildlife sanctuaries (Para 4.4.2), but it goes on to say that block forests like that of Shiwaliks should *gradually* be planted with lesser known (?) indigenous species *to the extent possible* (Para 4.4.6)—thereby providing a ruse for use of exotic species.
 - b) The Rajasthan State Forest Policy-2010 does not appear to have any serious issue with the IS or exotic species. It states that: “Though damage to forest due to pest and disease is rarely seen in forest areas of the State, it can be controlled by taking collaborative support from research institutes as and when required” (Para 5.3.12). The Policy stipulates that plantation in the desert areas should be taken up with indigenous xerophytic species but *exotic species can be used in lesser quantity depending upon locality factors* (Para 5.8.4). There is an obvious dilemma as how to

²⁷ For example, refer to Inspector General of Forest's note titled “Is the Lantana a friend or an enemy?” in the Indian Forester, December 1895.

- deal with *Prosopis juliflora*—a known IS. It is contended that *Prosopis juliflora*, which has extensively spread on all kinds of wastelands, is being used by the people as firewood and charcoal—thereby helping in reducing illicit felling of trees in natural forests, and therefore, a ‘careful review of the policy directives from time to time’ has been suggested (Para 5.5.3).
- c) The Uttarakhand State Forest Policy, which is otherwise silent on IS, calls for research to promote utilisation of Lantana (Para 4.7) and seeks to encourage industries based on forest products including Lantana (Para 4.8).
- IV. Interestingly, the Chattisgarh State Forest Policy-2001 is the only policy document which specifically prohibits introduction of exotic faunal species into the forests (Para 4.9.1).

1.1.2. National Working Plan Code-2014:

- I. If there is anything wanting in the National and the State Forest Policies as regards management of IS, the same has been amply compensated by the National Working Plan Code-2014. Working Plans form the cornerstone of forest management in the country. National Forest Policy-1988 stipulates that no forest should be permitted to be worked without the Government having approved the management plan, which should be in a prescribed format and in keeping with the National Forest Policy (Para 4.3.2). The Supreme Court of India, in its orders dated 12.12.1996 and 12.5.2001 in the Godavarman case [WP (Civil) No. 202 of 1995], has directed that no forests will be harvested unless in accordance with a Working Plan duly approved by the Central Government. The MoEF&CC has prescribed National Working Plan Code-2014 for preparation of Working Plans by State Forest Departments.
- II. The Code emphasizes upon the management of pests and weeds to maintain forest health (Para 13). It recommends assessment of area infested by invasive weed species in forests (Para 68). The Code prescribes that there should be provision in the Working Plan for exclusive or overlapping mandatory working circles related to various issues including management of invasive species and weeds (Para 89). It prescribes that the compartment description should classify the area for presence of weeds as very dense, dense, moderate, scanty and absent (Para 110). The Code also prescribes the maintenance of a register for keeping record of eradication of Lantana and other invasive species (Para 134).

1.1.3. National Wildlife Action Plan (2002-16):

- I. The NWAP (2002-16), framed by the MoEF&CC, can be treated as a supplementary policy statement by Government of India, and leaves no doubt that management of IS within or outside the Protected Areas (PAs) needs to be taken seriously.
- II. The NWAP calls for technical assistance to each PA for control and eradication of exotic invasive species (Chapter-II, Para 5.1). It calls for preventive action against the introduction of related species which may cause interbreeding among taxa and

hybridisation, and also ordains against ‘further introduction of floral and faunal species exotic to the locality’ in PAs or in areas from where they are likely to invade PAs (Chapter-III, Para 3.3).

1.1.4. Centrally Sponsored Schemes:

- I. The Central Government has been re-enforcing its policy towards control of IS in forest areas by providing financial support to the State Governments under various Centrally Sponsored Schemes (CSS).
- II. The Central Government has since long been providing financial support under some CSS, viz. Project Tiger, Project Elephant and Integrated Development of Wildlife Habitats, for improvement of wildlife habitats within and outside PAs. Management of IS in accordance with Management Plans is a permissible activity under the said schemes. The Central Government also provides financial support for removal of IS, particularly water hyacinth (*Eichornia crassipes*), from selected Wetlands.
- III. The Central Government has been providing financial support for eradication of IS from general forests under the CSS named ‘Intensification of Forest Management’ during the 12th Five Year Plan.
- IV. Many State Governments also provide funds to their Forest Departments for control of IS from wildlife habitats and forest plantations.

1.2. Agriculture and Livestock

1.2.1. National Agriculture Policy-2000:

The Policy seeks to give particular attention to quarantine, both of exports and imports, so that Indian agriculture is protected from the ingress of exotic pests and diseases.

1.2.2. National Policy for Farmers-2007:

The Policy (Para 5.2.1) acknowledges the importance of agricultural bio-security covering crops, trees and farm and aquatic animals since it relates to both the work and income security of a majority of the population and the food and trade security of the nation. It proposes to establish an integrated National Agricultural Biosecurity System (NABS) covering crops, animal husbandry, fisheries, forestry and agriculturally relevant micro-organisms. The objectives of NABS, *inter alia*, include organisation of an integrated national agricultural biosecurity programme on a hub-and-spoke model, with effective home and regional quarantine facilities capable of insulating the major agro- ecological and farming system zones of the country from invasive species of pests, pathogens and weeds as well as from the introduction and release of Genetically Modified Organisms (GMOs)’.

1.2.3. National Agroforestry Policy-2014:

The Policy, though silent on the use of exotic species in agroforestry, does seek to encourage agroforestry research, both in government and private sector, particularly for multipurpose

indigenous species with higher nitrogen-fixing ability, so as to meet the local needs for fuel, fodder and timber as well as improving the soil health (Para 6).

1.2.4. National Livestock Policy-2013:

- I. The Policy seeks to strengthen quarantine facilities to prevent the ingress of exotic diseases and synchronisation of the system of sanitary certification for export with global standards to promote export (Para 13.4).
- II. The Policy (Para 13.8) seeks to put in place a national institutional mechanism, in collaboration with the ICAR and other institutions, to deal with the issue of biosecurity in the livestock sector. It proposes necessary legislative back-up for enforcement of biosecurity along with strong quarantine facility, appropriate risk analysis and risk mitigation. It also proposes to regulate import of livestock, their products, vaccines and diagnostics to prevent ingress of exotic diseases.

1.3. Environment and Biodiversity

1.3.1. National Environment Policy-2006:

Despite the fact that the IS pose tremendous environmental hazards, they don't get any direct reference in the NEP-2006. But the NEP does reinforce the concerns raised by the agricultural policies about the negative fallouts of genetic-engineering and by the forest policies about the exotic species, as we can see below:

- I. The NEP [Para 5.1.1 (3)] recognises that the Living Modified Organisms (LMOs) may pose significant risks to ecological resources, and perhaps, human and animal health. It proposes the following actions:
 - a) Review the regulatory processes for LMOs so that all relevant scientific knowledge is taken into account, and ecological, health, and economic concerns are adequately addressed.
 - b) Periodically review the National Bio-safety Guidelines, and Bio-safety Operations Manual to ensure that these are based on current scientific knowledge.
 - c) Ensure the conservation of biodiversity and human health when dealing with LMOs in transboundary movement in a manner consistent with the multilateral Bio-safety Protocol.
- II. The NEP [Para 5.2.3 (i)] also seeks to promote plantation of only such species as are conducive to the conservation and sustainability of given ecosystems.

1.3.2. National Biodiversity Action Plan-2008 (amended in 2014):

The NBAP-2008 (amended in 2014), framed by the MoEF&CC, can be treated as supplementary to the National Environmental Policy-2006 and provides an exhaustive frame-work for managing IS in the country.

- I. The NBAP-2008 (Chapter-III, Para 3.3) recognises IS as a major threat to native plants, and animals (and their habitats)—second only to habitat loss. It welcomes the legislative and administrative measures adopted by some States for eradicating / containing IS but calls for more effective steps at the ground level.
- II. The NBAP (Chapter-4, Para 4.3) sets the following objectives in respect of regulation and management of IS:
 - To develop unified national system for regulation of all introductions including their quarantine check, assessment and release.
 - To improve management of IS and restore the adversely affected ecosystems.
- III. The NBAP (Chapter-5, Para 5.3) stipulates the following action points:
 - a. Develop a unified national system for regulation of all introductions and carrying out rigorous quarantine checks.
 - b. Strengthen domestic quarantine measures to contain the spread of invasive species to neighbouring areas.
 - c. Promote inter-sectoral linkages to check unintended introductions and contain and manage the spread of IS.
 - d. Develop a national database on IS reported in India.
 - e. Develop appropriate early warning and awareness system in response to new sightings of IS.
 - f. Provide priority funding to basic research on managing IS.
 - g. Support capacity building for managing IS at different levels with priority on local area activities.
 - h. Promote restorative measures of degraded ecosystems using preferably locally adapted native species for this purpose.
 - i. Promote regional cooperation in adoption of uniform quarantine measures and containment of invasive exotics.
- IV. The amendment in the NBAP in 2014, *inter alia*, seeks to integrate National Biodiversity Target No.4 which stipulates identification of IS and pathways and development of strategies to manage them by 2020 so that populations of prioritized IS are managed. The responsibility has been entrusted to the State Forest Departments, DoS, Wetlands International-South Asia, SACON, ICFRE (Forest Invasive Species Cell), WII, CMLRE, National Institute of Oceanography (NIO), Annamalai University (Faculty of Marine Sciences), and CABI South Asia. The following indicators have been set up for the target:
 - i. Number and coverage of management plans developed for prioritized invasive species and integration with PA management plans and wetland management plans
 - ii. Change in area affected by invasive species

As part of the updating of NBAP 2008, national biodiversity targets were developed in harmony with global strategic plan for biodiversity 2011-2020 and the Aichi Biodiversity

Targets. Recognising the crucial need to address invasive species threats, India formulated **National Biodiversity Target 4:**

- iii. *By 2020, invasive species and pathways are identified and strategies to manage them developed so that populations of prioritized invasive species are managed.*
- iv. India has established 'Forest Invasive Species Cell' in the Indian Council of Forest Research and Education, Dehradun. The major objectives of this cell are to establish database on forest invasive species in India, networking and capacity building towards management of invasive species and development of better technology to eradicate invasive species.

1.4. Foreign Trade Policy (Import-Export Policy)

- I. The Foreign Trade Policy (FTP), notified periodically by Director General of Foreign Trade (DGFT) under the provisions of Foreign Trade (Development and Regulation) Act, 1992, is a major tool for regulating import and export of plants and animals of all descriptions including IS. The item-wise export and import policy is specified in ITC (HS)²⁸ notified by DGFT, as amended from time to time.
- II. The Policy (Chapter-2, Para 2.2) stipulates that all imported goods shall be subject to domestic Laws, Rules, Orders, Regulations, technical specifications, environmental and safety norms as applicable to domestically produced goods. In particular, the ITC (HS), 2012 makes the following stipulations:
 - a) Import and export of all wild animals covered by WPA-1972 and their derivatives is prohibited.
 - b) Compliance with CITES is mandatory.
 - c) Export of wild animals covered by WPA-1972 for research and education purpose is permissible on recommendation from the MoEF&CC.
 - d) Export of exotic birds except 6 species [Ref. Chapter I of Sch.2 of ITC (HS), 2012] is also prohibited. Export of 39 taxa of plants [Ref. Chapter III of Sch.2 of ITC (HS), 2012] is also banned.
 - e) Import of live animals (not covered by WPA-1972) by research institutions, zoos, circuses and private individuals is permitted on the recommendation of the CWLW. For import by research institutions, approval is also needed from the Committee for the purpose of Control and Supervision of Experiments on Animals (CPCSEA).
 - f) Import of live cattle, swine and poultry requires recommendation of the Department of Agriculture and Cooperation, Government of India and compliance with quarantine regulations. Import of all livestock products is subject to a sanitary import permit to be issued by Department of Animal Husbandry, Dairying & Fisheries, Government of India, as per S.3A of Livestock Importation Act, 1898 as amended from time to time.

²⁸Indian Trade Classification (Harmonized System) Classification of Export & Import Items

- g) Import of plants is permitted subject to the Plant Quarantine (Regulation of Import into India) Order 2003. All imported plant consignments should be accompanied by the documents / certificates prescribed in the said Order. All imported materials are inspected and, if necessary, fumigated or otherwise disinfected at the port of entry by the Plant Quarantine Officer.
- III. The Policy [Chapter-2, Para 2.6 (b)] also empowers the DGFT to adopt and enforce any measure necessary for protection of human, animal or plant life or health.

1.5. International Conventions

India is a party to International Plant Protection Convention (IPPC-1951), Convention on Conservation of Migratory Species of Wild Animals (CMS-1979) and Convention on Biological Diversity (CBD-1992) and is, therefore, under obligation to take legislative and administrative measures required for regulating IS within the country and also their import and export. These conventions also provide a medium for seeking cooperation from the other countries.

- I. IPPC is fully dedicated to securing coordinated and effective international action to prevent and to control the introduction and spread of pests (including weeds) of plants (natural and cultivated) and plant products. The Convention also covers research materials, biological control organisms, germplasm banks, containment facilities, food aid, emergency aid and anything else that can act as a vector for the spread of plant pests – for example, containers, packaging materials, soil, vehicles, vessels and machinery. The Convention is recognized by the WTO's Agreement on the Application of Sanitary and Phytosanitary Measures (the SPS Agreement) as the only international standard setting body for plant health.
- II. CMS aims at conserving terrestrial, marine and avian migratory species throughout their range. Article III. 4 (c) of the Convention says that Parties that are Range States of a migratory species listed in Appendix I shall endeavour to the extent feasible and appropriate, to prevent, reduce or control factors that are endangering or are likely to further endanger the species, including strictly controlling the introduction of, or controlling or eliminating, already introduced exotic species.
- III. CBD is a comprehensive treaty which aims at conservation of biological diversity, sustainable use of its components, and fair and equitable sharing of the benefits from the use of genetic resources. Article 8 (h) says that each Contracting Party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those species which threaten ecosystems, habitats or species. The Cartagena Protocol on Biosafety (2000) to the CBD is an international agreement which aims to ensure the safe handling, transport and use of living modified organisms (LMOs) resulting from modern biotechnology that may have adverse effects on biological diversity, taking also into account risks to human health.

2. Legal instruments for dealing with IS

2.1. India Forest Act-1927 and State Forest Acts:

Forest officers have the authority to undertake management of weeds and IS in Reserved Forests and Protected Forests in accordance with Sections 26 (2) and 34 respectively of the IFA-1927 (or relevant Sections of the State Forest Acts). As stated earlier, they carry out required operations in accordance with the approved Working Plans.

2.2. Wildlife (Protection) Act-1972:

- I. S.33(c) and S.35(8) of WPA-1972 authorise the CWLW to undertake habitat improvement works (which include management of plant-based IS) in Sanctuaries and National Parks respectively.
- II. The Supreme Court issued an order on 14.2.2000 in IA No. 548 in the *Godavarman* case [WP (Civil) No. 202 of 1995] restraining the State Governments “from ordering the removal of dead, diseased, dying or wind-fallen trees, drift wood and grasses, etc. from any National Park or Game Sanctuary or forest.” On 28.2.2000, the Court modified the above instruction and dropped the word ‘forest’ from its order. The Court issued further instructions in IA No. 548 on 25.11.2005 and clarified that its order dated 14.2.2000 would not apply to certain activities in the PAs relating to habitat improvement, fire protection, management of grassland habitat, improvement of communication and protection in the PAs, and anti-poaching initiatives—provided the same are in accordance with the approved Management Plans; consistent with the WPA-1972, NWAP and other relevant guidelines.
- III. WPA-1972 also provide for management of invasive animal species (whether listed under the schedules of the WPA-1972 or not). S.12 authorises the CWLW to permit hunting of any scheduled wild animal for scientific management (which includes population management) with prior approval of the Central Government in respect of Schedule I animals and State Government in respect of animals covered in Schedules II, III and IV. However, S.12 does not permit killing or poisoning of wild animals for the purpose of population management, which restricts the choice of hunting to capture, translocation and fertility control. S.62 provides an alternative way in respect of animals covered in Schedules II (Part-I), III and IV which can be declared vermin with the permission of the Central Government for a specified period and then culled. There is no problem with the culling of animals already listed in Schedule V (vermins) or those not listed in any of the schedules.
- IV. However, all wildlife (which include vermins and non-scheduled animals) enjoy protection within Sanctuaries and National Parks under S.29 and S.35(6) respectively and the CWLW would need prior permission of the State Government before ordering destruction or removal of such wildlife—with an additional rider that the State

Government would consult SBWL in respect of a Sanctuary and NBWL in respect of a National Park before granting its permission.

- V. There are no legal problems in removing Elephants (Schedule I) and Chital (Schedule III) from the A&N Islands in case they are considered to be invasive species, but there are obvious logistic and financial problems.

2.3. Environment (Protection) Act-1986

- I. The preamble of the EPA-1986 suggests that it is meant for prevention of hazards to human beings, other living creatures, plants and property. S.3(1) of the EPA-1986 empowers the Central Government to take all such measures as it deems necessary or expedient for the purpose of protecting and improving the quality of environment.
- II. The Central Government has framed 'Manufacture, Use, Import-Export and Storage of Hazardous Micro-organism, Genetically Engineered Organisms or Cells Rules-1989'.

2.4. Biological Diversity Act-2002

- I. Management and control of IS is obviously related to conservation of biodiversity. S.18(3)(a) stipulates that the National Biodiversity Authority (NBA) may advise the Central Government on matters relating to the conservation of biodiversity. Similarly, S.23 (a) enjoins upon the State Biodiversity Board to advise the State Government on matters relating to the conservation of biodiversity.
- II. S.36(1) mandates the Central Government to develop national strategies, plans and programmes for the conservation, promotion and sustainable use of biological diversity. S.36(2) empowers the Central Government to issue suitable directives to the concerned State Government if it has reason to believe that any area rich in biological diversity, biological resources and their habitats is being threatened by overuse, abuse or neglect.
- III. S.36(4)(ii) mandates the Central Government to take measures to regulate, manage or control the risks associated with the use and release of LMOs likely to have adverse impact on the conservation and sustainable use of biological diversity and human health.
- IV. S.40 empowers the Central Government to declare, in consultation with the NBA, by notification in the Official Gazette, that the provisions of this Act shall not apply to an IS which also happens to be a 'biological resource'.

2.5. Prevention and Control of Infections and Contagious Diseases in Animals Act, 2009

This Act authorises the competent authorities of the Central and State Governments to prohibit or restrict the movement of animals suffering from specified diseases like Anthrax, Avian Flu, Swine Flu, etc. and carry out culling of the diseased animals if so required.

2.6. Criminal Procedure Code-1973

S.133 of Cr.P.C. empowers the District Magistrate or any other authorised Executive Magistrate to permit the destruction or confinement of any dangerous animal. S.47 of IPC-1860 defines

"animal" as any living creature, other than a human being. District Magistrates have sometimes been using S.133 of Cr. P.C. to order destruction of birds suspected to be carrying pathogens of Avian Flu.

2.7. Livestock Importation Act-1898

This Act empowers the Central Government to regulate, restrict or prohibit the import into India or any specified place therein, of any livestock which may be liable to be affected by infectious or contagious disorders.

- I. As defined in the Act, Livestock includes horses, kine, camels, sheep and any other animal which may be notified by the Central Government in the Official Gazette. Through a notification dated 26.6.1950, the Central Government included mules, asses, bulls, calves, bullocks, buffaloes, goats, swine, dogs, cats, poultry, parrots, pigeons, canaries and finches in the list of livestock.
- II. The Ministry of Agriculture has appointed Animal Quarantine officers at Delhi, Mumbai Chennai and Kolkata to verify the health of animals and birds before export and after import and to issue Quarantine Clearance Certificates. The Animal Quarantine Officer may, if needed, cause for the detention of any animal or bird to be imported at a quarantine station for observation and prevent the entry of such birds and animals as are diseased.
- III. The Act was extended through an amendment in 2001 to import of livestock products.

2.8. Destructive Insects and Pests Act, 1914

This Act seeks to prevent the import into India and the transport from one state to another in India of any insects, fungus or other pest which is or may be destructive to crops.

- I. A comprehensive set of regulations under the said Act was issued in 2003 under the title 'Plant Quarantine (Regulation of Import into India) Order 2003' (PQO-2003) which has since undergone a large number of amendments. The PQO-2003 contains many schedules, such as:
 - 1) Schedules I to III: Points of Entry / Inland Container Depots / Foreign Post Offices for imports of plants/ planting materials
 - 2) Schedule IV: List of plants/ planting materials prohibited for import and countries from where import is prohibited
 - 3) Schedule V: List of plants/ planting materials imports of which are restricted and permissible only by authorized institutions with additional declarations and subject to special conditions
 - 4) Schedule VI: List of plants/ planting materials permitted for import with additional declarations and special conditions
- 5) Schedule VII: List of plants/ planting materials permissible for import on the basis of phytosanitary certificate issued by the exporting country, the inspection conducted by Inspection Authority and fumigation, if required, including all other general conditions

6) Schedule VIII: List of Quarantine Weed Species

- II. As per S.3(14) of the PQO-2003, all consignment of seeds and plants for propagation and regulated articles such as live insects, microbial cultures, bio-control agents and soil shall only be imported into India through regional plant quarantine stations of Amritsar, Chennai, Kolkata, Mumbai or New Delhi or through any other points of entry as may be notified from time to time for this purpose, provided that no import of germplasm/ transgenic plant material and Genetically Modified Organisms (GMOs) shall be permitted through New Delhi Airport.
- III. As per S. 6(1) of the PQO-2003, no consignment of germplasm/ transgenics/ GMOs shall be imported into India for experimental purpose without valid permit issued by the Director, National Bureau of Plant Genetic Resources.

2.9. State Acts to deal with IS

- I. Bengal Water Hyacinth Act-1936 (amended in 1941) seeks to prohibit introduction and propagation of Water Hyacinth (*Eichornia crassipes*) in West Bengal.
- II. Some examples of State Acts dealing with agricultural pests and diseases are: Madras Agricultural Pests and Diseases Act-1919, Travancore Plant Pests and Plant Diseases Regulation-1919, Coorg Agricultural Pests and Diseases Act-1914 (came into force in 1933), Patiala Destructive Insects and Pests Act-1943, Bombay Agricultural Pests and Diseases Act-1947, Rewa State Agricultural Pests and Diseases Act-1947, East Punjab Agricultural Pests, Diseases and Noxious Weeds Act-1949, (also extended to Himachal Pradesh in 1949) and Assam Agricultural Pests and Diseases Act-1950.

2.10. Customs Act-1962

- I. All cases of violations of the Foreign Trade Policy are deemed to be an offence under the Customs Act and processed accordingly.
- II. S.11 of the Customs Act empowers the Central Government to prohibit or regulate, by a gazette notification, the import or export of goods of any specified description for the purpose of, *inter alia*, protection of human, animal or plant life or health.

3. Some observations on the Policies and Laws relating to IS in India

- i. The concept of IS is still evolving in India. It is, therefore, not surprising that one finds either no reference or only a passing reference to IS in old policy documents, such as the National Forest Policy-1988, National Agriculture Policy-2000, etc. But the newer policy documents like the National Policy for Farmers-2007, National Biodiversity Action Plan-2008 (amended in 2014) and National Working Plan Code-2014 are quite vocal about IS and together present a fairly comprehensive policy statement. It is, however, desirable that different ministries revise and update their policies and action plans with regard to IS.

- ii. National Biodiversity Action Plan has rightly pointed out that “There is, however, a need to develop a unified national system for regulation of introduction and management of all invasive species across jurisdiction of all concerned Ministries and relevant sectors.” (Para 5.3).
- iii. The paper by Kannan *et al* (2013), said to be based on interview with some retired forest officers and interaction with a few Park Managers, gives an inaccurate picture about inadequacy of policy and law for management of IS in PAs. As explained earlier, NWAP (2002-16) provides a clear policy statement on control of IS in PAs; Central Government provides financial support for this purpose under various CSS; and WPA-1972 provides the enabling legislation. A large number of PAs in India routinely carry out habitat improvement works by way of removal of IS and replacement of monocultures of exotic species with a mixture of indigenous fodder or fruit-bearing species. Removal of IS is usually done by uprooting or burning followed by plantation with bamboo or other fodder species. The results are not always encouraging. That is why the NWAP calls upon research institutes to provide technical assistance to the PA managers for control and eradication of IS (Chapter-II, Para 5.1).
- iv. The forest based IS are still in the process of identification and there is no final or authentic list for forest officers to act upon. Forest officers in India have been using exotic species for over 150 years either for increasing the productivity of forests or for afforestation of degraded lands. Most of these species were tried and recommended by the scientists of the FRI (now ICFRE) or the State Silviculturist. The recommended species were often included in the Working Plan prescriptions. One can understand the dilemma of the forest officers if some of such species were now to be dealt with as IS. An example is provided by *Leucaena leucocephala* (commonly known as Subabul)—a fast-growing tree species recommended during the mid-1970s by the FRI Scientists and the agricultural scientists as an excellent source of fuelwood and cattle-fodder, which has now been listed as IS for India²⁹. Two grass species listed as IS, viz. *Saccharum spontaneum* and *Imperata cylindrica*, are ironically also being planted by the West Bengal Forest Department (WBFD) for improving the rhino-habitat in Jaldapara National Park since 1980s. The success of these plantations is reflected in the increase in rhino population in Jaldapara from 14 in 1985 to 186 in 2013. *Imperata cylindrica* is also a source of thatch for the members of EDCs of Jaldapara NP helping the forest staff in protection of rhinos. It will be unrealistic to expect WBFD to change its management practice in Jaldapara NP overnight. A similar dilemma presented in the State Forest Policy of Rajasthan in respect of *Prosopis juliflora* has been discussed earlier. It is advisable that the MoEF&CC finalises its list of IS and corresponding management strategy in consultation with the State Forest Departments.

²⁹ Ref. Status of Forest Invasive Species in India—Country Report. Asia-Pacific Forest Invasive Species Network (www.apfisn.net)

- v. Management of IS is likely to involve clashes with policies and laws of other Ministries and Departments. Many of the plants identified as IS (e.g. *Ageratum conyzoides*, *Cassia tora*, *Dioscorea deltoidea*, *Tridax procumbens*, *Vitex negundo*, etc.)³⁰ are also known to be medicinal plants used in traditional medicinal system and being promoted by various government agencies (perhaps also National and State Medicinal Plant Boards), industries and NGOs and it will be unreasonable to take unilateral decisions about management of these species as IS. Likewise, many of the plant species identified as IS are also likely to be categorised as NTFPs collected by the members of the JFM Committees in accordance with the policies of the State Governments or reserved for use by the tribal people in accordance with PESA-1996. Many IS may also qualify to be called ‘Biological Resource’ and included in PBR in accordance with Biological Diversity Act-2002 with altogether different set of policies and legal provisions. It is, therefore, advisable that the list of IS and corresponding management strategy is finalised in consultation with all stakeholders.
- vi. Theoretically, PQO-2003 and the Foreign Trade Policy provide strong legal tools to check import of plant-based IS. But a large volume of plants and plant-products is known to move across the international land-borders and it is doubtful whether there are adequate plant quarantine stations to detect and take care of this movement.
- vii. Destructive Insects and Pests Act, 1914 also seek to regulate movement of insects, fungus or other pests from one state to another but PQO-2003 is not built to regulate inter-state movement of plant-based IS. Some of the States have their own Acts for this purpose but the efficacy of these Acts and corresponding enforcement machinery is doubtful.
- viii. The Foreign Trade Policy is effective against the import of only those animal-based IS which are specifically restricted or prohibited in the ITC (HS)—the other species, by implication, are permitted for free import. Presently, ITC (HS) covers wild animals as defined in the WPA-1972 (i.e. species listed in Schedules I to IV); species listed in the appendices of CITES; animals as covered by the Livestock Importation Act-1898, and a few more species listed in ITC (HS)-2012. A large number of animals, particularly, fish, crustaceans and invertebrates, are not covered by the restricted / prohibited list and their entry within the country is dependent on the discretion of the inspecting officers or the alertness of the Animal Quarantine Officers. It is advisable to develop regulations for import of animals on the lines of PQO-2003.
- ix. As in the case of plant-based IS, legislation and infrastructure for inter-state movement of animal-based IS is inadequate.
- x. IS are widely reckoned as environmental hazards but the definition of “Hazardous Substance” as provided in the EPA-1986 does not appear to cover IS³¹. It may be

³⁰ Ref. *ibid*.

³¹ According to S.2(c) of the EPA-1986, “Hazardous Substance” means any substance or preparation which, by reason of its chemical or physic-chemical properties or handling, is liable to cause harm to human beings, other living creatures, plants, micro-organisms, property or the environment.

examined whether the definition should be amended suitably to bring the management and control of IS under the ambit of a strong Act like EPA-1986.

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Annexures

Annexure 1. List of experts and participants under various themes of discussion

Experts	Participants	Experts	Participants
CARNIVORE		HERBIVORE	
Dr. Vinay Sinha	Prerna Sharma	Sh. Vinod Rishi	Sudip Banerjee
Sh. A.K. Singh	Kaushik Banerjee	Dr. A.J.T. Johnsingh	Rahul De
Dr. Vidya Athreya	Srinivas Y	Dr. B.K. Mishra	Bidyut Bikash
Dr. NVK Ashraf	Stotro Chakra	Dr. Bivash Pandav	Ashok Kumar
Dr. Samrat Mondal	Devanshi	Dr. S.P. Goyal	Neha Awasthi
Sh. Subharanjan Sen	Nikit	Dr. K. Sankar	Aisho Sharma
Dr. Bilal Habib	Pallavi	Sh. Jagdish kishwan	Keshab
Dr. Y.V. Jhala	Pragya		Varsha
	Ashutosh Singh		Dibyadeep Chatterjee
	Athar Noor		Dr. Dhawal Mehta
	Dipanjana Naha		Harshavardhan
	Indranil Mondal		
	Punit Pandey		
	Madhura Davate		
	Anindita		
	Dr. Parabita Basu		
	Manjari Roy		
INVASIVE		MACAQUE	
Dr. G. S. Goraya	Dr. David Anderson	Dr. Parag Nigam	Ridhima Solanki
Sh. Rajiv Bhartari	Dr. S.A.Hussain	Bitapi C. Sinha	Sonu Yadav
Dr. Abhijit Das	Dr. Dubey	Dr.R.B.S. Rawat	Pranay
Dr. B.S. Adhikari	Sh. Rajiv Bhartari	Sh. R. N. Mehrotra	Naithik
Dr. S.A. Hussain	Suresh Rana	Sh. Satpal Dhiman	Nikunj
Dr. J. A. Johnson	Sweta Singh	Dr. P.C. Tyagi	Saugato
Sh. R. Suresh Kumar	Priyamvada Bagria	R. Suresh Kumar	Ravi Sharma
Sh. A. K. Bhardwaj	Rupa Bharadwaj	Dr. Anupam Srivastav	Sougata Sadhu Khan
Dr. G.V. Gopi	Ravi Sharma	Dr. K. Ramesh	
Ninad Mungi	Dimpi Patel		
	Tamali Mondal		
	Sanjay Xaxa		
	Aftab Usmani		
	Ramesh C.		
LAW AND POLICY			
	Sh. Aseem Shrivastav	Swati Saini	
	Sh. Ajay Srivastav	Akanksha Saxena	
	Sh. S.K. Mukherjee	Animesh Talukdar	
	Sh. Dipankar Ghose	Naveen M	
	Sh. Samir Sinha	Deepak Anand	
	Sh.A.K. Wahal	Ahana Dutt	
	Sh. S. S. Bist	Monica Kaushik	
		Tabassum	
		Ahana Dutt	

No. 15-37/2012-NTCA
Government of India
Ministry of Environment and Forests
National Tiger Conservation Authority

Annexe No. 5, Bikaner House,
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Dated the 30th January, 2013

To,

1. The PCCF/HOFF(s),
Tiger Range States.
2. The Chief Wildlife Warden(s)
Tiger Range States.

Sir,

As you are aware, advisories have been issued by the Project Tiger / National Tiger Conservation Authority, time and again, for dealing with emergency arising due to straying of tigers in human dominated landscapes. Based on inputs from field officers, experts vis-à-vis the said advisories, a Standard Operating Procedure has been developed after fine tuning to meet the present challenges.

In this context, I am directed to forward herewith a copy of the said Standard Operating Procedure (SOP) for dealing with emergency arising due to straying of tigers in human dominated landscapes, duly approved by the competent authority, for implementation.

The SOP may please be translated in vernacular and widely circulated amongst the field staff for guidance.

Yours faithfully,

Encl: As above

(S.P. Yadav)
Deputy Inspector General (NTCA)

Copy for information to:

1. PS to MEF.
2. PPS to Secretary (E&F).
3. PPS to DGF & SS, MoEF.
4. PPS to ADG (WL).

Copy for information to:

1. Additional Director, WCCB, New Delhi.
2. IGF, Guwahati.
3. AIGs, Nagpur and Bangalore.

**STANDARD OPERATING PROCEDURE TO DEAL WITH
EMERGENCY ARISING DUE TO STRAYING OF TIGERS
IN HUMAN DOMINATED LANDSCAPES**



MINISTRY OF ENVIRONMENT AND FORESTS

GOVERNMENT OF INDIA

NATIONAL TIGER CONSERVATION AUTHORITY

STANDARD OPERATING PROCEDURE TO DEAL WITH EMERGENCY ARISING DUE TO STRAYING OF TIGERS IN HUMAN DOMINATED LANDSCAPES

1. **Title:** Standard Operating Procedure to deal with emergency arising due to straying of tigers in human dominated landscapes
2. **Subject:** Dealing with emergency arising due to straying of tigers in human dominated landscapes
3. **Reference:** Advisories of National Tiger Conservation Authority /Project Tiger on the subject
4. **Purpose:** To ensure that straying tigers are handled in the most appropriate manner to avoid casualty / injury to human beings, tiger, cattle and property.
5. **Short summary:** This Standard Operating Procedure (SOP) provides the basic, minimum steps which are required to be taken at the field level (tiger reserve or elsewhere) for dealing with incidents of tiger straying in human dominated landscapes.
6. **Scope:** The SOP applies to all forest field formations including tiger reserves besides other areas where such incidents occur.
7. **Responsibilities:** The Field Director would be responsible in the case of a tiger reserve / fringe areas. For a protected area (National Park / Wildlife Sanctuary), the concerned protected area manager would be responsible. In the case of other areas (revenue land/conservation reserve/community reserve/village/township) the Wildlife Warden, as per the Wildlife (Protection) Act, 1972, or Divisional Forest Officer/ Deputy Conservator of Forests (under whose jurisdiction the area falls), would be responsible. The overall responsibility at the State level would rest with the Chief Wildlife Warden of the concerned State.

8. Suggested field actions to deal with strayed wild carnivores (tiger / leopard)

(a) At the outset, constitute a Committee immediately for technical guidance and monitoring on day to day basis, as under:-

- i. A nominee of the Chief Wildlife Warden
- ii. A nominee of the National Tiger Conservation Authority
- iii. A veterinarian
- iv. Local NGO representative
- v. A representative of the local Panchayat
- vi. Field Director/ Protected Area Manager/ DFO I/C - Chairman

(b) Since it may not be always possible for experts from the Wildlife Institute of India to provide assistance, it is advised that some outside experts may be involved in the ongoing monitoring.

(c) Establish identity of the tiger by comparing camera trap photographs with National Repository of Camera Trap Photographs of Tigers (NRCTPT) / Reserve level photo database and find out the source area of the animal.

(d) Collect recent cattle / livestock depredation or human injury / fatal encounter data, if any, in the area. If it is an area historically prone to such incidences, detailed research work has to be carried out in order to assess the reasons for the frequent tiger emergencies in the area.

(e) In case of confirmed livestock depredation / human injury / fatal encounters or frequent straying of tiger near human settlements, set traps (automatic closure) with appropriate luring while avoiding disturbance, to trap the animal.

- (f) Set up camera traps near kill site to confirm / establish the ID of the animal.
- (g) Ensure unobtrusive guarding of the kill to allow feeding of the carcass (if not close to a human settlement) besides safeguarding from poisoning (for revenge killing).
- (h) Create 'pressure impression pads (PIPs)' in the area to ascertain the daily movement of the animal, while plotting the same on a map (4"=1 mile scale or 1:50,000 scale).
- (i) Proactively involve District Collector / DM and SSP / SP of the area to maintain law and order in the area, besides avoiding crowding by local mobs. Acquaint them with human-tiger conflict issues and guidelines of the NTCA to deal with the situation.
- (j) In all instances of wild carnivores like tiger / leopard straying into a human dominated landscape, the district authorities need to ensure law and order by imposing section 144 of the Cr.Pc. This is essential to avoid agitation / excited local people surrounding the animal spot which hampers capture operation, leading to serious injuries on people and staff. It is also necessary that police and local administration be involved at an early stage. Effective coordination with them is critical to control mobs which as has been seen in several instances, worsen the situation and lead to avoidable fatalities/ tragedies.
- (k) Take help of the district level officials to alert the villages in the vicinity of the area having the spatial presence of the tiger.
- (l) If successive trapping efforts fail, chemical immobilization of the wild carnivore should be done by an expert team having a veterinarian, as per the protocol at **Annexure-I**.

- (m) In case, the tranquilised tiger is found to be healthy in prime or young age without any incapacitation (loss of canine, injury, broken paw etc.), as confirmed / certified by the Committee as constituted at para (1), then it may be released after radio collaring in a suitable habitat with adequate prey base, away from the territory of a resident male tiger (if any) or human settlements, under intimation to the National Tiger Conservation Authority. (Under no circumstances an injured / incapacitated tiger should be released back, and the same needs to be sent to a recognized zoo).
- (n) Under no circumstances, a tiger should be eliminated by invoking the Wildlife (Protection) Act, 1972, if it is not habituated for causing human death. The guidelines for dealing with 'man-eaters' are annexed for compliance / guidance in this regard (**Annexure-II**).
- (o) In case of a healthy tiger/encumbered tigress occupying a sugar cane field or similar habitat, attempt should be made first to attract it to nearby forest area, while avoiding disturbance. If such operations fail, the animal should be captured through immobilization for release in low density area of a nearby tiger reserve/protected area after radio collaring.
- (p) An authorized spokesperson of the Forest Department, should periodically update the media (if required) to prevent dissemination of distorted information relating to the operation / incidents. Sensalization or distorted information can lead to further damage.
- (q) In case monitoring using camera traps (Phase-IV) is ongoing in the area, the minimum tiger numbers based on individual tiger captures, should not be given undue publicity without due cross checking with the National Tiger Conservation Authority.

- (r) The Chief Wildlife Warden has to take the final decision on whether a tiger has to be released back in the wild or transferred to a zoo.
 - (s) It is important to have properly designed suitable cages and transport mechanism which cause least stress to the captured carnivore.
- 9. **Preventive / Proactive Measures** to be followed in tiger straying incidents / areas prone are at **Annexure-III**.
 - 10. Guidelines for prioritizing areas for tiger monitoring are at **Annexure-IV**.

**PROTOCOL ON
IMMOBILIZATION AND
RESTRAINT OF TIGERS**

PROTOCOL ON IMMOBILIZATION AND RESTRAINT OF TIGERS

General Consideration

Behavior: Tigers in conflict or those strayed into human habitation differ considerably in behavior as compared to those in native/ natural habitats. The animals may be stressed, shy, elusive, secretive and even unpredictable thereby posing challenge in capture. These animals may even pose safety threats for human involved in capture as well as to general public. *Utmost care needs to be taken to ensure safety of humans when attempts for capture are made.*

Capture options: Tigers can be captured employing physical and chemical restraint methods or combination of both. The physiological and emotional status of the animal; length of the procedure; the environmental conditions; terrain/ escape cover; equipment availability; drug appropriateness and availability and most importantly the safety of the operator/team needs to be considered prior to making a choice of procedure. Both the procedures have their benefits and limitations however the present guidelines would focus primarily on the chemical restraint procedures.

Chemical Restraint

Chemical immobilization has become an important tool in wildlife management over the last few decades. Advancement and development in this field has resulted in use of newer and safer drugs for immobilization, and efficient and reliable systems of drug delivery. Chemical Immobilization involves use of drugs to restrict animal's movement by inducing a state of insensibility and preventing deliberate and coherent mobility. The technique is well suited for tigers in conflict as it allows capture of select individual, enables selection of time of capture and causes minimal stress to the animal. Chemical restraint drugs alter certain CNS functions without compromising the vital functions and produce a state of anaesthesia which immobilizes the animal to the extent that provides considerable safety both for human and animal.

Immobilization Equipment

Due to difficulty of directly approaching and handling wild animals, it is necessary to have safe and effective methods by which drugs can be administered. Projected darts have proved to be effective and safe option

for delivering drugs to wild animals. The dart is projected through an equipment and discharges the medicaments intramuscularly upon impact. The darts are available in different sizes, however are specific to the type of equipment used to propel them. Different power projection systems have been used for projecting the darts however for tigers; the system that employs compressed gas/CO₂ to propel the dart should be selected. Light weight plastic darts of 3-5 ml. capacity should be used for remote injection using air powered/CO₂ tele-injection projector. Needle length is critical factor while darting tigers. The outside diameter of the needle should be 1.5- 2.0 mm and length of 38- 40 mm.

Immobilization Drugs

Though there are varieties of drugs that have been used for capturing tigers, a combination of alpha-2 adrenergic agonists (sedatives) and dissociatives have proved to be effective for immobilizing tigers.

Alpha-2 adrenergic agonists/ Sedatives: These drugs are CNS depressants with good sedative, muscle relaxant, and analgesic properties. These drugs need to be used with caution in animals as they produce initial hypertension followed by severe hypotension, bradycardia, hyperglycemia and glucosuria, disrupts thermoregulation and may lead to regurgitation/ vomiting in carnivores. These drugs however have the advantage of being non-controlled, inexpensive and reversible. The drugs have been extensively used in felids in combination with dissociatives. A mixture of *Xylazine* and *Ketamine* in a proportion of 1.25 :1 known as Hellabrunn mixture has been effectively used in tigers and other carnivores.

Another new Alpha-2 agonists Medetomidine in combination with ketamine has proved to be effective and specific sedative in large carnivores as it induces rapid drug induction and has specific antidote for reversal.

These Alpha-2 adrenergic agonists can be negated by antidote.

Examples: Xylazine, Detomidine, Medetomidine.

Antidotes include Yohimbine hydrochloride, Atipamezole hydrochloride, Tolazoline hydrochloride.

Dissociatives

These include the psychotomimetic drugs that are cyclohexamine derivatives. The drugs act by separating the conscious mind from sensory and motor or control mechanism in the brain (dissociative) producing, rapid analgesia and a trance-like state (psychosis) which may be as a

result of over stimulation of the CNS. The animal appears unaware of human presence. They have the advantage of being rapidly absorbed following IM, IV administration, have good safety margin and cause little depression of the respiratory and circulatory system. Pronounced muscle rigidity, hyperthermia, hyper salivation, convulsion and rough recovery are common side effects. These effects can be considerably reduced by combining these drugs with a tranquilizer or sedatives. Their effect cannot be reversed and the animal has to be monitored for long till complete recovery takes place. These drugs lack specific antidote.

Examples: Phencyclidine, Ketamine hydrochloride, Tiletamine Hydrochloride

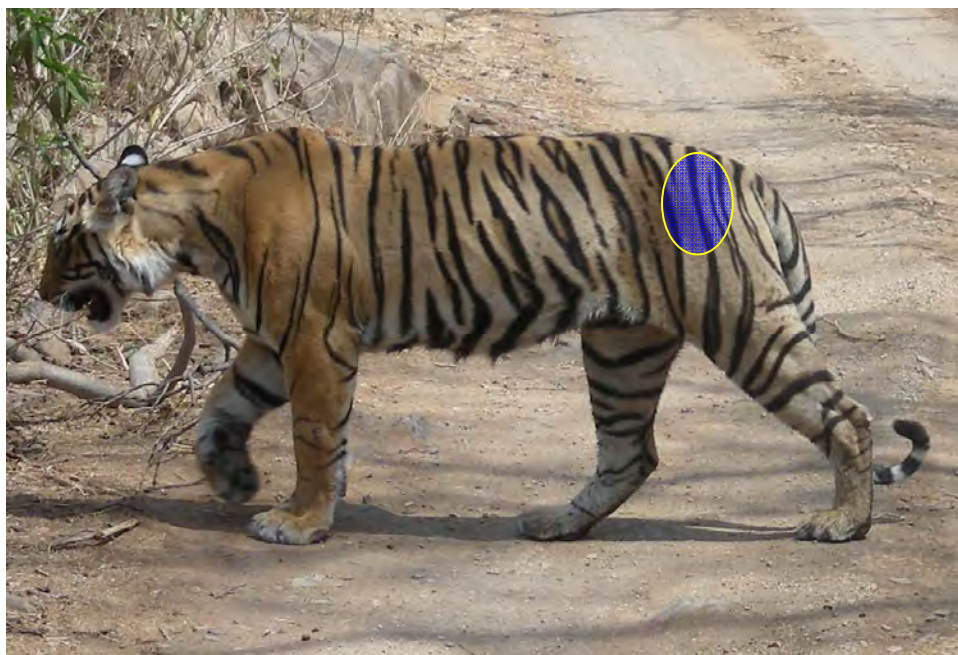
The choice of drug for immobilization may include the Hellabrunn mixture (HBM) (Xylazine –Ketamine mixture in ratio of 1.25:1) in appropriate doses. The dosage can be decided on the spot, taking into consideration the animal's health and condition, level of excitement, physiological status, sex, time of the day, and ambient temperature besides other habitat parameters. Medetomidine in combination with ketamine has proved to be effective for capturing tigers in conflict as it provides short and rapid induction thereby ensuring minimal movement of animal following darting.

Recommended drug/ dosages for immobilization of adult tiger

Sr. No.	Drug(s) for immobilization	Male	Female	Reversal drugs (antidote)
1.	Hellabrunn mixture (HBM) [Xylazine (XYL) and Ketamine (KET)] mixture in a ratio of 1.25:1	3.0 ml (375 mg XYL & 300mg KET) to 3.5 ml (437.5 mg XYL & 350 mg KET)	2.5 ml (312.5 mg XYL & 250 mg KET) to 3.0 ml (375 mg XYL & 300mg KET)	Yohimbine hydrochloride (0.125 mgkg ⁻¹ body weight)
2	Medetomidine (MED) and Ketamine (KET)	50-60 µg kg ⁻¹ body weight MED and 1-2 mgkg ⁻¹ body weight KET		25-35 mg of Atipamezole hydrochloride

Approach to the Target Animal

A four wheel field vehicle or trained captive elephants may be used to approach the animal taking due care of human safety and an overriding degree of patience. In a terrain where the vehicle cannot be used, possibility of darting the animal from a *machan* (raised platforms) may also be considered. Tigers in conflict provide limited opportunities for darting and therefore require adequate experience by personnel in effective darting as well as knowledge of anatomical peculiarities. Hindquarters should be preferred for tele-injection however depending on the opportunities; other suitable areas can also be explored.



Preferred darting site in a large carnivore

Induction Phase

The time interval between injection (darting) and the point when the animal is rendered immobile is induction period. The total time for the completion of induction may vary from 10-15 minutes. A close observation should be kept by the team for any movement of the animal however the team should ensure minimal disturbance during induction.

Handling and Care of the Immobilized Animal

The animal should be approached quietly and following steps should be followed:

- Removal of dart
- Blindfolding to protect the cornea from direct sunlight, dust and injury.
- Ensuring proper animal positioning (sternal or lateral recumbancy) to maintain patent airways and ensure normal breathing and circulation.
- Assessing the status of animal, the degree of muscle relaxation and the rate and depth of respiration. Assessment of anesthesia should be done using following methods:

- Monitor tissue perfusion: Anesthetic drugs frequently depress the contractile force of the heart and vasodilatation results in decreased tissue perfusion. Evaluation of tissue perfusion should be done by observation, auscultation, palpation and capillary refill time.
- Monitor gas exchange: Respiratory rates are highly variable during anesthesia.
- Quality of respiration should be evaluated by observing animal's chest movement.
- Monitor level of CNS depression by assessing the muscle tone-jaw tone and eye reflexes.
- Monitor vital signs such as respiration, heart rate and body temperature.
- Examine animal for any wound or injuries (including status of canines and claws).
- Estimate animal body weight and if possible take bodily measurements.

Shifting of the Animal to Stretcher

The animal should be shifted to a stretcher and placed in lateral or sternal recumbancy. Animal should then be shifted to a transport container.

Reversal of Anesthesia

Specific Alfa-2 antagonists (Yohimbine HCl , Atipamezole HCl) should be used to reverse the anesthesia.

Supplemental Information

- Preparedness:** All equipment for crating the animal, radio collars and accessories, emergency medicaments, biological sampling accessories, transport containers and any other essentials should be in place before the animal is darted.
- Data recording:** A complete immobilization record, particularly including each drug given, amount given, time of administration and physiological parameters should be maintained during the procedure. These details should be recorded in the datasheet in the format provided. It would be appropriate to ensure human safety considerations to meet any eventuality at all the time.
- Assessing depth of anaesthesia:** It should take about 15 minutes for the drug induction to happen. Prior to approaching the animal, the depth of anaesthesia should be assessed by either tapping on the tail or ears with the help of long pole and if the animal does not react, it should be approached. The depth of anaesthesia should be optimum if the jaws can be opened and the

tongue exteriorized with little or no resistance. Other indicators would include responses to stimulation of body, feet, cornea, ears and tongue. The physiological parameters should be assessed and should include assessment of temperature, respiration, pulse and color of mucous membrane including condition of pharynx, gingiva and teeth. In case of emergency (depressed respiration or cardiac arrhythmias or depression) the animal should be revived. Emergency drug including cardiac and respiratory stimulants should be kept handy at all times. The physiological parameters should be assessed and should include assessment of temperature, respiration, pulse and color of mucous membrane including condition of pharynx, gingiva and teeth.

- d. **Managing emergencies:** Emergency drugs and equipment would be available during the entire operation. Adequate supplies of emergency drugs should be ensured at all times.
- e. **Composition of team:** Capturing large felids poses a challenge and therefore requires a skilled team comprising wildlife managers, biologists, trained veterinarians and most preferably an individual specializing in animal anaesthesia.

Data Sheet for Recording and Monitoring Immobilized Animal

Area Details

Date

Location GPS Lat..... Long.....

Collar Frequency

Purpose of capture

Ambient temperature Day (cloudy, bright)

Animal Details

Species Physical condition

Emotional state before drugging Sex

Approximate age Weight (kg).....

Breeding status

Body Measurements

Nose tip to Tip of tail Nose tip to base of tail

Nose tip to base of skull (Occipital) Tail length.....

Height (Shoulder blade to heel) Hind limb length

Left fore limb or Hind limb paw dimension Length Width

Neck girth Length of Canines

Immobilization Details

Name of Immobilizing Drug(s)	Time of Injection	Drug dose given	Route	Site
1.				
2.				
3.				
4.				

Behaviour at the time of darting

(running, walking, standing, excited)

Induction time when animal goes down/ approached.....**Animal Monitoring**

Time	Signs shown following immobilization	Respiration Shallow/ deep/ irregular & rate	Temperature (°F)	Pulse (rate)

Drug reversal

Name of reversal Drug(s)	Time of Injection	Drug dose & volume given	Route	Site
1.				
2.				

Time when animal shows first sign of recovery -

Details about recovery event till animal regains consciousness /shows signs of recovery

.....

Any other comments -

Supplemental drugs

Name of other supportive Drug(s)/antibiotic(s) etc. given	Trade name	Volume used	Route	Site
1				
2.				
3.				
4.				

Biological sampling

Name of sample	Preservative used	Examination required	Handed over to	Remarks

Annexure-II

GUIDELINES FOR DECLARATION OF BIG CATS AS ‘MAN-EATERS’

- Both tiger as well as leopard are known to cause habituated loss of human life (man-eaters). Such confirmed ‘man-eaters’ should be eliminated as per the statutory provisions provided in section 11 of the Wildlife (Protection) Act, 1972.
- Tiger as well as leopard are categorized under Schedule I of the Wildlife (Protection) Act, 1972, with highest statutory protection against hunting under section 9 (1) of the said Act. Hence, such species can be killed if they become dangerous to human life or are so disabled / diseased beyond recovery.
- Under section 11 (1) (a) of the Wildlife (Protection) Act, 1972, the Chief Wildlife Warden of a State alone has the authority to permit hunting of such animals becoming dangerous to human life or disabled or diseased beyond recovery. However, as per the statutory requirement, the Chief Wildlife Warden of the State has to state in writing the reasons for permitting elimination before hunting.
- There are several reasons for a big wild cat like tiger or a leopard to get habituated as a ‘man-eater’, viz. disability due to old age, incapacitation due to serious injury or loss / breakage of its canines etc. However, there may be several exceptions, and hence specific reasons have to be ascertained on a case to case basis.
- The tiger bearing forests and areas nearby prone to livestock depredation, besides having human settlements alongwith their rights and concessions in such areas, are generally prone to ‘man-eaters’. Besides, loss of habitat connectivity in close proximity to a tiger source area owing to various land uses also foster straying of tiger near human settlements, eventually ending up as a ‘man-eater’.

Suggested steps on loss of human life due to tiger / leopard

- Constitute a team for technical guidance and monitoring on day to day basis, as below:
 - A nominee of the Chief Wildlife Warden
 - A nominee of the National Tiger Conservation Authority
 - A veterinarian
 - Local NGO representative
 - A representative of the local Panchayat
 - Field Director/Protected Area Manager/DFO I/C - Chairman
- Set up camera traps near kill sites, besides creating pug impression pads to monitor the day to day spatial movement of the wild carnivore.
- Inform the district officials (Collector / DM / SP) for duly alerting the local people to refrain temporally from the area where human death(s) has / have been reported, besides ensuring tranquility in the area from mobs / crowds of local people.
- Obtain / establish the ID of the aberrant animal causing loss of human life, through the committee constituted for the purpose, through camera trappings or direct sightings or pug impressions if camera trappings could not be done, besides collecting pieces of hair / scats of the carnivore (if available) for DNA profiling.
- A differentiation should be made between 'human kill' due to chance encounters and 'habituated man-eaters'. As most of our forests outside protected areas are right burdened, the probability of chance encounters is very high. Further, tigers often use agriculture / sugar cane field and similar cover along river courses while feeding on livestock or blue bull, which may also cause lethal encounters with human beings. Such animals should not be declared as 'man-eaters'. However, confirmed habituated tiger / leopard which 'stalk' human beings and feed on the dead body are likely to be 'man-eaters'.
- The declaration of an aberrant tiger / leopard as a man-eater requires considerable examination based on field evidences. At

times, the human beings killed due to chance of encounters may also be eaten by the animal (especially an encumbered tigress in low prey base area). However, such happenings are not sufficient for classifying a tiger / leopard as a 'man-eater', which can best be established only after confirming the habituation of the aberrant animal for deliberate stalking of human beings, while avoiding its natural prey.

- Under no circumstances, mere an animal resorting to cattle depredation should be declared as a 'man-eater', despite the fact it may venture close to human settlements. To avoid untoward incidents in such situations, the efforts to trap the animal (chemical immobilization / use of traps) should alone be resorted to.
- Set up trap cages (automatic closure) in areas most frequented by the carnivore (with appropriate luring) for trapping.
- In case successive trapping operation fails set up an expert team for chemical immobilization of the aberrant animal as per the annexed protocol.
- The option of capturing the aberrant animal either through traps or chemical immobilization should be invariably resorted to as the first option. The wild carnivore thus captured, should be sent to a nearest recognized zoo and NOT released in the wild.
- Elimination of a tiger / leopard as a 'man-eater' should be the last option, after exhausting the option of capturing the animal live as detailed in the SOP.
- The Chief Wildlife Warden of the State after the above due diligence should record in writing the reasons for declaring the tiger / leopard as a 'man-eater'.
- After 'declaring' the man-eater, its elimination should be done by a Departmental personnel having the desired proficiency, while providing the fire arm with the appropriate bore size (not below .375 magnum). In case, such expertise is not available within the Department, an expert may be co-opted from the other State Governments or outside with due authorization.
- No award / reward should be announced for destruction of 'man-eaters'.

Annexure-III

DETAILED INSTRUCTIONS FOR THE PROCEDURE TO BE FOLLOWED IN TIGER STRAYING INCIDENTS / AREAS PRONE FOR SUCH INCIDENTS : PREVENTIVE / PROACTIVE MEASURES

- (a) Identify the crisis spots / districts in the State.
- (b) Conduct science based research and analysis to arrive at reasons for frequent straying of tigers in such areas.
- (c) Prepare a google map indicating forest patches, territory of the tigers, nearby habitation and corridors.
- (d) Form monitoring teams consisting of locals with wireless communication on 24X7 basis besides rapid response team.
- (e) Establish an early warning system.
- (f) Issue alert to all nearby villages to take utmost caution.
- (g) Monitor the cattle kill and immediately pay ex-gratia / compensation in the case of eventuality.
- (h) Use electronic surveillance to monitor the movement of the tigers during the night.
- (i) Water holes, cattle kill, transmission lines should be regularly monitored.
- (j) Put in place Rapid Response Team (RRT) for capturing the animal to avoid lethal encounter. The RRT to be equipped with the following:-
 - (i) A field van/mini-truck with built in rails for accommodating a trap cage, with space for equipments, attendants and staff.
 - (ii) A tranquilization kit with drugs for chemical immobilization.
 - (iii) Taser gun for instant immobilization of the animal.
 - (iv) 2 mobile phones for continued communication with the authorities.
 - (v) 4 wireless handsets.
 - (vi) 2 GPS sets.
 - (vii) 1 long ranging night vision for seeing objects in the dark.

- (viii) A digital camera.
 - (ix) 4 trap cages (2 for tiger and 2 for leopard).
 - (x) 1 mini-tractor for transporting the cage in rugged terrain.
 - (xi) 2 search lights.
 - (xii) 2 radio collars with receiver and antenna.
 - (xiii) 2 portable tents.
 - (xiv) Portable hides – which can be set up fast, to be used for persons with tranquilizers
 - (xv) 2 folding chairs with table.
 - (xvi) Hand held audio system.
 - (xvii) Rope and net.
 - (xviii) First aid kits
- (k) The rapid rescue team is required to ensure unobtrusive close monitoring of the animal with least disturbance, for tracking its movement.
- (l) In addition, at places which are not waterlogged, camera traps should be set up (fixed to a post or a tree) for establishing the identity of the animal.
- (m) The rapid rescue team also requires due capacity building and 'hands on' field training involving the Wildlife Institute of India and other relevant outside experts, if needed.

PRIORITISING AREAS FOR TIGER MONITORING

The tiger source areas and its surrounding forests have the maximum tigers, besides some protected areas and forest patches. The districts/forest divisions having spatial occupancy of tiger as indicated in the maps need ongoing monitoring on a daily basis. In this context, the following actions are indicated:

- (a) Monitoring the tiger source areas using camera traps to generate photo ID for creating a photo database (Phase-IV monitoring)
- (b) Implementing Phase-IV monitoring in areas having tiger occupancy as indicated in the map
- (c) Periodic comparison / review of camera trap tiger photos to fix ID of tigers reported in several areas near a source site
- (d) Complementing the camera trap monitoring with simple foot patrolling in the peripheral areas, while maintaining day-to-day record as per Phase-IV monitoring protocol
- (e) Monitoring livestock depredation by tiger and ready payment of compensation
- (f) Keeping track of sudden change in land use in areas having tiger presence
- (g) Avoiding blockage of traditional tiger / wildlife corridors in areas outside the tiger reserves falling in various forest divisions
- (h) Monitoring sudden change in cover values in tiger areas (change in cropping pattern etc.)
- (i) Monitoring tiger movement along river courses
- (j) Keeping track of insecticides sale outlets and their use in tiger bearing areas (to avoid poisoning of water)
- (k) Networking through local workforce for gathering information relating to wandering gangs traditionally involved in poaching of wild animals
- (l) Keeping track of local market days

- (m) Fostering creation / maintenance of wildlife monitoring register at the Gram Sabha level in areas outside tiger reserves, with incentives for informing tiger presence
- (n) Creation / maintenance of 'wildlife / tiger offence register' at the Gram Sabha level with reward system for assisting in crime detection
- (o) Deploying special monitoring teams around highways, open wells, railway tracks, electrical transmission lines, village ponds, natural water holes, irrigation canals
- (p) Insulating high tension electrical transmission poles in tiger bearing areas, besides covering open wells and irrigation canals
- (q) Keeping track of encumbered tigresses in tiger bearing areas for monitoring the dispersing young ones
- (r) Periodic checking of samples from water points/perennial water sources for lethal contamination
- (s) Alerting local people in right burdened, tiger bearing areas to prevent lethal encounters
- (t) Periodic disease monitoring of village cattle in the tiger bearing areas to avoid disease transmission to natural prey base for tiger
- (u) Monitoring natural salt licks to prevent poisoning / poaching in tiger bearing areas
- (v) Keeping track of local ironsmiths engaged in preparation of 'gin traps', snares etc.
- (w) Creation of wildlife crime dossier and exchange of such information with field units in tiger bearing areas under intimation to the NTCA
- (x) Fortnightly monitoring of tiger mortality and progress of tiger offence cases ongoing in the courts of law by the Chief Wildlife Warden
- (y) Monthly monitoring of tiger mortality and progress of tiger offence cases ongoing in the courts of law by the PCCF/HOFF
- (z) Use sniffer dogs for detection of body parts, escape routes and other leads

(The SOP has been prepared by the NTCA with inputs from Shri P.K.Sen, Dr Ullas Karanth, Ms Prerna Singh Bindra, Dr P.K.Malik, Dr Parag Nigam and field officers)

No. 15-37/2012-NTCA
Government of India
Ministry of Environment & Forests
National Tiger Conservation Authority

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Telefax: 2338 9883
E-mail: jdntca@gmail.com

Dated: 18th March, 2013

To

1. The PCCF/HOFF (s),
Tiger Range States.
2. The Chief Wildlife Warden (s),
Tiger Range States.

Sub: Standard Operating Procedure (SOP) for disposing Tiger/ leopard carcass/ body parts – reg.

Sir,

Advisories have been issued by Project Tiger/National Tiger Conservation Authority from time to time, on different issues relating to tiger mortality, post mortem, reporting etc. Based on the same and with inputs from field officers / experts, a Standard Operating Procedure (SOP) for disposing tiger/ leopard carcass/ body parts has been developed to meet the present challenges.

A copy of the said Standard Operating Procedure (SOP) for disposing tiger/ leopard carcass/ body parts, duly approved by the competent authority, is forwarded herewith for information and necessary action.

The SOP may please be translated in vernacular and widely circulated amongst the field staff for guidance.

Yours faithfully,
SD/-

Encl: As above.

(S.P. Yadav)
Deputy Inspector General (NTCA)

Copy to:

1. PS to MEF.
2. PPS to Secretary (E&F).
3. PPS to DGF & SS, MoEF.
4. PPS to ADG (WL)
5. Additional Director, Wildlife Crime Control Bureau, New Delhi.
6. Inspector General of Forests, Regional Office, Guwahati.
7. Assistant Inspector General (NTCA), Nagpur and Bangalore.

**STANDARD OPERATING PROCEDURE FOR DISPOSING
TIGER/ LEOPARD CARCASS/BODY PARTS**



MINISTRY OF ENVIRONMENT AND FORESTS

GOVERNMENT OF INDIA

NATIONAL TIGER CONSERVATION AUTHORITY

STANDARD OPERATING PROCEDURE FOR DISPOSING THE TIGER/ LEOPARD CARCASS/BODY PARTS

1. **Title :** Standard Operating Procedure for disposing the tiger/ leopard carcass/ body parts.
2. **Subject:** Tiger death/seizure of body parts
3. **Reference:** Advisories of the Ministry of Environment & Forests/ Project Tiger/ NTCA on the subject (Advisory No: 1-60/89-WL I dated 04-11-1994 from the Addl. IGF (wildlife) Ministry of Environment and Forests)
4. **Purpose:** To ensure that the carcass/ body parts of tiger/ leopard are disposed of in a transparent manner to prevent any pilferage for illegal market.
5. **Short summary:** This Standard Operating Procedure (SOP) provides the basic, minimum steps which are required to be taken at the field level (tiger reserve or elsewhere) for disposing of tiger/leopard carcass/ body parts where carcass is available or the body parts have been seized.
6. **Scope :** The SOP applies to all forest field formations including tiger reserves besides other areas where the incident has occurred.
7. **Responsibilities:** The Field Director would be responsible in the case of a tiger reserve. For a protected area (National Park / Wildlife Sanctuary), the concerned protected area manager would be responsible. In the case of other areas (revenue land/conservation reserve/community reserve/village/township) the Wildlife Warden, as per the Wildlife (Protection) Act, 1972, or Divisional Forest Officer/ Deputy Conservator of Forests (under whose jurisdiction the area falls), would be responsible. The overall responsibility at the State level would rest with the Chief Wildlife Warden of the concerned State.
8. **Detailed instructions for the procedure to be followed for disposing of the tiger/ leopard carcass/ body part(s) where body part(s) / carcass is available**

(i) At Scene of crime (SoC) / incident: when carcass or parts available:

- Follow the SOP issued by the NTCA on dealing with the tiger mortality/ seizure of body parts.
- Dispose of the carcass by incineration in the presence of the Field Director or an officer not below the rank of the Conservator of Forests besides the Post Mortem (PM) Team having representation from the civil society institution
- While incinerating the carcass, the sequence must be photographed and video recorded.
- Before leaving the site, ensure that the whole carcass including bones are fully burnt.
- After ensuring the complete incineration of the carcass, prepare a 'Panchnama (Memo) on disposal of the carcass, duly signed by the PM Team and officer incharge, and send a final report (Annexure-I) to the CWLW under intimation to the NTCA with supporting photographs/ documents.

(ii) In case of seizure of body parts (Skin – dry or fresh/ bones/meat or other body parts):

- Follow the SOP issued by the NTCA on dealing with the tiger mortality/ seizure of body parts.
- In case of seizures of body parts, the same may be required as evidence for prosecution in the courts of law and hence in such situations do not dispose the same till the orders of the concerned court for such disposal are obtained.
- Once orders have been obtained by the competent authority, dispose of the body part (s) by incineration in the presence of the Field Director or an officer not below the rank of the Conservator of Forests besides the Team (same as prescribed for the Post Mortem) having representation from a civil society institution
- While incinerating the body parts, the sequence must be photographed and video recorded.
- Before leaving the site, ensure that the whole/ all body parts are fully burnt.
- After ensuring the complete incineration of the body part (s), prepare a 'Panchnama' (Memo) on disposal of the body part (s), duly signed by the said Team and officer incharge, and send a final report (Annexure-I) to the CWLW under intimation to the NTCA with supporting photographs/ documents.

(iii) In cases of seized stock of wildlife trophies obtained during seizure/ confiscation:

- All seized stock of wildlife trophies, where no case is pending in a Court of law, should be destroyed through incineration in the presence of the Field Director or an officer not below the rank of the Conservator of Forests besides a team (same as prescribed for the post mortem) having representation from a civil society institution.
- While incinerating the body parts, the sequence must be photographed and video recorded.
- Before leaving the site, ensure that the whole/ all body parts are fully burnt.
- After ensuring the complete incineration of the body part (s), prepare a 'Panchnama' (Memo) on disposal of the body part (s), duly signed by the said Team and officer incharge, and send a final report (Annexure-I) to the CWLW under intimation to the NTCA with supporting photographs/ documents.
- The provisions of the Wildlife (Protection) Act, 1972 must be followed before destroying such stock.

FINAL REPORT

To be submitted for disposal of each case of tiger/ leopard carcass/ body part (s)/ trophy

1	Name of Office	
2	Locational details of the mortality: description, GPS, Compartment /Block/Range /Sub-Division/ Forest Division/ Tiger Reserve or place/ time	
3	Date of Mortality/ carcass report	
4	In case of seizure of body parts details indicating the status of carcass or seized material	
5	Details of the person (staff/ Others) who reported the incident first: name/address/ contact details/ telephone numbers/e-mail	
6	For carcass: Date, time and Place of Post Mortem (PM)	
7	Details of PM Team (names/designation/ address/ contact)	
8	Details of the missing body parts, if any	
9	Cause of death as ascertained after the PM	
11	Colour photographs of the carcass/ body part (s)- (close ups, indicating injury, if any); details of comparison with camera trap photo data base	
12	Cause of death: Natural/ Poaching	
13	In case of poaching/ seizure of body parts: i. further action taken/ proposed: ii. attach colour photographs of the seized body part/s iii. attach certification regarding species identity (for bone pieces/ meat/ other body parts which are not physically	

	identifiable) iv. action taken with respect to offenders/ suspects (if arrested) v. status of Case/ complaint: number, date of filing the complaint, Sections of law, name of Court where filed	
14	Panchnama/memo of disposal of carcass/ body part (s)	Enclosed/ not-enclosed
15	Remarks if any	
16	Signature of the Officer In-charge with name, designation, date and stamp	

(SOP prepared with inputs from Field Officers of Tiger Reserves)

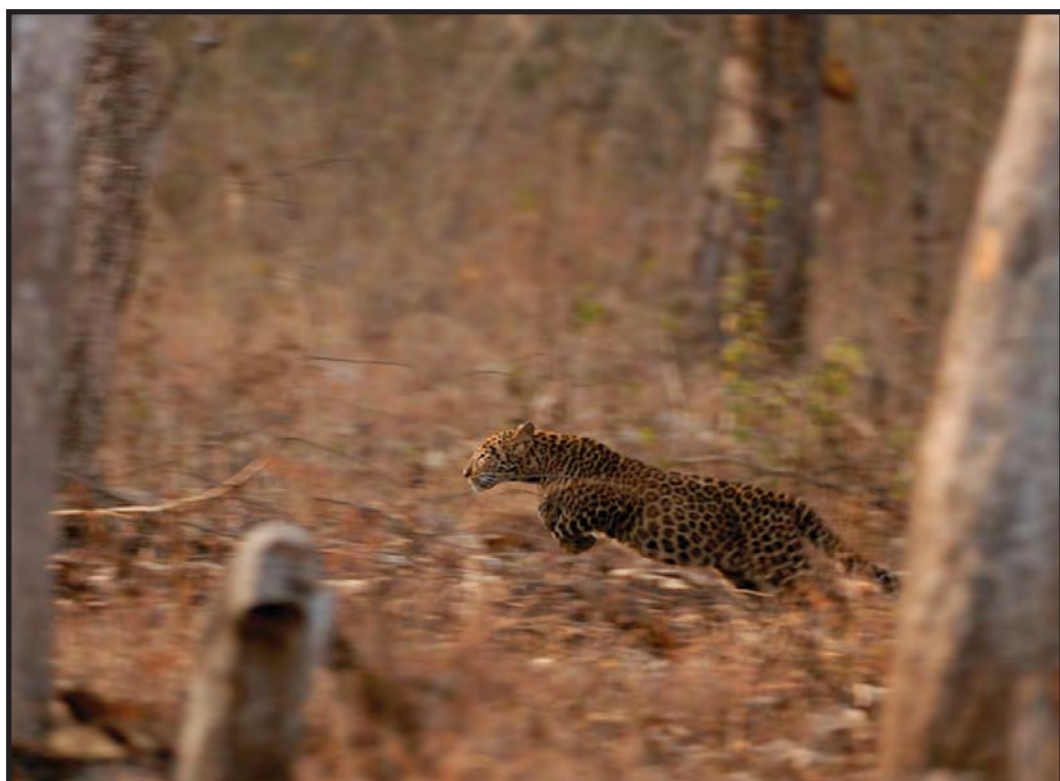
GUIDELINES FOR HUMAN-LEOPARD CONFLICT MANAGEMENT



APRIL 2011



Ministry of Environment and Forests
GOVERNMENT OF INDIA



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FOREWORD

Man-leopard conflicts have been hitting the headlines regularly in different States. I have been consulting various experts on what should be done to deal with such situations. This booklet, the first of its kind from the Ministry of Environment and Forests, is a result of the consultations with, and the suggestions from, a wide range of individuals and organizations involved in the subject, besides drawing upon reports and scientific studies available on human-leopard conflict. Knowing full well that such conflicts are locale-specific, this booklet is intended to provide a guidance framework to be adopted to deal with incidents of loss of life and livestock caused by leopards. I am sure the local communities, field forest officers, and revenue and other district administration officials will find this booklet useful in dealing with such situations.



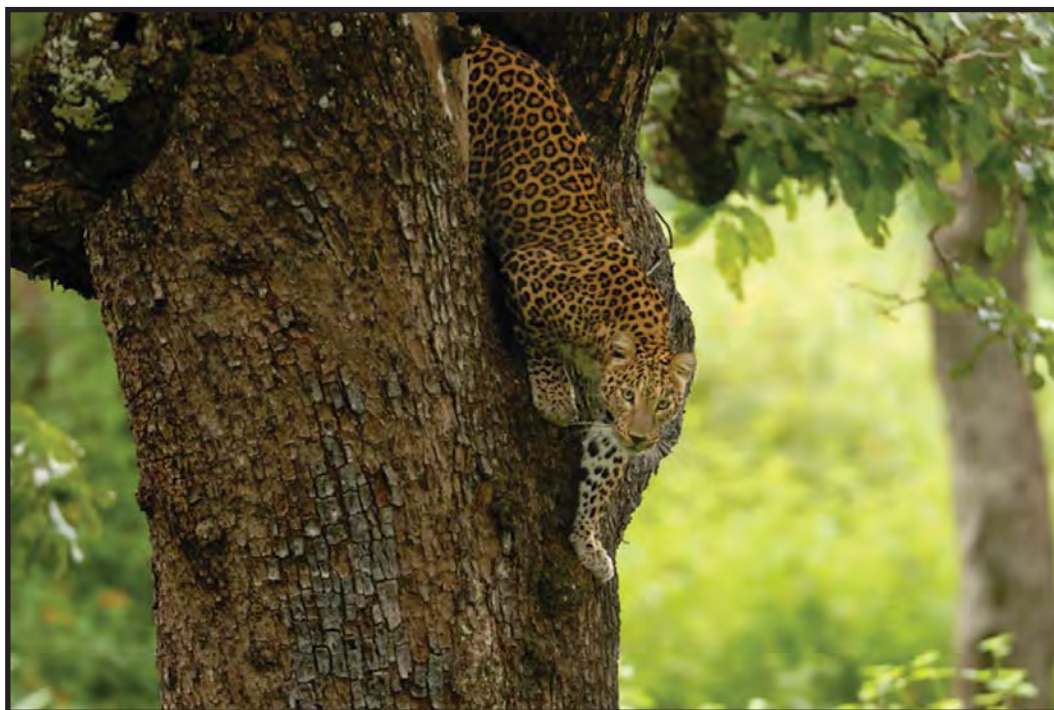
Jairam Ramesh
Minister of State (Independent Charge)
Environment & Forests
Government of India
18th April, 2011



INTRODUCTION

Leopards are a highly adaptable species that live in and around many human-dominated, agricultural landscapes. It is a daunting challenge to ensure the peaceful coexistence of leopards among high densities of humans of the order of 200 or more to a sq.km. Research indicates that even in such high human density areas, attacks on humans and domestic animals in most cases can be kept to very low levels. The goodwill and trust of people especially in rural areas are vital to dealing with crisis situations arising out of loss of life and livestock by leopards in rural areas. The Forest department is the first to face the heat of the public reactions and requires the goodwill and confidence of the rural community much more than any other government department.

These guidelines provide a framework not only to address the conflict after its occurrence, but also to minimize such conflicts through adoption of necessary pro-active measures.



BACKGROUND

Incidences of leopards ‘straying’ into settlements causing human casualties, and the retaliatory killing of leopards by the public have been on the rise. The efficacy of capture and translocation of leopards from conflict areas as a mitigation measure is increasingly being questioned. This has necessitated the need for having broad policy guidelines and management options to effectively deal with this gradually intensifying problem in a diversity of human-dominated landscapes across the country.



After careful consideration of the inputs received from a variety of stakeholders, the following framework guidelines are suggested for managing the human-leopard conflict situations in areas where leopards coexist among high densities of humans.

I. AWARENESS GENERATION AND INVOLVEMENT OF PEOPLE

Modern practices in wildlife conservation call for involvement of all stakeholders in the planning and implementation of conflict mitigation measures to muster greater support and cooperation from people.

The overall aim should focus on a participatory approach, ensuring support of local communities and other stakeholders for conservation and management of wildlife. Awareness programmes should target the people sharing space with leopards, in human dominated landscapes like sugarcane fields, tea gardens, fruit orchards, etc., and also the local communities living in forest dominated landscapes, especially in the hilly States of Uttarakhand, Himachal Pradesh and Jammu and Kashmir.

Sensitizing the media about the nuances of the problem of human-wildlife conflict in general and leopard depredation in particular should be an essential part of the awareness strategy. Media should contribute to diffusing the tense situation surrounding conflict with objective reporting aimed at highlighting the measures to mitigate conflict. Reporting mainly aggressive encounters with leopards can erode local people's tolerance and worsen the situation by forcing the Forest Department to unnecessarily trap the wild animal due to public pressure.

Salient Points for Awareness Campaigns

- i. Leopards often take up residence in croplands and tea-gardens.
- ii. They are not usually inclined to attack people; on the contrary, they avoid people.
- iii. Wild carnivores may attack in self-defence, and, therefore, it is advisable to avoid provoking them.
- iv. Mere sighting of a leopard in the vicinity of human habitations does not necessarily mean that the animal has strayed from a forest and needs to be captured.
- v. Arbitrary removal of leopards could lead to increased conflict. The space vacated by a captured animal will soon be occupied by another leopard.
- vi. The focus should be on long term solutions. These include better sanitation measures including proper garbage disposal in villages and towns so that feral pig and dog populations are kept under check, and do not attract wild carnivores. Providing proper toilet facilities in rural areas would go a long way in reducing incidences of accidental encounters with leopards.
- vii. Farmers should be made aware that livestock sheds should be strong, robust and leopard proof.



II. TEAMWORK IN TACKLING CONFLICT

Efforts should be made to involve all departments, wings and agencies of the government to use a well coordinated mitigation approach which is scientific, field-tested and practical, and *inter-alia*, capable of dealing with emergencies related to attacks by leopards.

In this regard, it is vital to involve the Police and Revenue Departments as they are crucial for maintaining law and order in the face of extreme public reactions. Proper training of police and local administrative staff, and constitution of a Primary Response (PR) Team, along with awareness campaigns are essential ingredients of a successful conflict mitigation strategy.

PRIMARY RESPONSE TEAM

These teams may comprise of paid or volunteer members from the local communities, who are trained to respond immediately to a conflict situation. Their primary aim should be to control the crowd and secure the area until the next level of help arrives. In the hills, where the terrain is difficult, and where houses are scattered in a forest landscape, an Emergency Response (ER) team may take time to reach the conflict site. The establishment of a Primary Response (PR) team is important to ensure crowd control before the ER team reaches the spot.



III. ESTABLISHMENT OF EMERGENCY RESPONSE MECHANISM

- ❖ Immediate response is crucial to manage all conflict situations. A trained Emergency Response (ER) team consisting of an officer not below the rank of Assistant Conservator of Forests, one qualified veterinarian, and a minimum of five trained support staff may be formed in the identified conflict area.
- ❖ Each Forest Division should have a well trained operational ER team.
- ❖ Each ER team should be equipped with chemical capture equipment, drugs, appropriate cages, etc. and should wear specially designed uniforms so that they are easily identifiable during the operation. They should also have specially designed baffle boards for protection.
- ❖ The protocol for Emergency Response should be periodically rehearsed and reviewed to incorporate corrective measures to make it more efficient.
- ❖ Establishing such well advertised ER teams that respond effectively and quickly to conflict situations will help diffuse the usual public outrage and retaliation that invariably follows such conflicts. It will also harness the goodwill of local communities. In the long term, the efficient working of the ER teams will prevent escalation and spread of conflict. It will also prevent the situation from going out of control with people taking the law in their own hands.

The Maharashtra Case Study

In response to frequent attacks on humans by leopards, the Forest Department dealt with the issue by:

- Training field staff to handle emergencies of man-leopard conflict, which led to better understanding and management of the issue.
- Micro-chipping captured leopards to understand their movements after translocation, and to monitor the efficacy of translocation.
- Initiating research on leopards living in human-dominated landscapes, to understand the dynamics of human-leopard conflict.
- Improving design of trap cages.
- Creating awareness to avoid as much as possible, unnecessarily capturing the animal.
- Encouraging interaction with media and researchers to create awareness of the complex nature of the issue.

All these experiences were outlined in a management manual that was published in 2007 by Maharashtra Forest Department.





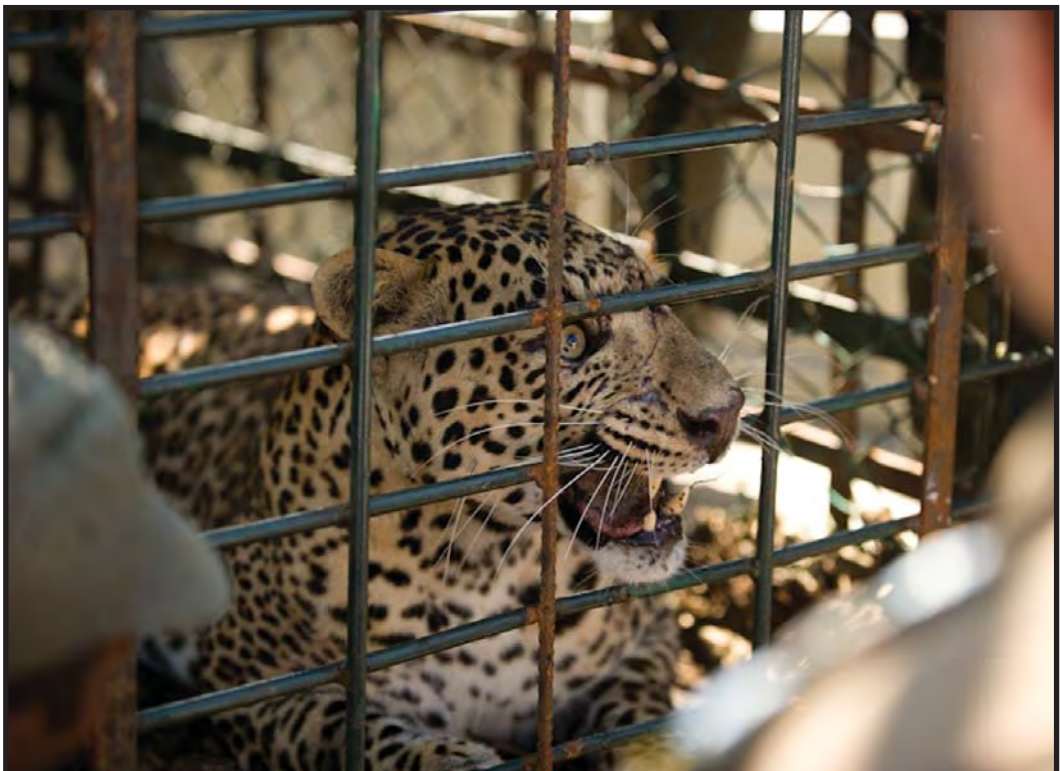
III A. MANAGEMENT OF CROWD

- ❖ Crowd management is crucial to any successful animal rescue operation. The ER team, more often than not, is obstructed and hindered in its activities by furious mobs, making it difficult to discharge its responsibilities.
- ❖ Support and cooperation of the police and civil administration should be ensured in advance to facilitate effective crowd control and to discourage formation of crowds.
- ❖ The area should be cordoned off with barricades, and the public alerted through a public address system. Regular updates should be made available to the administration and local public.
- ❖ There should be an ambulance kept ready to take care of any medical emergencies

A case study from Jammu and Kashmir

In recent years, conflict with black bear and leopards has reached serious proportions in Jammu and Kashmir. In response, the State Wildlife Protection Department proposed the following measures in 2010:

- Setting up of a Central Conflict Mitigation Command Centre with 24/7 helpline facility to receive phone calls from local people in the event of a conflict emergency.
- Feeding the details of the incident into a central database for quick future response.
- Centrally based monitoring and analysis of conflict patterns from information received in the helpline.
- Creation of community level Primary Response Teams consisting of paid or volunteer members from amongst the local communities, trained in the management of crowds in an emergency situation, till the arrival of the forest staff.





III B. MANAGEMENT OF THE ANIMAL

- ❖ The objective should be to give the animal enough space and opportunity to return to its habitat, and situation-specific rescue measures should be followed. The best method of dealing with a wild cat, in the absence of attacks on humans, is not to intervene.

Following steps are prescribed to deal with different situations.

Unconfined or Open Area:

- i. Open situations could mean a barren land, grassland, street, thicket, crop field with standing crop or woodland, with the leopard being either up on a tree or on the ground.
- ii. If the animal is in an open area surrounded by people, all attempts should be made to keep the crowd and local people from approaching near the animal, and the animal should be allowed to escape under the cover of darkness.
- iii. Drug immobilization should be avoided in situations where the animal is in the open, even if the target presents itself in an appropriate position, since a darted animal in the open can retaliate injuring people.
- iv. To trap the animal, a suitably designed light-weight trap that minimizes injury to the animal, should be used. The caution outlined in Annexure-I should be followed while designing trap cages.

Semi-confined:

- i. If the animal is confined in a dry well or trench, a ladder let down into the well will allow the animal to escape in the night.
- ii. Here too, the public must be kept away from the site, and the rescue team should monitor the situation until the animal escapes.



Animal Confined in a Closed Area:

- i. If the animal is confined in a closed area, for example in a house, garage, under a culvert, or caught in a snare, etc., the surrounding entrance and exits should be made secure to ensure no injury to the public.
- ii. If the area is adjoining a forested area, the animal should be allowed to escape in the night, but if it is in a high human density area it should be tranquilized.

III C. CAPTURE AND HANDLING OF THE TRAPPED ANIMAL

Captured leopards should not be put on display after capture. Such unintended forced close contact with humans may alter the behaviour of captured animals with highly adverse consequences following their release. Ideally, such leopards should be kept in covered cages (Annexure-I). Only healthy fit individuals should be returned to the wild.

Following advice may be followed scrupulously while handling captured or trapped wild animals.

- i. All captured animals, irrespective of the method used to capture (chemical/trapping), should be chemically restrained for evaluation of its condition for prognosis and suitability for release.
- ii. While confined, the animal can be micro-chipped, scanned (if already micro-chipped), treated, and various morphometric parameters recorded.
- iii. If the animal is to be released back in the wild in a few days, it should be housed in a suitable transit facility with minimum exposure to humans.
- iv. If the animal is to be placed in captivity, the life time care facility to house the animal should meet the standards prescribed by the Central Zoo Authority.
- v. If an animal kept in captivity is intended to be released, thorough investigation of

its fitness, and evaluation of its response to humans should be conducted before releasing it into the wild.

- vi. If the animal has been kept for more than a month in captivity, it should not be released back into the wild.
- vii. If the animal is injured beyond recovery or permanently disabled, euthanasia is recommended as the best option. Even if the exceptional decision for euthanasia has been arrived at, the animal must be chemically restrained.
- viii. NSAIDs (Non-Steroid Anti Inflammatory Drugs) should never be used for treatment of the animal as these are contraindicated in felids. Long acting antibiotics should be used for sustained therapeutic effects even after release.

III D. RELEASE OR TRANSLOCATION OF CAPTURED LEOPARDS

The decision to capture an animal should be the last option. It is very important that human intervention is restricted to the minimum to avoid future conflict. If the captured leopard is to be released, it should be in the immediate vicinity of capture, i.e., within animal's home range.

Leopards are highly adaptable animals, and exhibit amazing homing instincts¹. A translocated leopard trying to navigate to its home territory through a dense human landscape may lead to increased incidences of conflicts rather than reducing the same. **Therefore, it is best to avoid translocation.**

No animal captured after a deliberate attack on a human should be released into the wild.



¹ In Africa, a translocated leopard traversed back a distance of 400 km to return to its home territory.



III E. TRANSPORTATION OF CAPTURED ANIMAL

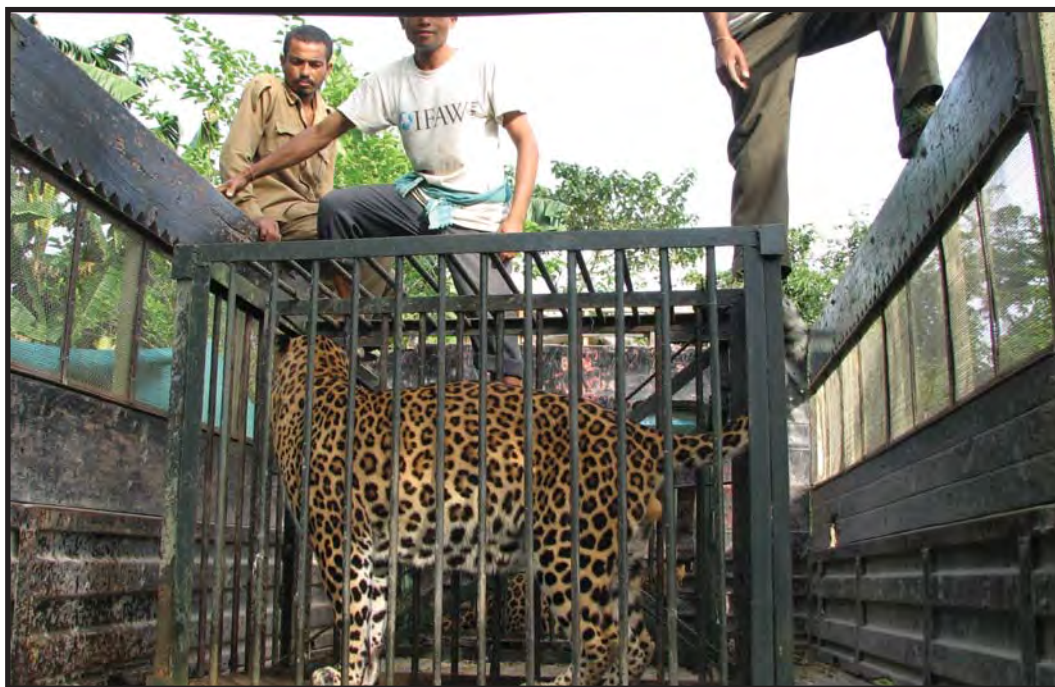
Captured animals often get injured or stressed during transportation. Stress could be detrimental to the health of the animal, which coupled with excessive exposure to humans may adversely alter its behaviour towards humans after release.

The animal once captured should be kept and transported in a stress free environment, insulated from the public. It is important that humans are not allowed to come close to the caged animal, and that the cage is also completely covered with tarpaulin or other appropriate material.

Tranquilized/captured animals must be transported in the trap itself (if suitable) or in a separate transportation cage. Care should be taken to avoid crowded places, and the animal's health condition frequently checked during transit.

III F. MONITORING OF TRANSLOCATED LEOPARDS

The success of translocation or release of leopard has to be measured and evaluated against appropriate post-release monitoring protocols. Translocation very often leads to the transfer of conflict to another unaffected site. Individual identity of all the released animals should be monitored by marking them with microchips and ear tags or colour coded collars before release. Radio collars should be put on a sub-set of released animals to monitor post-release movements and survival. Scientists and experts must be involved in such radio-tracking programmes.



III G. AVOIDABLE “RESCUE” OF LEOPARDS

A cub without its mother usually does not need “rescue” as the mother leaves the cubs when she goes hunting. Equally, cubs released without its mother have poor survival probabilities. If cubs are found alone, a watch must be kept for their mother without disturbing them. Cubs are not to be “released”, but only require “reuniting” with their mother. Reuniting should be attempted immediately in the night in the same area, from where they were picked up. A suitable camera trap placed overnight near the ‘reunion site’ would facilitate the confirmation of the reunion.

Cubs that are hand-reared in captivity have a negligible possibility of future release back to the wild. Lifetime care is the only suitable option for such cubs, since their release in the wild even after a long term rehabilitation process may only worsen the already existing conflict situation.

IV. HELPING RURAL PEOPLE BETTER PROTECT THEIR LIVESTOCK – A CONFIDENCE BUILDING MEASURE

- ❖ Subsidy should be provided for simple but sturdy and leopard-proof livestock sheds.
- ❖ Vaccination camps for livestock could also be organized in collaboration with the Animal Husbandry Department.
- ❖ Possibility of initiating state sponsored insurance schemes for livestock also needs to be explored.



IV A. EXPEDITIOUS AND EFFECTIVE DELIVERY OF *EX-GRATIA*

Immediate response to loss of life, livestock, and property caused by leopards will help calm people. This will prevent violent reactions towards the problem animal in particular and wildlife in general.

Payment of *ex-gratia* should be made fast and hassle free. The possibility of initiating self financed insurance schemes should be explored.

- i. In case of **attack on humans**, it is recommended that senior level officers immediately visit the site. A vehicle should be provided to take the victim to the nearest medical facility. **The *ex-gratia* payment should be made immediately.**
- ii. In case of **attacks on livestock**, *ex-gratia* amount should be provided within a week. The complaint should be made at the Gram Panchayat office, and the Forest Guard should visit the site immediately. The protocol should be verified by Forest Guard and Gram Sevak. Extra travel and phone allowance should be provided to the Forest Guard to enable him to effectively discharge this responsibility without delay. Veterinary certificate and photographic evidence should not be made compulsory requirements for disbursement of *ex-gratia* amount. The amount should be dispatched through a bank demand draft.
- iii. The use of an 'sms' based updating system to inform the victim or his relatives about the status of his/her claim, and also to receive complaints should be explored.
- iv. It is extremely important that the animal is allowed to feed off the livestock it has killed. After inspection by the forest Guard and the Gram Sevak, the carcass should be taken to a nearby secluded area, the same evening. If a leopard is deprived of its kill, it will make more kills, inflicting more losses on the farmers. Also, it is possible that after being deprived of its kills repeatedly, the animal may become desperate, increasing the intensity of conflict. This aspect also needs to be explained to the villagers.

- v. Bi-yearly meetings should be held where local MLA, panchayat heads, revenue, veterinary, health and forest department officials should discuss the problem of human-wildlife conflict, and how effectively it is being managed. Such meetings could also review the existing practice and options of mitigation with a view to making these more effective and people friendly. The above exercise should involve trained wildlife biologists and other experts.

V. COLLECTION OF INFORMATION ON LEOPARD CONFLICT

- ❖ Management of a species should be based on systematic long term data. Information on conflict incidences should be collected systematically in an appropriate format to aid decision-making.
- ❖ Long term research, focused on estimating the population and abundance of leopards in high conflict areas, should be taken up on priority.
- ❖ Identification of conflict prone areas, with data on conflict intensity, nature of conflict, and trends, must be collected for better preparation and pre-emption.

VI. DEALING WITH MAN-EATER LEOPARDS

Attacks by man-eating leopards are deliberate with an intention to kill, and usually result in death, e.g., child being lifted from the precincts of the house, and attacks on people sleeping inside the house. In such cases, every attempt must be made to identify the correct animal, and trap the animal as per the guidance outlined. Immediately after the first attack by a man-eating leopard, orders from the Chief Wildlife Wardens should be obtained to eliminate the problem animal with the help of shooters. Trap cages should be installed to capture the man-eater. This is especially crucial when such attacks occur in highly populated landscapes. **Animals trapped after deliberate attacks on humans should never be released back into the wild.** Humanely euthanizing such animals should be the preferred option.

VII. PROTOCOL TO BE FOLLOWED IN CASE OF LEOPARD ATTACKS

In case leopard attacks are reported against human beings or cattle, the protocols suggested in Annexure-II and Annexure-III respectively may be followed.

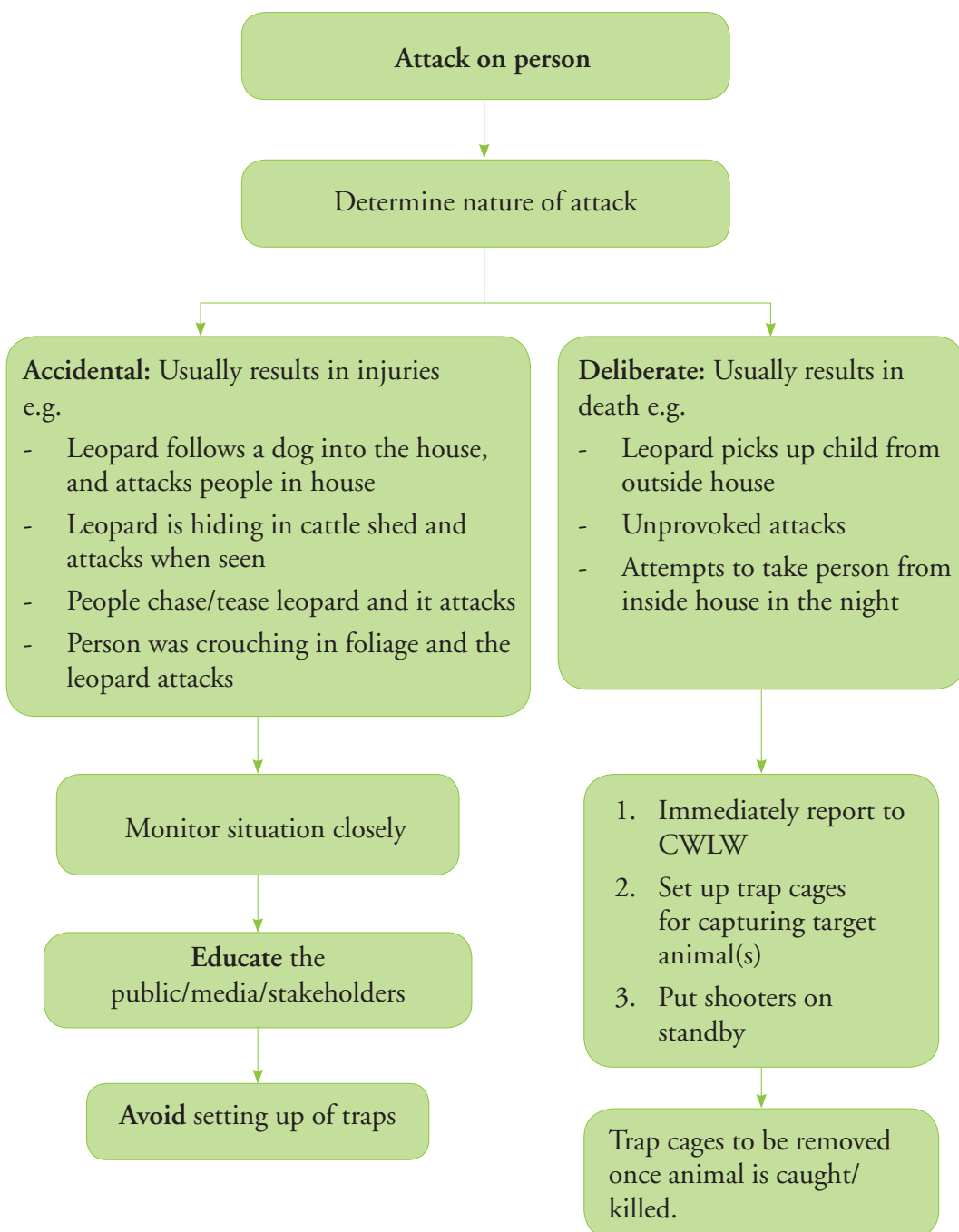
ANNEXURE-I

CARE AND CAUTION IN DESIGNING TRAP CAGES

1. Trap cages should be completely enclosed (new designs use fiberglass) with holes for ventilation.
2. Iron rods should not be used (thick chain link is preferable) anywhere in the trap cage as leopards struggle to escape by pulling at the bars which results in canines being broken.
3. Old rusty, iron cages should be discarded, and not used to house leopards.
4. There should be a gap of 1.5 inches between the cage floor and the lower edge of the trap door to prevent tails getting slammed.
5. Trap cages should be well ventilated.
6. Trap cages should be at least 6 feet in length with the trap door activation system being at the opposite end of the trap door. The height of cage should be around 4-4.5 feet and width ~ 3.5 feet. Cages made of fiber glass (currently being used in Maharashtra) are lightweight and can be carried by 4 people. Collapsible cages should also be designed and physically tested in the field to assess their effectiveness.
7. **Some Do's and Dont's for holding leopards in trap cages:**
 - (a) Trap cages should not be used for long term captivity (no more than one week). Separate temporary transit facility should be created for long term captivity.
 - (b) Only one animal can be held at a time in a trap cage.
 - (c) Water should be made available at least two times a day – either through a pipe which can be inserted in a hole at the side of the trap cage or by placing a steel bowl of water inside.
 - (d) Trap cage should not have any artificial padding (no rubber etc) as leopards have a tendency to rip off and eat it while struggling to escape. These synthetic materials could get lodged in the stomach of leopards and result in their death.

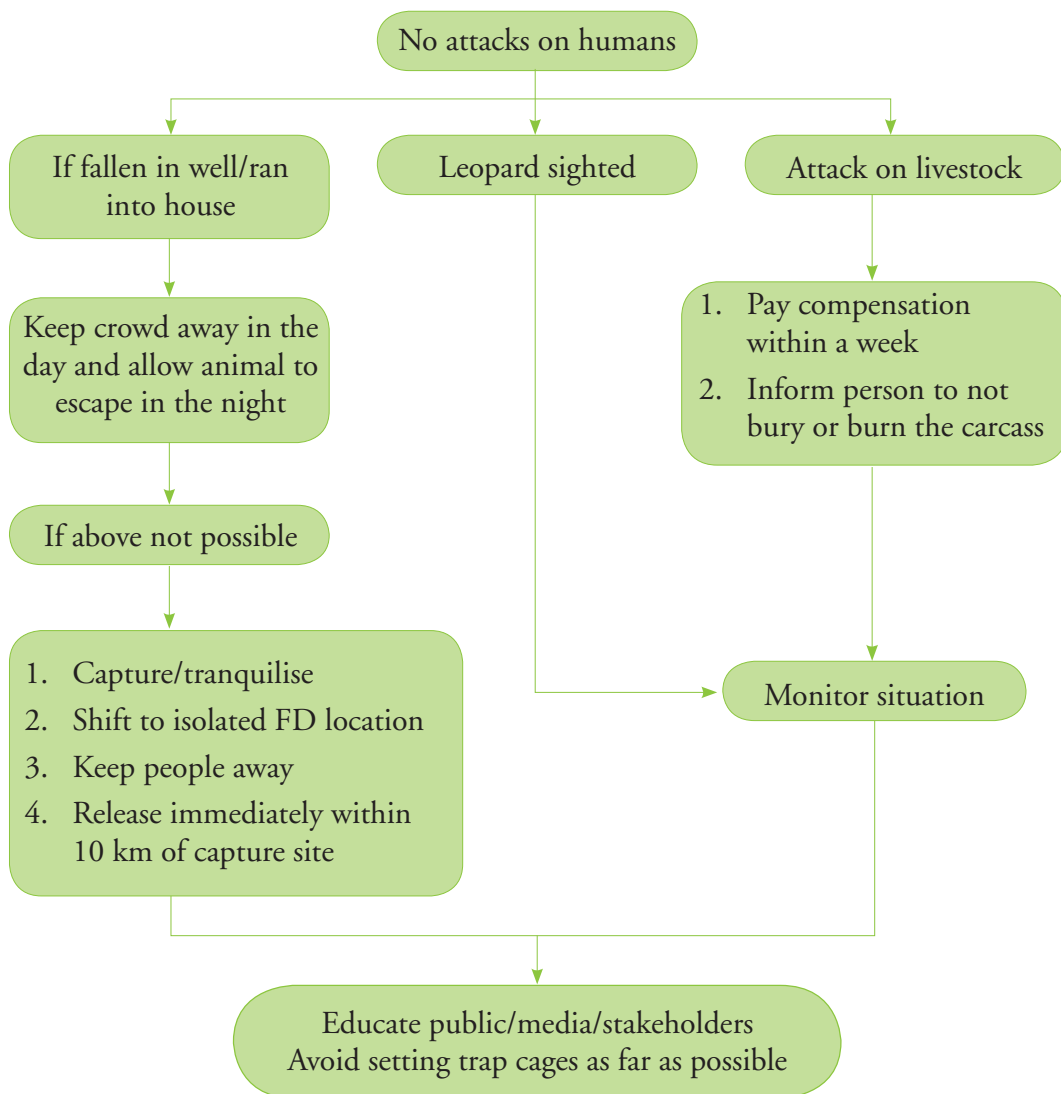
ANNEXURE-II

IN CASE OF ATTACKS ON PEOPLE



ANNEXURE-III

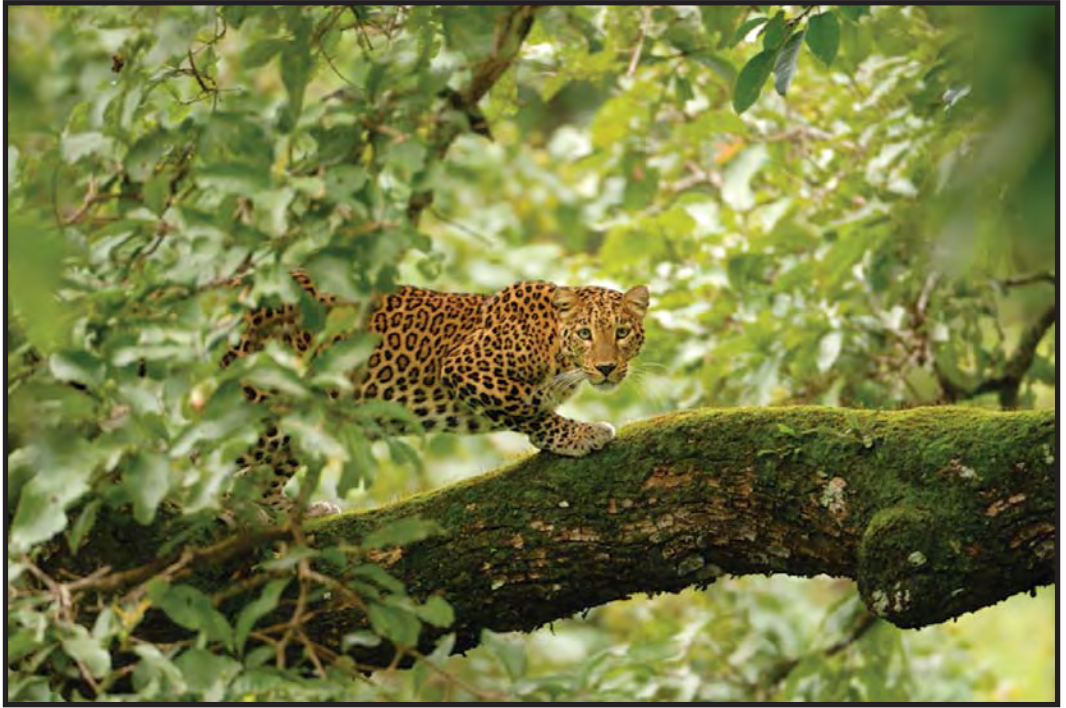
IN CASE OF ATTACKS ON LIVESTOCK OR SIGHTING OF A LEOPARD



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STANDARD OPERATING PROCEDURE TO DEAL WITH EMERGENCY ARISING DUE TO STRAYING OF BEARS IN HUMAN DOMINATED LANDSCAPES

- Title:** Standard Operating Procedure to deal with emergency arising due to bear-human interactions (conflicts) in human dominated landscapes
- Subject:** Dealing with emergency arising due to bear-human interactions in human dominated landscapes
- Purpose:** To ensure that bears are handled in the most appropriate manner to avoid casualty / injury to human beings and/or livestock, and loss to property or crops.
- Summary:** This Standard Operating Procedure (SOP) provides the basic, minimum steps which are required to be taken at the field level (Protected Area /Reserved Forest or elsewhere) for dealing with incidents of bear-human interactions in human dominated landscapes.
- Scope:** The SOP applies to all forest field formations including human dominated landscapes near forested areas where such incidents occur.
- Responsibilities:** The Protected Area Manager would be responsible in the case of a protected area (National Park / Wildlife Sanctuary). In the case of other areas (revenue land/conservation reserve/ community reserve/village/township) the Wildlife Warden, as per the Wildlife (Protection) Act, 1972, or Divisional Forest Officer/Deputy Conservator of Forests (under whose jurisdiction the area falls), would be responsible. The overall responsibility at the State level would rest with the Chief Wildlife Warden of the concerned State.

Suggested field actions to deal with strayed bear or bear-human interactions

- (a) On receiving confirmed reports of bear-human interaction (conflict) or straying of bear into human habitations in an area, constitute a Committee immediately for technical guidance and monitoring of the situation on day to day basis, as under:-
 - i. A nominee of the Chief Wildlife Warden
 - ii. A veterinarian
 - iii. Local NGO representative
 - iv. A representative of the local Panchayat
 - v. Field Director/ Protected Area Manager/ DFO I/C - Chairman
- (b) Constitute a Rapid Response Team (RRT) (See Annexure-I), if not created earlier. Since it may not be always possible for experts from the Wildlife Institute of India to provide assistance, it is advised that some outside experts who have experience on bears or other large carnivores may be involved in the ongoing monitoring.
- (c) Collect recent crop/livestock depredation or human injury / fatal encounter data, if any, in the area. If it is an area that has been historically prone to such incidences, detailed research work has to be carried out in order to assess the reasons for the frequent bear emergencies in the area.
- (d) In case of confirmed crop/livestock depredation / human injury /fatal encounters or frequent straying of bears near human settlements, rush to the site along with the RRT and local police to maintain law and order in the area, besides avoiding crowding by local mobs. This is essential to avoid agitation / excited local people surrounding the animal spot which hampers safe exit to bears or capture operation, leading to serious injuries on people and staff. It is also necessary that police and local administration be involved at an early stage. Effective coordination with them is critical to control mobs which as has been seen in several instances, worsen the situation and lead to avoidable fatalities/ tragedies. If the bear has just strayed into the village and has been surrounded by people, manage the crowd in such a way so as to provide a safe exit for the bear to move into the nearest bear habitat.
- (e) If the bear had killed livestock or injury to humans or loss to crops/property, the RRT along with the local villagers should use indigenous methods such as beating of drums or empty metal containers to prevent bears returning to human habitations. This situation should be monitored until the problem is solved or reduced. Indigenous crop protection measures have to be strengthened through community participation. Burning red chillies on cow dung cakes or firewood in the periphery of villages or crop field during dusk and nights, would repel bears from those areas. However, care should be taken to avoid discomfort to humans living in the villages by selecting sites far away from habitations and taking consideration of the wind direction.

- (f) Create awareness amongst the villagers on bear behaviour and the ways to avoid a bear encounter and the ways to respond in such situations. For instance, moving in groups with sticks in hand and avoiding moving singly during dawns, dusks and nights would reduce encounters with bears.
- (g) If the bear has killed livestock inside the night shelter in a village/village fringe or raided crops in fields near villages, set up camera traps near the conflict sites to ascertain the age (adult, subadult, young) or whether single or mother with cub(s) or a pair.
- (h) Ensure unobtrusive guarding of livestock kill to allow feeding of the carcass (if not close to a human settlement) besides safeguarding from poisoning (for retaliatory killing). Reinforce roof, windows and doors of livestock night shelters, food storage rooms, shops etc. and if required replace with metal doors.
- (i) Set up hair snares around the livestock kill/crop field or on the approach path to the kill site or crop field using two or three barbed wire strands to collect hair samples of the animal for genetic analysis. Also collect bear scats at the site and the nearby bear habitats for genetic analysis.
- (j) If the bear is repeatedly straying into the village set up of bear traps (automatic closure) with appropriate luring while avoiding disturbance, to trap the animal.
- (k) In case, the captured bear is found to be healthy in prime or young age without any incapacitation (loss of canine, injury, broken paw etc.), as confirmed / certified by the Committee as constituted at para (1), then it may be released after applying an ear-tag or radio-collar (optional) in the nearest bear habitat away from human settlements. While releasing the capture bear back into the wild, 'aversive conditioning' has to be done by bursting of crackers, beating drums or firing with rubber bullets.
- (l) If in case, the captured bear is old, sick or injured, it should not be released back into the wild and instead sent to a recognized zoo or Rescue/Rehabilitation Centre.
- (m) Under no circumstances, a bear should be eliminated by invoking the Wildlife (Protection) Act, 1972, if it is not confirmed as a "problem bear" through individual identification based on genetic analysis.
- (n) An authorized spokesperson of the Forest Department, should periodically update the media (if required) to prevent dissemination of distorted information relating to the operation / incidents. Sensitization or distorted information can lead to further damage.
- (o) The Chief Wildlife Warden has to take the final decision on whether a bear has to be released back in the wild or transferred to a zoo or Rehabilitation Centre.

Instructions for the constitution and operation of a Rapid Response Team

The Rapid Response Team (RRT) comprises of a small team of well trained, well equipped field staff and one veterinarian led by a Forest Range Officer for capturing the bear to avoid lethal encounter. The rapid rescue team is required to ensure unobtrusive close monitoring of the animal with least disturbance, for tracking its movement. The RRT to be equipped with the following:-

1. A field van/mini-truck with built in rails for accommodating a trap cage, with space for equipments, attendants and staff.
2. A tranquilization kit with drugs for chemical immobilization.
3. Taser gun for instant immobilization of the animal (optional).
4. Two mobile phones for continued communication with the authorities.
5. Four wireless handsets.
6. Two GPS sets, Two binoculars.
7. One long ranging night vision for seeing objects in the dark.
8. One digital camera and Six camera traps
9. Two portable culvet traps with wheels; six bear snares
10. One mini-tractor/all terrain vehicle for transporting the trap in rugged terrain.
11. Two search lights.
12. Some Ear tags and one tag applicator and radio collars (optional) with receiver and antenna.
13. Two portable tents, camp stools.
14. Barbed wire strands (2 x 10 m) & 6 poles (2 m long)
15. Net, stretcher, ropes.
16. First aid kits, bear pepper sprays (optional), red chillies
17. The rapid rescue team also requires due capacity building and 'hands on' field training involving the Wildlife Institute of India or other expert agencies.



***Prosopis juliflora*: A Miracle Species of Hot Arid and Semi-Arid Regions of India**

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Prosopis juliflora for which most of people still have not a value more than a weed that has become now one of most significant tree species of hot arid and semi-arid regions of India after it has been known for its multiple usefulness. Central Arid Zone Research Institute (CAZRI), Jodhpur has been pioneer in finding out of multitude products from *Prosopis juliflora* and developed methodology of various products for consumption not only by animals but also by human being, some of which important products are described in this article.

Introduction

Prosopis juliflora (Sw.) DC, an evergreen tree is native to South America, Central America and the Caribbean. It is commonly known as Vilayati Babool in India and its first introduction into India has been reported differently by different people. Rawat et al. (1992) reported that *Prosopis juliflora* was first introduced in India during 1875 in Punjab whereas Reddy (1978) stated that the first introduction of *P. juliflora* into India took place in 1877, with seeds from Jamaica that arrived in the country one year earlier. The seeds were first sown in various arid areas around Kamalapuram, in the Cuddapah District of Andhra Pradesh (old Madras Presidency) and the plant was named as “the exotic lady of South America”. Different from both these, Gupta and Blara (1972) reported that *Prosopis juliflora* was introduced in India in 1857 from Mexico. Based on these reports, it can be stated that *Prosopis*

juliflora was introduced in India somewhere during 1870s. In the present state of Rajasthan, it was first introduced in Jodhpur in 1913 where the ruler of the then state of Jodhpur named it “Royal Plant” in 1940 because of its excellent growth rate and evergreen nature in all environmental condition (except frost). Large scale aerial seeding of this tree was undertaken to establish sand dunes and sand storms in Rajasthan (Harsh et al., 1996). Further introductions of this species followed gradually into the states of Haryana, Uttar Pradesh, Madhya Pradesh, Maharashtra and Tamil Nadu (Harsh and Tewari 1998; Muthana 1985). Today, owing to its fast growth and drought hardiness with extraordinary ecological amplitude, the species has been spread throughout the length and breadth of the country, from Haryana in north to Tamilnadu in down south, and from Kutch, Gujarat in west to drier parts of Orissa in east (Tewari et al., 2000).

The false impression of *Prosopis juliflora* has been till now that it has been considered as a horribly invasive useless species in most parts of the world. It is so perhaps due to unknowingness of its multiple usefulness by most of the people. The research at Central Arid Zone Research Institute (CAZRI), Jodhpur has led the concept to be turned into a useful resource of hot arid and semi-arid ecosystem. The usefulness of *Prosopis juliflora* has long been recognized since the work by Muthana and Arora (1983). It was then considered to be a valuable tree species of the desert ecosystem. Its multiple use possibilities have attracted growing interest in this species, especially in arid zone. The view of usefulness of *Prosopis juliflora* got strengthened further among the rural community when a sub-project “Value chain on value added products derived from *Prosopis juliflora*” was launched at CAZRI during 2008-09 under National Agricultural Innovation Project (NAIP). Under the project, CAZRI has successfully developed a value chain on value added products of the species by involving farmers, NGO and Industry. Various products technologies were developed for animal consumption as well as human consumption and transferred to industry for large scale production and marketing. Some of popular products are being described in this article.

Products for Animal Consumption

Cheaper concentrate feed: A very simple process technology was developed by utilizing *P. juliflora* pods mixing with

other ground feed ingredients available locally viz., tumba (*Citrullus colocynthis*) seed cake, guar (*Cyamopsis tetragonoloba*) korma, til (*Sesamum indicum*) seed cake, wheat bran, maize grain, common salt and mineral mixture. Farmers readily accepted this process technology and it is very much possible at livestock owners’ doorsteps.

Multi-nutrient feed block: Guar seed meal is commonly used in multi-nutrient feed blocks. *P. juliflora* seed meal contained 2.77% minerals, 8.35% ether extracts, 44% crude protein and 44.9% total carbohydrates. These values are comparable with seed meal of guar. Therefore, multi-nutrient feed blocks were prepared



by replacing guar meal by *P. juliflora* seed meal. Other contents of this block are tumba (*Citrullus colocynthis*) seed cake, molasses, urea, common salt, dolomite and vitamin-mineral mixture. This reduces the cost of multi-nutrient feed block in one hand and added to its nutritive value on the other.

Densified complete *P. juliflora* block:

The pods, which have less amount of mesocarp (good source of sugar) was directly crushed/ground in the hammer mill.



Ground pods were compressed for densification in the block making machine

up to pressure 160 kg/cm² to make it as a block. The volume reduction was found more than 80 percent, which is very helpful for storage and transportation; and as well as enhancing the shelf life.

Products for Human Consumption

Prosopis coffee: *P. juliflora* coffee is major one among some of human consumption products developed from *P. juliflora*. The coffee has given brand name as 'Juli Coffee'. The technology of *P. juliflora* coffee preparation has been standardized and passed to partner industry of the project. However, toxicity analysis for human consumption of *P. juliflora* pod flour is in progress at NIN, Hyderabad. Once a clean chit is obtained in this context, *P. juliflora* coffee will also be launched in the market. The coffee was prepared by roasting *P. juliflora* pod flour at different temperatures and mixing chicory (*Cichorium intybus*) with raw coffee powder. The prepared coffee contained 70% *P. juliflora* pod powder and 30% chicory mixture (containing 20% raw coffee powder + 10% chicory powder).



***Prosopis juliflora* syrup:** Ripe and sound pods were selected, washed and broken into small pieces. One liter of water is added to 350 g of pods, and then boiled for two hours. The product is then sifted to separate the coarse particles. One hundred

gram liquid was obtained from 350g pods. To obtain the syrup, the liquid is boiled until it reaches the necessary consistency. This thick liquid was yellowish brown in colour and can be used as a beverage. It can also be mixed with milk and fruit juices. This syrup is widely used in Latin and South America countries. The residue left after preparing the syrup was used for processing fine flour and fine fiber. The quantum of fine flour and fiber obtained from used 350g pods was 62 g and 26 g, respectively. The flour obtained by this process was quite fine, which was highly suitable for use in confectionary items. The process technology standardized for these products is given below:

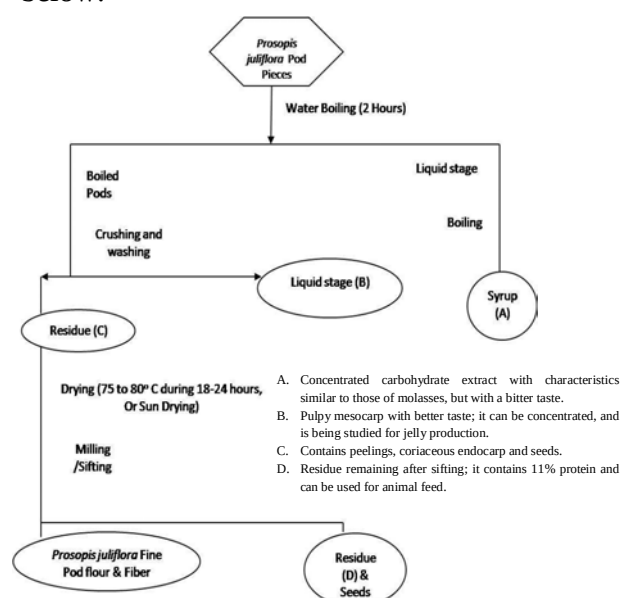


Fig. Schematic representation of process technology to prepare Juli Syrup, Fine Pod Flour and Fine Pod Fiber

All these above mentioned products are few examples of *Prosopis* pod utility. There can be numerous uses of its pods and other plant parts. The general uses of *P. juliflora* are mentioned as follows:

1. **Used as fuel:** Although the initial plantations in India were mainly established for the purpose of conservation, *Prosopis juliflora* has become the main source of fuel in rural areas and to a large extent, in urban and semi-urban areas also. Today it fulfils more than 70 percent of the firewood requirements of the rural people in the tropical arid and semi-arid regions of India (Harsh and Tewari 1998).
2. **Use of *Prosopis juliflora* wood:** Larger branches and trunks yield a high quality timber, comparable in colour, finish and physical attributes to Indian rosewood and other commercial hardwoods. Its exceptional property is its negligible shrinkage (4.17%) which is much less than for oak, maple or walnut trees (14-16%). Because of this quality furniture items made from *Prosopis* wood develop little or no cracking or warping later on (Singh, 2008). In India use of *Prosopis* wood in furniture industries is very limited because of non-availability of straight bole trees and also some extent because of a lack of knowledge. In other countries, *Prosopis* species are widely used for making furniture because of their high quality wood. The wood of *P. juliflora* is soluble to varying degrees in water, sodium hydroxide, alcohol and benzene, which

means that it can be successfully pulped for the production of writing and printing papers, textile fibres, tyre cord or cellophane. Tests have indicated that writing and printing papers could be produced from *Prosopis juliflora* logs having 30 to 50 cm in girth with 50 per cent cellulose and 30 per cent lignin (Madan and Tandon, 1991).

3. **Use of *Prosopis juliflora* biomass:** *Prosopis juliflora* is the most efficient species to convert energy into biomass. It is an excellent candidate for short rotation energy plantations considering its fast growing nature, higher biomass production potential, drought and heat tolerance and excellent coppicing ability. It produces biomass about 25 to 30 tons/ha/year at the short rotation age of 4 to 5 years (Patel, 1986). It was reported that total biomass from *Prosopis juliflora* ranked first amongst the high biomass producing native trees of arid and semi arid regions of India. (Singh, 2008). *Prosopis juliflora* trees maintain their greenery and continue to grow even during severest of the severe droughts in desert states like Rajasthan. It will be worthwhile to mention here that during 2002 drought in India, it were the *Prosopis* trees which provided livelihood security to the rural population, settled in arid and semi arid drought prone regions of the country. Wherever thickets of *Prosopis juliflora* are creating danger of encroachments to agricultural fields, they can be harvested to generate

electricity. Kutch region of Gujarat has ample scope for electricity generation as *Prosopis* thickets are naturally growing in this tract.

4. **Use of *Prosopis juliflora* Gum:** *Prosopis juliflora* exudes gum from the sap wood. On average, about 40 g of gum is produced from one plant. However, under drought conditions more gum is exuded. A single person has been estimated to be able to collect 1-2 kg of *P. juliflora* gum/day in India (Tewari, 1998). The trade in exudate gum has been increasing in India, with *P. juliflora* gum estimated to make up approximately 80% of that total gum production in Gujarat (Tewari, 1998). *P. juliflora* gum exudation increased at higher temperatures and ceased completely at the beginning of the rainy season (Tewari, 1998). The gum forms adhesive mucilage, with favourable physical and chemical properties, that can be used as an emulsifying agent. *Prosopis* gum also finds use in confectionery, mending pottery, and as an adulterant and substitute for gum arabic. (Krochmal et al., 1954). It possesses fairly good adhesive strength and can be used as paper adhesive for brown paper and wall paper (Vimal and Tyagi, 1986).

5. **Medicinal value of *Prosopis*:** In India, boiling wood chips, a bark extract is used as an antiseptic on wounds, and gum is used to treat eye infections (Vimal and Tyagi, 1986). Research done at Central Arid Zone Research Institute, Jodhpur (Azam et al., 2011) resulted in identification of antioxidant compound which is present in

concentrated form (6-8%) in the heart wood of *P. juliflora*. The compound was identified as (-)-mesquitol ($C_{15}H_{14}O_6$) which was compared with existing pharmacologically / therapeutically accepted antioxidant probucol and α -tocopherol and found that (-)-mesquitol is better than probucol and α -tocopherol drugs. *Prosopis* wood is reported to have medicinal value for treatment of rheumatism and against miscarriage. Some of the alkaloids of *Prosopis* species are reported to be antifungal and antibacterial. In Brazil, *P. juliflora* flour is used as an aphrodisiac, syrup as an expectorant and tea infusion against digestive disturbances and skin lesions (Rocha, 1990).

6. **Role of *Prosopis* in Carbon sequestration:** Wide spread of *Prosopis* trees may account for a significant amount of sequestered carbon, though tree species in arid and semi-arid zones are not considered at present for calculating carbon balances. But a considerable quantity of carbon can be stored in woody biomass of the species. Even a single rotation of *P. juliflora* would lead to significant amounts of total carbon sequestered. Arid zones presently contain the lowest levels of carbon in the world on a per hectare basis, and it is necessary to consider the role of arid zone forests in carbon sequestration on a regional and global level.

7. **Soil Reclamation by *Prosopis juliflora*:** *Prosopis* litter falling on the ground adds to the humus content of the salt affected soils. The organic acids

produced from the decomposed litter react with native calcium carbonate and release calcium, which exchanges with sodium on the exchange complex. Being highly tolerant to soil sodicity, the *Prosopis* roots open up otherwise impermeable sodic soil and thus facilitate entry of water in the deeper layers. The carbon dioxide released by its roots during respiration interacts with water and produces weak acids like carbonic acid. Such acid facilitate dissolution of precipitated calcium carbonate already present in sodic soils. Thus, help in reclamation of the sodic soil. It reclaims the soil to such an extent that agricultural crops can be grown without amendments (Singh, 2008).

8. ***Prosopis juliflora* combating desertification:** Desertification is an international problem and *P. juliflora* is solution to this. No single species should ever be seen as the sole answer but rather as a tool in the continuing fight against desertification, land degradation and resource depletion. Shelterbelts of *P. juliflora* and *P. pallida* are planted around fields in many semi-arid regions to reduce wind speed. This reduces wind-induced soil erosion, decreases desiccation by reducing transpiration and consequently increases plant and animal production. Shelterbelts can comprise one or more rows of trees, commonly three but up to ten. In India, shelterbelts of *P. juliflora* were found to have a positive effect in reducing soil erosion compared with other species and control plots. Gupta et al.

(1983) noted a 36% reduction in the magnitude of wind erosion behind *P. juliflora* shelterbelts. Shankarnarayan and Kumar (1986) noted a decrease in area wind speeds of 33-38%, 17-26% and 12-21% at distances of 2, 5 and 10 times the height of the trees, with consequent reduction in the quantities of soil removed by erosive forces. In Sudan, wind speed was reduced by an average of 14% inside *P. juliflora* plantations, and with reductions up to 36% at high wind speeds (El Fadl, 1997). Seed disposal of this species on vast areas has helped natural regeneration and produced significant results in creating green belts and windbreaks to check the rapidly spreading problem of desertification.

Conclusion

No species in the nature is useless; we need to just find out their utilities. The countless uses of *P. juliflora* have put it in the category of species of economic importance. Gone are the days when *Prosopis juliflora* was called for nothing more than a useless weed. Due to its multiple uses, it has gained public acceptance as a plant of recognized economic value. Today it is the tree species utilized for its each and every part in various ways on a commercial basis. However, we need to spread its usefulness far and wide so that it can be recognized by everyone. The inherent capacity to withstand in any environmental conditions (except frost) and huge productivity potentiality of *Prosopis* can be converted into an even greater asset besides generating tremendous local employment opportunities and numerous benefits through application of scientific and technical methods.

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Original Research Article

Expanding niche and degrading forests: Key to the successful global invasion of *Lantana camara* (sensu lato)Ninad Avinash Mungi^a, Qamar Qureshi^b, Yadvendradev V. Jhala^{c,*}^a Wildlife Institute of India, Dehradun, Uttarakhand, 248001, India^b Department of Population Management, Capture and Rehabilitation, Wildlife Institute of India, Dehradun, Uttarakhand, 248001, India^c Dean, Faculty of Wildlife Sciences, Wildlife Institute of India, Dehradun, Uttarakhand, 248001, India

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ABSTRACT

Estimating the distribution of invasive species and understanding the ecological reasons for their success is crucial for their management. Moreover, their ability to invade biogeographically distinct regions in short timespans poses interesting ecological questions. *Lantana camara* (sensu lato) is one such invasive species of global concern. In an unprecedented effort, we surveyed 207,100 km² of Indian forests by sampling 13715 grids of 5 × 5 km, each with 1–31 plots of 10 m diameter, to record the abundance of *Lantana*. For India, we modeled occupancy of *Lantana* in the sampled area by accounting for imperfect detection; and potential invasion outside the sampled area using MaxEnt with covariates of climate, soil, forest and human disturbance. Further, *Lantana*'s response in comparable areas of its native and global invaded range was modeled using MaxEnt to provide a better understanding of its changing relationship with environmental factors. *Lantana* invaded 154,837 km² of the surveyed area, and threatened 303,607 km² of total Indian forests (44%); with preference to warm, humid, fertile areas, degraded by extractive human use. By combining our large-scale ground surveys with published data, we show that *Lantana* has expanded its climatic niche worldwide, with >11 million km² suitable for its invasion. Niche comparison revealed that *Lantana* might have adaptive plasticity in its invaded range; where it was found to be more tolerant to higher temperatures, lower fertility and shade as compared to its native range. In light of *Lantana*'s introduction history that suggest excessive hybridization between previously allopatric populations, and its known genetic diversity in the invaded range, the existing adaptive plasticity is suggestive of contemporary evolution. This adaptive nature can increase area under its invasion and pose an ecological conundrum of managing an evolving neophyte.

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1. Introduction

A few decades ago, many scientists speculated that the introduction of invasive species by humans could be one of the top threats to the global biodiversity (Elton, 1958; Diamond, 1989; Sala, 2000). Recent global studies validated these speculations by showing homogenization of global biota and increased extinction of native species catalyzed by biological invasions (Simberloff et al., 2013; Bellard et al., 2016; IPBES, 2019). Biological invasions have caused an enormous economic loss by

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affecting livelihoods, human health and ecological integrity of the invaded areas (Pimentel et al., 2001). With increased global connectivity, the chances of introducing potentially invasive species have increased, particularly in developing countries that have higher demand for international goods exchange and poor quarantine policies (Meyerson and Mooney, 2007). Additionally, over extraction of natural resources for livelihood in developing countries has degraded their native ecosystems, making them vulnerable to biological invasions (Byers, 2002).

Amongst invasive plants, *Lantana camara* L. (sensu lato) (Goyal and Sharma, 2015) (hereafter Lantana), a woody shrub of tropical American origin (Fig. 1), is regarded as one of the ten worst invasive species in the world (Ghisalberti, 2000; Richardson and Rejmánek, 2011) and a major concern in India (Mungi et al. 2018). Previous studies found multiple species and varieties of Lantana introduced during the 1800s across the tropics where it was introduced. These species and varieties were introduced as hedge plants and were subsequently hybridized for improved stand and other ornamental properties (Kannan et al., 2013). This potential hybridization added to the number of varieties, which were later reported to invade native forests (Bhagwat et al., 2012). What is now identified as '*Lantana camara*' in its invaded range is thus a hybrid of many species/varieties. This hybrid is caused by multiple sources of introductions, artificial selection and subsequent escape into natural systems to express the altered phenotype (Ray and Ray, 2014). As a consequence, recent studies have categorically identified this group of Lantana as '*Lantana camara* (sensu lato)' (e.g. Goyal and Sharma, 2015). Dense invasion of Lantana has been suspected of causing a decline in wildlife habitat and native plants (Aravind et al., 2010; Wilson et al., 2013). Lantana has also affected the livelihood of communities dependent on forest resources (Sundaram and Hiremath, 2012). Its management is estimated to cost around \$18,700 per km² in India (Babu et al., 2009). A prerequisite to tackling macro-ecological concerns like biological invasions is at first a reliable assessment of state variables such as occurrence and abundance of species at landscape scales (Hastings et al., 2005). Despite 200 years of managing Lantana in India (Bhagwat et al., 2012), little information regarding its distribution at the country level or its biogeographic correlates is available. Published literature on these aspects rely on the potential distribution of Lantana derived through climatic niche modelling and suffers due to data deficiency (Panda et al. 2018).

An understanding of mechanisms that enable or restrict invasion would be useful in designing control mechanisms. These mechanisms can be evaluated by comparing the niche within native and invaded ranges of an invasive species (Peterson et al., 2006). For a valid comparison, it is essential that models used for explaining a species' niche be within the same ecological space (analogous areas) used for training and prediction (Barve et al., 2011). Often this basic assumption of statistical modelling is violated, making the inferences questionable (Araujo and Guisan, 2006; Rodda et al., 2011; Qiao et al., 2017). To assess and demonstrate niche expansion in an invaded range, comparison of niche space should be limited to analogous areas in the native and invaded range (Peterson, 2011). However, this limitation of comparing only analogous areas, is often overlooked by many studies that demonstrate niche expansion (e.g. Rödder and Lötters, 2009; Di Febbraro et al., 2013). Therefore, inferences from such studies cannot differentiate between actual change in the niche space in invaded area or the species' inability to express its full niche potential due to the unavailability of niche space in its native or introduced range.

Though climatic niche change in analogous areas is often used as a proxy for fundamental niche change, changes estimated from non-analogous areas can be used as a proxy for realized niche change (Escobar et al., 2016). Unlike the climatic niche expansion, which hints at physiological adaptations in a species, realized niche change provide a unique natural experiment to disentangle the biogeographic responses of the species when freed from natural controlling agents like competitors, predators and diseases. Hence, increasing number of studies include an influence of biotic parameters in understanding niche changes (Tingley et al., 2014). Changes in realized niche also explain how different disturbance regimes and facilitating agents influence the spread of invasive species, thus providing insights for their management. As an example, Lantana distribution is known to be influenced by native forest fragmentation in invaded areas (Mungi et al., 2018).

Ravindranath et al. (2012) estimated forest loss in India at a rate of 173 (± 39) km²/year, which is lower than many other tropical countries (www.globalforestwatch.org). While forest loss is restricted to loss in the tree cover, changes in grasslands

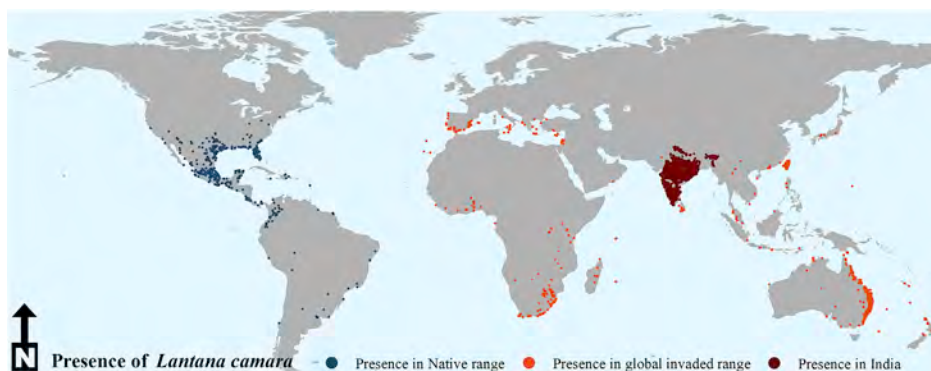


Fig. 1. *Lantana camara* presence locations from its native range in tropical America (blue), and invaded range (GBIF data (orange) and field sampling based data from India (maroon)) used in the study.

and savannas are more insidious and undocumented (Ratnam et al., 2016). These modifications of vegetation are known to facilitate the invasion of many plants, including *Lantana* (Gudiel et al., 2016). However, most often the conversion of native vegetation into invaded vegetation is neither reported as forest loss, nor is it quantified. As a consequence, government policies compensate forest loss by compensatory afforestation or similar measures, while the management of invasive plants and restoration of native vegetation remains unattended. Secondly, the facilitation of invasion by degradation of forest, though significant, is often overlooked. Forests in tropical developing countries, including India, are used by people for their livelihood (e.g. timber extraction, forage extraction, etc.). These unsustainable extractive dependencies can degrade quality of the native vegetation community (Raghubanshi and Tripathi, 2009). It is hence, essential to quantify and understand the effect of forest loss and degradation on biological invasions so as to prioritize the conservation investment.

We address lacunae in invasive species management by providing evidence of how forest degradation is influencing the *Lantana* invasion in India. In the current study, we use data from one of the largest and the most extensive sampling efforts undertaken for any invasive species to develop an accurate countrywide map of *Lantana* invasion for informed conservation actions. By combining this information with globally available presence information of *Lantana*, we investigate the environmental factors that facilitate *Lantana* invasion globally and India in particular. We provide a reliable estimate of the potential global range of *Lantana* invasion. We interpret our results in the light of phenotypic plasticity of *Lantana* and its implications in the era of climate change and forest degradation.

2. Materials and methods

2.1. Sampling and data sources

We generated a spatial grid of 5*5 km for India in ArcGIS 10.6.1. Our study was limited to forested areas, therefore we computed the area under forest within each grid. For this, we used the forest cover map from Survey of India (Indian State of Forest 2013), wherein the categories of scrub land, open forest, moderately dense forest, and dense forest were combined as 'forests'. We sampled forested grids in 18 Indian states by laying 1 to 5 transects of 2 km length in each of these grids. On these transects, at every 400 m nested circular plots of 30 m for human disturbance and 10 m for shrub species were sampled. Shrub cover (including *Lantana*) was scored into four categories using a modification of Daubenmire's scale (1968) (absent, low abundance < 10% of groundcover, moderate abundance 10–50% of groundcover, and high abundance > 50% of ground cover) (Jhala et al., 2010). *Lantana* invasion is known to be facilitated by human disturbances and perturbation of the ecosystem (Hiremath and Sundaram, 2010; Mungi et al., 2018). We therefore collected data in every 30 m diameter plot on a) the number of trees lopped, b) the number of trees cut, c) evidence of grass and bamboo cutting (as present or absent), d) number of people seen from the plot, and e) number of livestock seen from the plot and f) number of livestock-human foot trails within the plot. A forest guard, who is the front-line staff of the forest administration across the country and has an intimate knowledge of the forest, participated as a team member for sampling these plots. The survey path and plot locations were recorded using a handheld GPS unit (Garmin Etrex model 72). The sampling was conducted between November 2009 and March 2010. In total 117,104 plots were sampled (Fig. 1) within 13,715 grids covering 207,107 km² of forested area. The field data were then spatially attached to the grids in a GIS platform (ArcGIS ver. 10.6.1).

We procured spatial presence information of *Lantana* from its native and global invaded range from the Global Biodiversity Information Facility Portal (accessed through GBIF.org (May 11, 2018) GBIF Occurrence Download <https://doi.org/10.15468/dl.6wjktz>). Occurrence data with accurate geolocation obtained after the year 1970, within a comparable temporal range of the climate data, was used for subsequent analysis. In total 11,500 occurrences were obtained for the native region, and 25,106 occurrences were obtained for invaded regions (Asia, Africa and Australia). We subsequently plotted these locations on Google Earth and selected only those locations, which were observed in forested areas of native Central America (n = 4495) and from across the global invaded range (n = 16,633) (Fig. 1). *Lantana* presence from ground sampling (n = 38,079) in India was added to these records to get a total of 54,712 locations of *Lantana* in its global invaded range. This presence information was used for developing niche models.

For modelling occupancy of *Lantana*, it was essential to incorporate environmental covariates that determine its occurrence in the grid. To do so, we reviewed studies that incorporate distribution modelling of *Lantana* in India and developed following ecological hypotheses as predictors of *Lantana* occurrence: a) As *Lantana* is native to the hot and moist areas of Central and South America, as well as since it has invaded the tropical parts of the old world, we hypothesized that its distribution would be determined by climatic factors like conducive range of temperature and precipitation. *Lantana* would likely prefer warm and humid areas (Goncalves et al., 2014; Kannan et al., 2013; Mungi et al., 2018; Taylor and Kumar 2013). b) As most of the warm and humid forests in India are occupied by dense woody plants, the understory shrub density is mostly determined by light availability, which is a function of forest canopy cover as well as forest degradation (Didham et al., 2005). Being an under-canopy shrub, we expected *Lantana* invasion to be facilitated by moderate to high light penetration through the canopy to the shrub strata. c) Studies suggest that frequent burning of forests was likely to facilitate *Lantana* invasion (Mungi et al., 2018). Fire in controlled conditions was also demonstrated to enable seed germination of *Lantana* (Hiremath and Sundaram, 2010) and could hence be an important determinant of its occupancy. d) We hypothesized that soils in which nutrient uptake was easier would be preferred by *Lantana* (Osunkoya and Perrett, 2011). e) Human disturbances like tree cutting, tree lopping, and livestock grazing can remove the native plants thereby reducing competition and making conditions favorable for invasive *Lantana* (Raghubanshi and Tripathi, 2009). We use remotely sensed and global data

repositories to index the above-mentioned parameters. We used minimum temperature of coldest month and rainfall of the driest quarter to represent the climatic determinants of Lantana. We indexed light availability on the below canopy strata by i) Seasonal Normalized Differential Vegetation Index (NDVI) (Huete et al., 2002) clipped by forest cover (Indian State of Forest, 2013) so as to represent canopy cover and ii) Rate of forest attrition by computing change in Gross Primary Productivity (GPP) (Heinsch et al., 2003) for the past seven years. A higher positive value of GPP change indicates improvement in forest quality while a large negative value indicates forest degradation. We obtained information on fire occurrence from the Fire Information for Resource Management System (FIRMS) database, which is a composite of daily Moderate Resolution Imaging Spectroradiometer (MODIS) hotspots and Visible Infrared Imaging Radiometer Suite (VIIRS). VIIRS detects fire at 375 m resolution using multispectral bands (Schroeder et al., 2014) and complements MODIS, which detects fires at 1 km resolution through middle-infrared and thermal infrared brightness temperature (Giglio et al., 2003). We used soil Cation Exchange Capacity (CEC) from the Global Harmonized Soil Index as an index of soil fertility (Batjes, 2009). We used tree cutting, tree lopping and livestock grazing information recorded during the field sampling to incorporate the role of disturbance in facilitating the invasion by Lantana. All covariates were resampled to 25 km², the scale of inference used throughout in this paper. Subsequently, we estimated the correlation amongst different covariates, and used only those covariates for which the Pearson's Correlation Coefficient (r) was insignificant ($-0.7 > r > 0.7$). In case of correlated covariates, only one was used. Details on the source, scale and relevance of these covariates are provided in Supplementary material 1, Table S1.

2.2. Occupancy modelling

The number of sampled plots within 25 km² grids ranged between 1 and 31. Since these plots were small as compared to the grid size, there was a possibility of sample plots not detecting Lantana presence in a grid, when in fact it was present outside the sampling plots in a grid (MacKenzie et al., 2017). We explicitly account for detection bias by modelling and correcting for detection probability of Lantana. We modeled Lantana occurrence with covariates as a logit link function in the program Presence (Hines and MacKenzie, 2006). In order to reduce the redundancy of information and model complexity, only one covariate of a significantly correlated pair ($-0.7 > r > 0.7$) was used in the model. Covariates representing each of the major factors (climate, soil, forest attributes, and human disturbance) were used by themselves, and together to construct ecologically meaningful models. Covariates that substantially and parsimoniously improved model fit to the observed data based on Akaike information criterion (AIC) (Akaike, 1973) were retained. Model with least AIC was considered to be the best model (Johnson and Omland, 2004) that explained occurrence of Lantana. When models differed by < 5 AIC, we used model average estimates weighted by AIC weights to incorporate model uncertainty in parameter estimates (MacKenzie et al., 2017). We used bootstrap function to generate 1300000 iterations for evaluating the goodness of fit of the best model to our data and used $\hat{c}$ statistics to correct for over dispersion, if any (MacKenzie et al., 2017).

2.3. Species distribution modelling

To get an estimate of areas suitable for Lantana that were not sampled by ground surveys; as well as for comparing niche disparity and similarity between the native and invaded ranges, we used Maximum Entropy (MaxEnt) (Elith et al., 2011; Phillips et al., 2004), one of the most widely used algorithms for niche modelling. MaxEnt calibrates environmental variables from species presence locations and compares them with a set of random sample locations from the study area (Presence-background model). It uses this calibrated relationship of species presence with environment variables to seek similar locations that would likely support the target species. The most unconstrained model developed is considered as the MaxEnt model (Phillips and Dudík, 2008).

We divided the Lantana presence into three subsets based on the regions considered: native region (the central American), Indian invaded region (the tropical India) and global invaded range (Africa, Asia and Australia). Being presence-background model, the range of background environment substantially influences the response curve and subsequent distribution modeled through MaxEnt. It necessitates appropriate ecological criteria and sampling strategy to define the background (Elith et al., 2010; Webber et al., 2011). Since we only consider forested landscapes for this manuscript, background points were obtained only from the forested areas of the regions considered. Since, Lantana was not sampled systematically across its global range and to avoid any bias in our model by having background points that may come from areas underrepresented in our sampling, we first modeled the kernel density of our sampling locations and specified the model to select background points from within this kernel surface in proportion to our sample distribution after dropping the pixels in which Lantana was detected. Within each region, we modeled the kernel density of the presence locations using kriging and used this surface to select background points. By doing this, we eliminate the effect of outlier in the environmental covariates that can result in overfitting the distribution of species. Within forests defined by this surface, we randomly selected 10,000 points (no more than one in 1 km²) to estimate the background environment in each region. The covariates from these background data were used to define the available environment for modelling climatic and ecological niches. Lantana presence points determined the selection of niche space in this environment by the species.

In order to avoid autocorrelation of the GBIF records, which tends to be biased towards more visited popular areas, we randomly selected only one presence within each pixel area (1 km²) in all regions. We randomly divided the presence locations into training (80%) and testing (20%) sets, using k-fold partitioning design, with $k = 5$. We used each k-partitioned presence as an input data for MaxEnt. In the present study, linear and quadratic features were used to generate the MaxEnt

model with 100 replicates for each model. Different thresholds of regularization parameter result in different MaxEnt output, where with increase in the regularization parameter, the output probability distribution gets smoothened (Elith et al. 2010). We built multiple models using these presence locations and covariate information with regularization parameter set as 0.25, 0.5, 0.75, 1, 1.25, 1.50, 1.75 and 2. MaxEnt modeled niche suitability as a probability for every pixel that varies from 0 to 1. In the present study, all pixels of the output raster that were greater than a threshold provided by the 10th percentile training presence, were considered as potential suitable regions. Though somewhat subjective, these threshold criteria were considered as a robust cutoff in previous studies on Lantana in parts of India (Panda et al., 2018; Mungi et al., 2018). We further estimated the True Skill Statistics (TSS) for every model output in the Indian and global invaded region, wherein we used the confirmed occurrence location of Lantana from the ground surveys/GBIF and assessed the proportion of accurately classifying the testing data (20% data) (Liu et al., 2013). Area Under the Curve (AUC) of the MaxEnt model was considered as an additional criterion to assess the ability of the MaxEnt model to predict Lantana presence for each region (Hosmer and Lemeshow, 1989). For Indian and global invaded region, we used the TSS as a primary indicator of accuracy and AUC as secondary, and rank different MaxEnt models generated with different settings of the regularization parameters, to select the model that yielded best TSS and maximum AUC. This regularization parameter was then used to model Lantana distribution in native region as well.

2.3.1. Regional ecological niche

We define the species' realized ecological niche as the space, where the species is constrained by abiotic and biotic factors (Colwell and Rangel, 2009). We used the native and Indian invaded region to estimate the difference in realized niche, as we intend to understand the change in species relationship with its overall available environmental predictors using its realized niche. First, we used the presence points in the native range ($n = 2572$) along with climatic covariates (annual mean temperature, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, precipitation of wettest quarter and precipitation of driest quarter), soil CEC, summer NDVI, fire frequency and cumulative loss in GPP, in the above described MaxEnt settings. This provided us the realized ecological niche of Lantana in its native region. In order to understand the areas available for Lantana in India, we projected this native ecological niche of Lantana to all forested areas of India. We call this the potential ecological niche of Lantana in India. Secondly, we used the surveyed Lantana presence ($n = 7238$) with the same environmental covariates (used for the native range model) in India to model the observed ecological niche of Lantana. Realized ecological niche represents suitability of area for being invaded by Lantana. We used it as an index of Lantana invasion in non-surveyed forests of India, as it was derived from a training sample of Lantana presence in surveyed forests and its eco-climatic covariates.

Further, we compared the relation between Lantana occurrence probability and environment covariates in its native and invaded range, also often known as functional response traits (Keddy, 1992; Lavorel and Garnier, 2002). For this, we used the response of Lantana to maximum temperature of warmest month as an index of thermal tolerance; soil CEC as an index of nutrient transfer; and pre-monsoon NDVI as an index of tolerance to the dense canopies (as explained earlier for occupancy models). In addition to this comparison of response, we plotted the distribution of Lantana along these variables in its native and invaded range and compared the difference in the distribution using a Student's *t*-test in the R ver. 3.5.0 environment (R Core Team, 2018).

2.3.2. Global climatic niche

We define a species' climatic niche as the set of climates in which the species currently exist in its native range (Atwater et al., 2018). Unlike the covariates of ecological niche, to which the species can likely adapt in a shorter span of time and differentially in different ecological settings, adaptation to climatic covariates are known to take longer time and have an evolutionary footprint on the species (Gallagher et al., 2010; Mandle et al., 2010). However, the evidences of change in the climatic niche are shadowed by the statistical limitations arising from data bias due to comparisons in climatically non-analogous areas.

To establish a valid comparison between the native and global invaded range, we defined the analogous climatic area by considering the following variables: annual mean temperature, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, precipitation of wettest quarter and precipitation of driest quarter for native and global invaded region (40° N to 60° S) at 30 Arc-second resolution (~ 1 km²).

For every pixel from within the native and global invaded region of Lantana, we extracted the values of the above-mentioned variable as well as information on the occurrence of Lantana in that pixel. The entire set of these pixels from native and invaded range was then collated for each of the climatic variable. Principal components (PCs) were then extracted from the combined dataset of native and invaded range for all climatic variables to reduce dimensionality and redundancy of information (Jolliffe, 2002). PCs that had Eigen values > 1 were further used for assessing climatically analogous areas in native and invasive range. Subsequently, pixels with Lantana from the native and invaded range were plotted on the PC axes to visually discriminate them on the climatic niche axes. A formal analysis to identify analogous climatic space was undertaken using four different methods; NicheA, Mobility-Oriented Parity (MOP), Multivariate Environmental Similarity Space (MESS) and ExDent tool. NicheA generates two convex polyhedrons around the native and invaded climatic space, and estimates the overlap between polyhedrons, which represents similar climatic conditions in both the ranges. This overlapping climatic area of the polyhedrons was projected to the geographic space of both the native and global invaded region to identify analogous areas (Escobar et al., 2016). MOP measures Euclidean distances between climatic space of native and

invaded range and excludes that climatic space, which is outside the calibration region (Owens et al., 2013). MESS identifies dissimilar areas based on the statistical distance of climatic variables in native and invaded range from their common mean value (Elith et al., 2010). While these three methods identify univariate similarity in two areas, there might be a novel climatic combination not present in the native region, but only in the global invaded region; and is not addressed by using the abovementioned three methods. ExDent tool addressed this correlational similarity and helped identify climatic combinations that are novel in the global invaded region, as compared to the native region (Mesgaran et al., 2014). We subsequently visualize the output of these four methods for the Indian invaded region to understand the parity between the similar areas identified. The final area identified as analogous between the native and global invaded region was derived by intersecting the results obtained by these four models, in ArcGIS 10.6.1. This final analogous area was used as a conservative model of similar climatic surfaces for modelling and comparing climatic niche of Lantana.

We used the analogous areas between the native range of Lantana and its global invaded range to compare its potential climatic niche with the observed climatic niche. For this analysis we used presence locations of Lantana from its native range ($n = 2572$) and the climatic variables (annual mean temperature, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, precipitation of wettest quarter and precipitation of driest quarter) in MaxEnt, and projected this native climatic niche across the global invaded region. Subsequently, we used Lantana presence ($n = 17,895$) from across its global invaded region to model its observed climatic niche using the same climatic covariates used for modelling in its native range. The difference in potential and observed climatic niche of Lantana across its global invaded range was estimated by using Schoener's D and Hellinger's distance I metrics available in 'phyloclim' package of R 3.5.0 (Heibl et al., 2013, R Core Team, 2018). Secondly, the percentage of Lantana presence points that were not classified as presence by native climatic niche were used as an estimate of niche expansion within the analogous niche space in the invaded range.

We used analogous climatic space between native and invaded areas to compare and understand Lantana's response to bioclimatic variables. However, we also modeled climatically suitable areas for Lantana outside of this analogous space based on its global occurrence data. For this we used global occurrence ($n = 30,116$), bias sampling mask file for MaxEnt to select background points (Elith et al., 2010), and the best regularization parameter determined by MaxEnt, using the aforementioned method. This approach allowed us to estimate the global potential area that could be invaded by Lantana.

3. Result

3.1. Occupancy modelling

Out of 13,715 grids surveyed, Lantana was detected in 5334 grids (Fig. 2a) giving a naïve occupancy estimate of 38.8%. Of the total 207,100 km² forest surveyed, Lantana was detected in 86,806 km². The model that best explained Lantana presence while correcting for imperfect detections differed from the next competing model by ΔAIC of 207, and from the null model by a ΔAIC value of 810 (Table 1). Lantana occupancy was best explained by a) Climatic variables: higher rainfall in the driest quarter and warm winters; b) Soil fertility surrogated by CEC and c) human impacts surrogated by logging and decline in GPP (Table 2). The model inferred Lantana occupancy was estimated to be $\psi = 39.39\%$ (SE 0.2). With high detection probability (64.3%), the increment in Lantana occupancy from 38.8% naïve estimate to 39.39% model inferred estimate was little. Since the survey was limited to forested areas, this occupancy estimate depicts Lantana presence in forests of 18 Indian states. The bootstrap distribution of 1300000 runs from the best model did not differ from the observed data, suggesting that the model was a good fit (goodness-of-fit test, $P = 0.13$) and the $\hat{C}$ statistic was 0.97, suggesting absence of over-dispersion. Out of the total 207,100 km² of surveyed forest, 86,831 km² forests had high occupancy probability of Lantana with $\psi > 0.5$; 68,006 km² had low occupancy probability with $0.1 < \psi < 0.5$ and in 52,270 km² Lantana was practically absent, where $\psi < 0.1$ (Fig. 2b).

3.2. Regional ecological niche

Highest modelling accuracy, as depicted by TSS = 0.69 (± 0.04), was when the regularization parameter was kept at 1. Minimum temperature of coldest month, soil CEC, maximum temperature of warmest month, pre-monsoon NDVI and loss in GPP explained more than 80% of Lantana presence in its native and invaded Indian range (Suppl. material 1, Table S2). Lantana's ecological niche model trained on its native environment had an AUC = 0.80 (± 0.06), suggesting a good model fit. When projected to India, this potential ecological niche was a subset of its realized ecological niche, which in turn had a good model fit (AUC = 0.73 $\pm$ 0.01, TSS = 0.68). Furthermore, the realized ecological niche in India estimated the area suitable for its invasion outside the surveyed area to be 148,770 km² (Fig. 2c).

The relationship of Lantana occurrence with covariates differed substantially in magnitude and form between its native and invaded range (Fig. 3). In case of temperature of warmest month, the distribution in India significantly exceeded (P -value < 0.005; Fig. 3c) the upper range of distribution in Central America (41 °C; Fig. 3a and b). Lantana showed a parabolic relationship with soil CEC in its native range (Fig. 3d) with maxima at 50 meq⁺/100 g, while in India the relationship was a reverse parabolic with CEC (Fig. 3e); however, the difference in distribution against soil CEC was insignificant (P -value > 0.9; Fig. 3f). In case of pre-monsoon Normalized Differential Vegetation Index (NDVI) that represents canopy cover, the distribution of Lantana in India was seen to be constrained within a small range which is significantly different subset ($P = 0.1$) of its distributional range in Central America (Fig. 3i). However, within this range, the response of Lantana to NDVI has changed. Lantana distribution in Central America increased with NDVI till the threshold of 0.2, after which it decreased (Fig. 3g); while

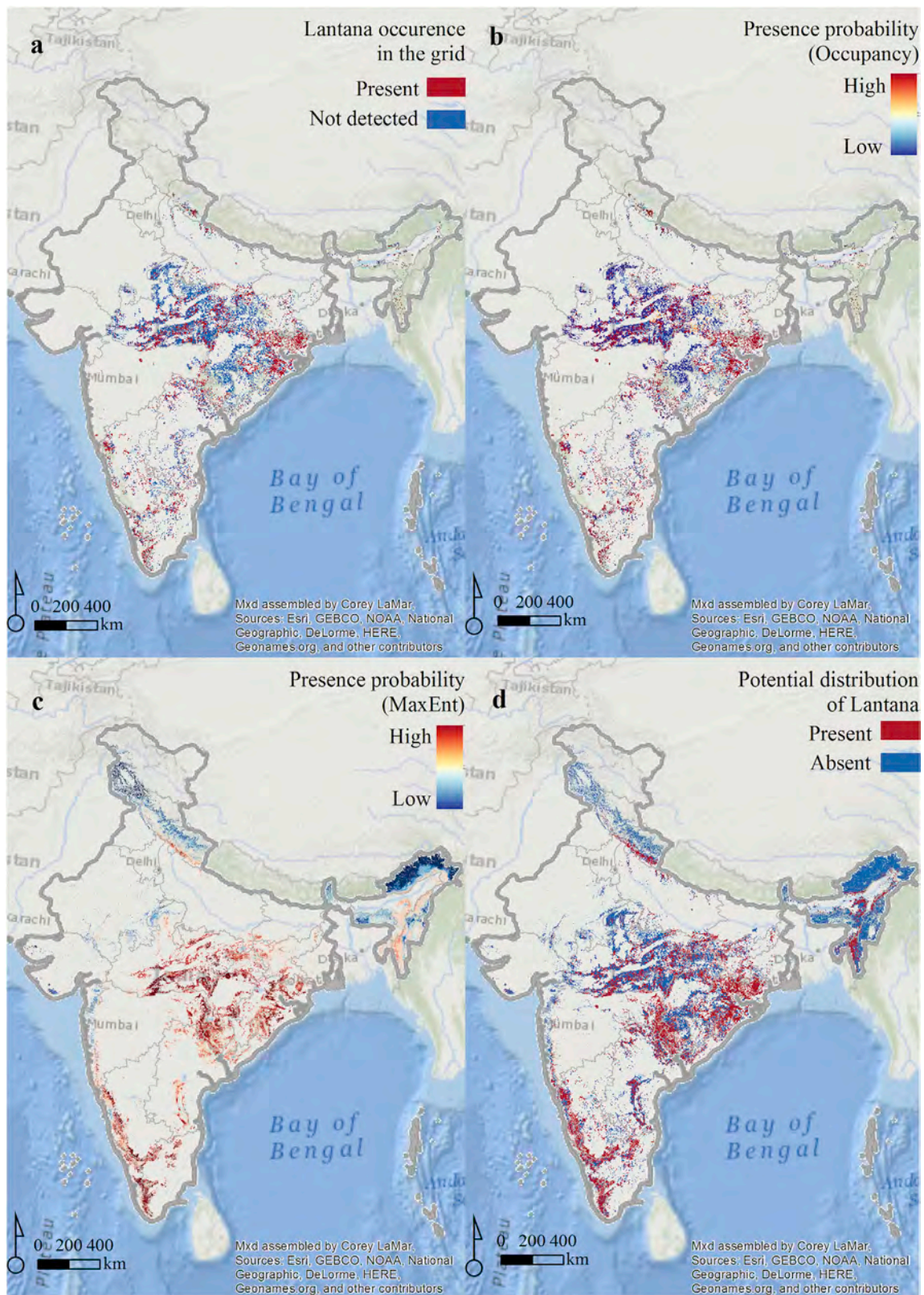


Fig. 2. *Lantana camara* distribution in India. (a) Grid cells with *Lantana* presence (red) and where *Lantana* was not detected (blue), (b) Potential distribution of *Lantana* corrected for imperfect detection and site covariates in an occupancy framework (c) Areas susceptible for *Lantana* invasion modeled by MaxEnt for non-surveyed area using the information from surveyed area and, (d) An aggregated distribution of *Lantana* in forests of India, obtained by ensembling occupancy estimates for ground surveyed areas (in the year 2010) and MaxEnt models beyond ground surveyed areas.

Table 1Model selection statistics of various models used to *Lantana camara* occupancy in tropical India.

Model covariates	AICestimate	Δ AIC	No. Par	$-2 \times$ loglikelihood
Null model				
ψ (.). P(.) Null model	79414.2	810.1	2	79410.2
Climate				
ψ (Precipitation of driest quarter (PD)). P(.)	79102.5	498.5	3	79096.5
ψ (Minimum temperature of coldest month (TM)). P(.)	79139.3	535.2	3	79133.3
ψ (PD + TM). P(.)	78836.2	232.2	4	78828.2
Soil				
ψ (Soil fertility (CEC)). P(.)	79374.2	770.2	3	79368.2
Anthropogenic Disturbance				
ψ (Tree logging (TL)). P(.)	79401.5	797.5	3	79395.5
ψ (Tree cutting (TC)). P(.)	79428.9	824.8	3	79422.9
ψ (Livestock seen (LS)). P(.)	79284.4	680.4	3	79278.4
ψ (Number of human trails (HT)). P(.)	79377.2	773.1	3	79237.1
ψ (Cumulative loss in productivity (GPP)). P(.)	79076.5	472.5	3	79070.5
Combined climate, soil and anthropogenic disturbance				
ψ (TL + TC + LS + HT + PS). P(.)	79203.4	599.4	7	79189.4
ψ (PD + TM + CEC + TL + TC + LS + HT + PS + GPP). P(.)	78811.5	207.5	11	78789.5
ψ (PD + TM + CEC + TL + GPP). P(.)	78604.1	0	7	78590.1

Table 2Coefficients of the best model that explained *Lantana camara* occupancy, while accounting for imperfect detections. Coefficients are listed in reducing order of importance following the intercept.

Covariates	Coefficient estimate	Standard error
Constant (Intercept)	-0.444	± 0.018
Rainfall of the driest quarter	0.316	± 0.02
Minimum temperature of coldest month	0.26	± 0.019
Soil cation exchange capacity	0.036	± 0.019
Average logging	0.016	± 0.018
Cumulative loss in productivity	-0.287	± 0.02
Detection Coefficient	0.587	± 0.01

in India the threshold was observed to have shifted to 0.7 and the response was a linear increase with a short asymptote (Fig. 3h).

3.3. Analogous areas in native and invasive range

Three Principal Components cumulatively explained 99% of the variance in the climatic data in native and global invaded region (Suppl. material 1, Table S3). The first PC comprised areas with increasing annual precipitation and decreasing temperature; the second PC represented wet areas that have lower annual temperature and winter temperature; and the third PC represents areas with increasing annual precipitation and reducing aridity (higher rainfall in driest month) (Fig. 4). These PCs were used for assessing the climatically analogous areas in native and invasive range. When the subset of results for India was explicitly visualized for the four models (NicheA, MOP, MESS and ExDent) to see consistency in identifying areas of similar climatic conditions, the models were consistent in identifying a common analogous climate area in the drier areas in western and southern India, the Gangetic river basin, northeastern hills and the Eastern Ghats (Suppl. material 1, Fig. S1). In doing so, the largest dissimilar area was identified by ExDent, followed by MESS, NicheA and MOP. An intersection of these model helped derive the largest dissimilar climatic surface, and remove from the analysis of niche comparison.

3.4. Global climatic niche

Highest modelling accuracy, as depicted by TSS = 0.72 (± 0.05), was when the regularization parameter was kept at 1. Annual precipitation and precipitation of the driest month together explained more than 90% of the global *Lantana* distribution (Table S4). The climatic niche model of *Lantana* had an AUC = 0.74 (± 0.01) in native region, and an AUC = 0.70 (± 0.02) and TSS = 0.76 in global invaded region. The native niche when projected on the global invaded region (Fig. 5a) was found to be a subset of the observed global invaded climatic niche of *Lantana* (Fig. 5b). Within the invaded range 58% ($\pm 6\%$) *Lantana* presence points were outside the projected native climatic niche of *Lantana*. The Hellinger distance I and Schoener's D value of similarity in potential and observed climatic niche of *Lantana* was 0.39 and 0.42 (P-value = 0.12), suggesting an ecologically relevant, but statistically insignificant difference.

For the global model, highest accuracy as depicted by TSS = 0.66 (± 0.08), was when the regularization parameter was kept at 1. Annual precipitation, precipitation of the driest quarter and temperature of the coldest month together explained more

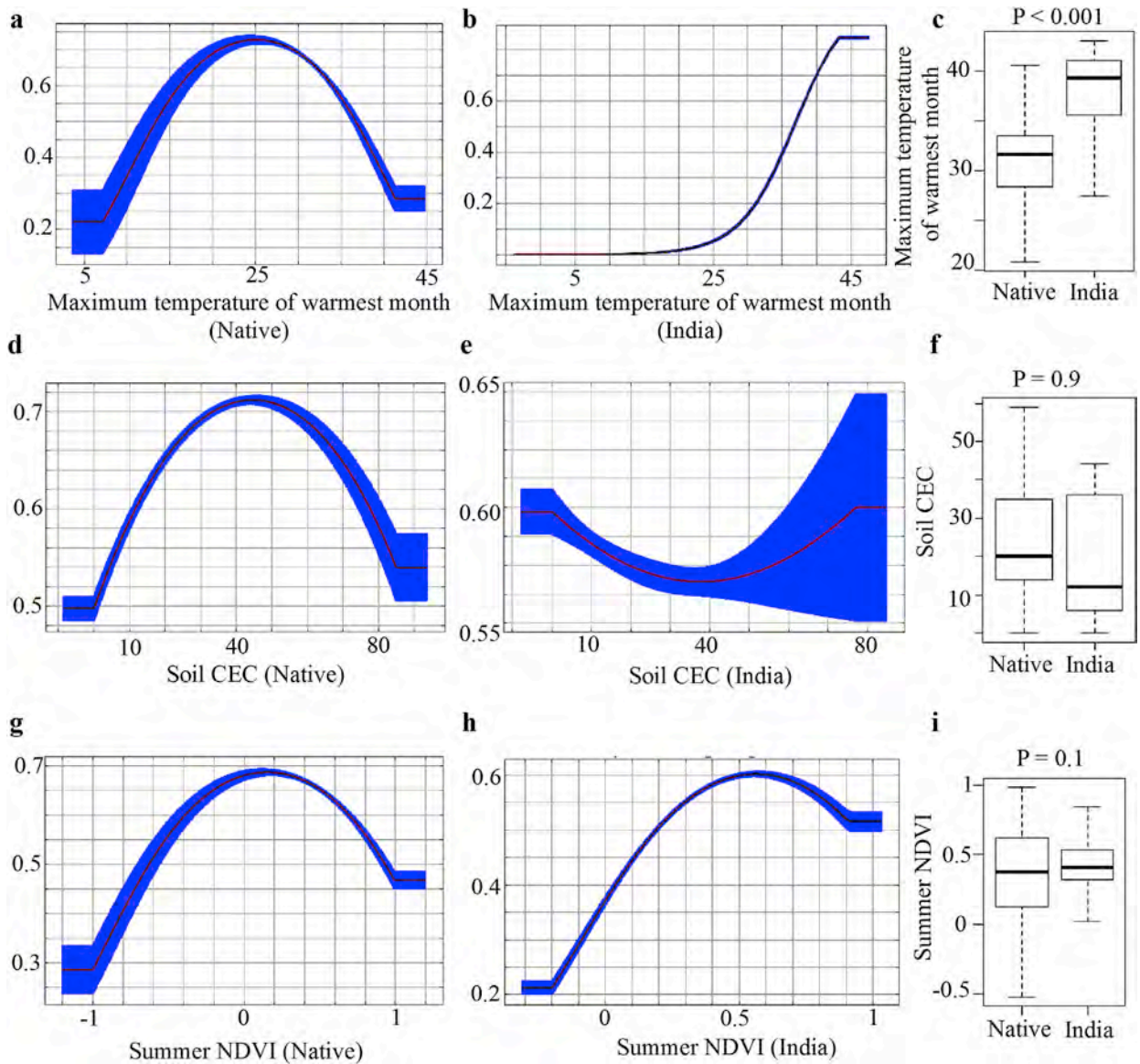


Fig. 3. Response of *Lantana camara* heat tolerance, soil fertility, and light availability in native Central America and in invaded India. Response of *Lantana* to highest temperature in the warmest month in Native America (a), Invaded India (b), and the box plot showing the increase in high temperature tolerance in India (c); Response of *Lantana* to soil Cation Exchange Capacity (CEC) in native America (d), observed in India (e), and the box plot showing *Lantana* distributed within the same range in Native America and invaded India (f); With regard to summer Normalized Differential Vegetation Index (NDVI) *Lantana* decreased with increased NDVI in native America (g) and increased in invaded India (h), but the niche width of *Lantana* with respect to NDVI was similar (i).

than 90% of the global *Lantana* distribution (Table S5, response curves provided in Fig. S2). This climatic niche model of *Lantana* had AUC = 0.62 (± 0.02). Across the global range, an area of ~11,631,000 km² (10,898,000 to 12,225,000 km²) was found to be climatically suitable for *Lantana* invasion (Fig. 5c, Fig. S3). Within countries, highest suitable areas available for *Lantana* were in: India (~1,351,000 (1,303,000 to 1,381,000) km²), Australia (~867,980 (790,000 to 929,000) km²), China (~317,970 (283,770 to 349,790) km²), Mozambique (~287,280 (263,170 to 311,250) km²), Madagascar (~244,360 (223,670 to 261,710) km²), Ethiopia (~241,070 (212,230 to 265,390) km²), Myanmar (~183,750 (165,550 to 195,330) km²), Vietnam (~106,340 (98,130 to 111,260) km²), Tanzania (~104,850 (87,560 to 121,490) km²) and South Africa (~98,710 (88,080 to 107,100) km²).

4. Discussion

Lantana invaded 86,806 km² forests (38.8%) of India, particularly degraded forests of hot and humid areas. It was widely distributed across landscapes with maximum invasion in fragmented dry deciduous forests of Central India, Shivalik hills and

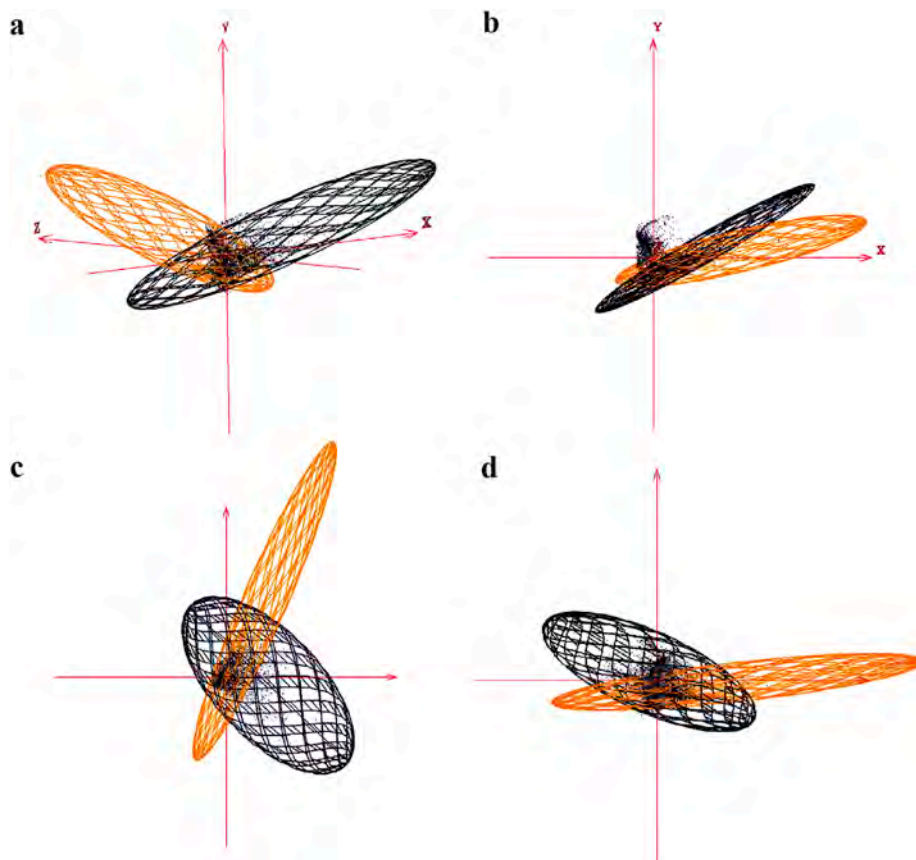


Fig. 4. Distribution of *Lantana camara* along the three principal components representing climatic factors of native (Central America: yellow polyhedron) and global invaded region (Africa, Asia and Australia: black polyhedron). Grey points represent climatic space not occupied by *Lantana*. Axis X represents increasing annual rainfall and increasing temperature, axis Y represents increasing cooler winters and axis Z represents reducing aridity (Suppl. material 1, Table S3). Visualization of distribution on (a) three-dimensional climatic axes, (b) X and Y axis, (c) Y and Z axis, and (d) X and Z axis.

Southern Western Ghats. Relatively lesser area was recorded to be invaded in the Northeastern tropical forests, Northern Western Ghats, semi-arid and arid landscapes of Western India (Fig. 6). With this large invaded range, *Lantana* is probably the most widely distributed invasive plant in India, as compared to other invasive plants (Mungi et al. 2019; Mathur et al., 2015). Addition of the recorded locations of *Lantana* from India to the global presence locations, revealed that an area much larger than ever recorded was suitable for *Lantana* invasion. This expansion in its invaded range was found to be correlated with its increased tolerance to higher temperatures, lower fertility and denser canopy cover as compared to its native range. For an invasive species, change in its thermal tolerance and resource preference within a short span of time poses an interesting question on its plasticity and/or adaptability, which in either case suggests that a larger area could be globally invaded with time. Our results highlight the role of forest degradation and climate change in elevating the global risk of biological invasions, and the importance of large-scale ecological monitoring for a better understanding of invasions that can potentially guide management actions.

In the case of *Lantana*, we sampled plots of 10 m diameter ranging between 1 and 31 within each 25 km² grid cell. Detection within each of these plots was not a concern as *Lantana* presence would be detected without bias, but it was possible that the placement of plots missed *Lantana* occurrence within the 25 km² grid. Occupancy analysis explicitly addresses the limitation of imperfect detection, while providing insights into relationships of occurrence with covariates (MacKenzie et al., 2017). We found that the average detection probability by a single plot for a grid was 0.64 (SE 0.03) and bias resulting from imperfect detection was negligible as the model inferred occupancy estimate of *Lantana* differed from the naive estimate by only 0.71%. Thus, we probably missed detecting *Lantana* on 92 out of 13,715 sampled grids. The total forested area in the 18 states covered 15,312 grids, out of which 13,715 were sampled, which amounted to ~81% of total forested area being sampled. The unsampled grids were either under political unrest or inaccessible due to logistic constraints. The occupancy model helped us understand the potential status of *Lantana* in these areas. The occupancy covariates enhanced our understanding on factors that facilitated and limited the occurrence of *Lantana* in India at a scale of 25 km², which is relevant for ecological understanding and management interventions. MaxEnt models rely on presence information, modeled against the background with covariates to predict suitable sites where the species can potentially occur (Elith et al.,

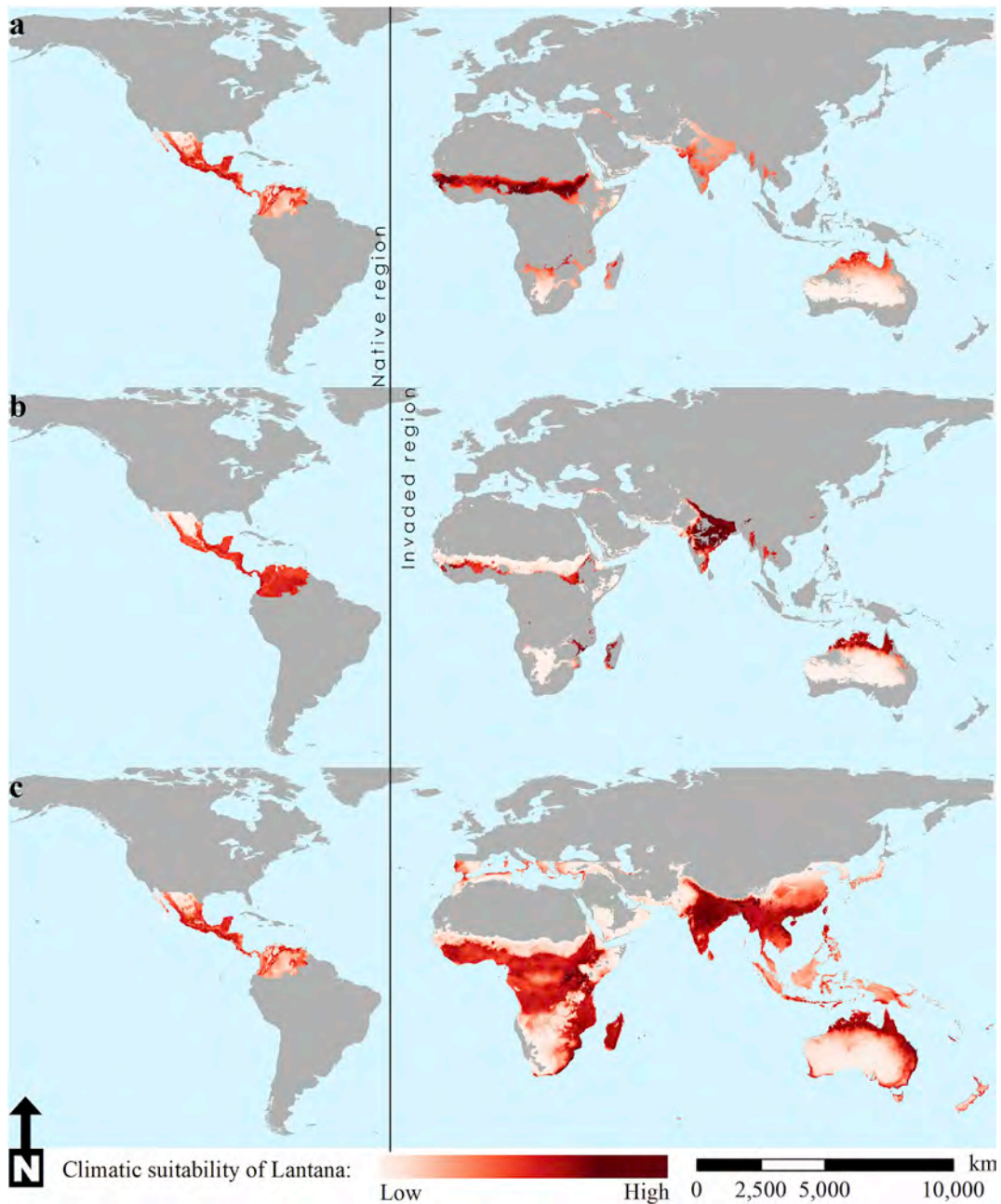


Fig. 5. Climatic niche of *Lantana camara* in its global range: (a) climatic niche of *Lantana* modeled from presence in the its native range and projected to analogous areas in its global invaded range (b) climatic niche of *Lantana* in analogous areas of its global invaded range as modeled from its presence in these areas (c) global climatic suitability of *Lantana* modeled from its global presence).

2011). Additionally, occupancy models also consider imperfect detections and therefore, are more reliable. For this reason, we used occupancy-inferred presence within 207,100 km² of forests that were ground surveyed and MaxEnt inferred suitable areas for invasion within the remaining 494,573 km² to get the most reliable total estimate of areas threatened by *Lantana* invasion to be 303,607 km² in forested landscapes of India (Fig. 2d).

Previous studies used climatic niche model of *Lantana* as a surrogate for its distribution (not as potential habitats) using a limited number of secondary or primary occurrence data (e.g. 2526 locations by Panda et al. 2018; 2526 locations by Bahuguna, 2015). These studies suffer from paucity of data and faulty inferences from the models. In the current study, we used data that were obtained from one of the largest known systematic sampling for any invasive plant. Thus, the ground

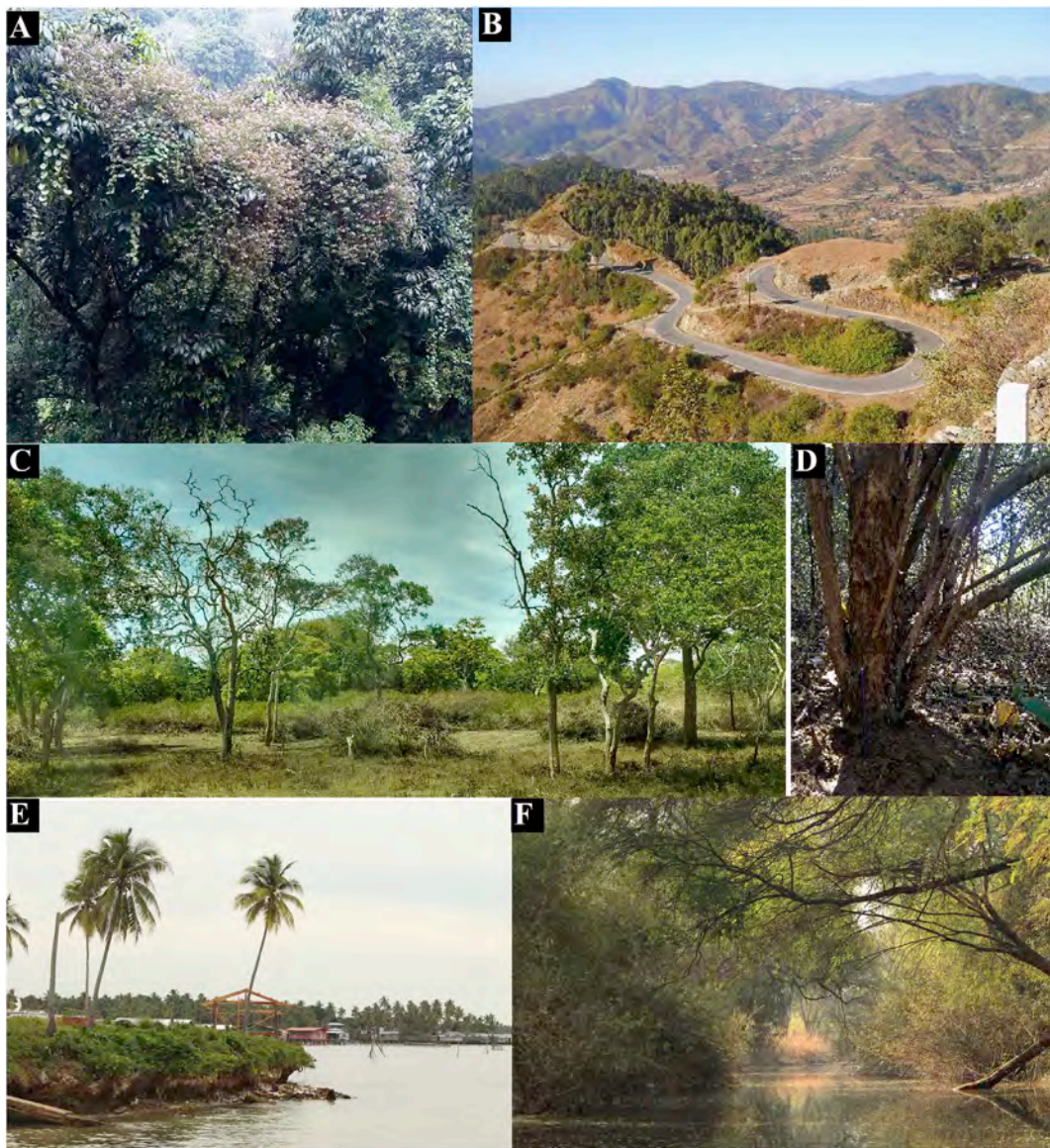


Fig. 6. Diverse habits and habitats of *Lantana camara* in India: *Lantana* was recorded in different habits across different biogeographic realms in India. Here we show the climber ecotype of *Lantana* in evergreen forests of the Western Ghats (A); shrub ecotype in the Western Himalaya (B) and dry savannas of Central India (C); Tree (bole girth > 15 cm) ecotype in the mesic savannas of central Indian highlands (D); short shrub ecotype on the coastal sand dunes (E); and emergent shrub ecotype in the wetlands of semi-arid India (F).

validation data we used is much larger and from across an ecological scale relevant for modelling multi-landscape distribution. We subsequently used a robust approach to model-based inference using ecologically relevant covariates (e.g. Qiao et al., 2017; Beck et al., 2014).

Furthermore, previous few studies have attempted modelling the global distribution of *Lantana* using proportionally fewer occurrences from India from a smaller geographical extent, and this is likely the scenario of data from other countries as well (e.g. Taylor and Kumar 2012; Taylor et al., 2012; Bhagwat et al., 2012; Taylor and Kumar 2014, Goncalves et al. 2014, Qin et al., 2016). By the use of a substantially larger training dataset the reliability of our inferences are better than previous estimates and with the associated uncertainty. The climatic niche of *Lantana* in its global invasion range was substantially larger than the one projected from its native region. This expansion was estimated only in the climatically analogous areas of its native and invasive range, thus having a statistical power to highlight the expansion. As compared to previous global projections, we show that *Lantana* could potentially invade novel climatic regions in India, Myanmar, Thailand, Philippines, Pakistan, Northern Australia, Madagascar, Mozambique, Malawi, Ethiopia and parts of Oceania. Our global potential niche revealed large extent in Nigeria, Mali, Gambia, Sudan, and surrounding countries, from which *Lantana* presence was not

available. This could either be due to paucity of sampling in these areas or actual absence. Future invasions in these countries should be monitored in order to arrest the invasion in its initial phase. It is also possible that Lantana has already invaded many of these potential areas which have not yet been sampled for occurrence. Our models highlight such areas across the world which should be sampled on priority. Across its invasive range, the expansion was partial towards warm and humid climatic areas and coincided with mesic savannahs in the region.

As a consequence of the ongoing global climatic changes, the countries invaded by Lantana are prone to warmer winters and rainfall in the driest season (Devraju et al., 2015), which in turn will elevate the humidity of an area (Jin and Wang, 2018). We show both of these traits to facilitate the invasion of Lantana across its global range. Management of Lantana, in India costs ~\$18,700 per km² (Babu et al., 2009). With the current expanse, the cost estimate of Lantana management exceeds \$5.5 billion in India (which exceeds the annual fund allocation to the Ministry of Environment, Forest and Climate Change, Government of India, for the year 2019 by a factor of 10 India), and proportionately more globally. While management of Lantana can be a costly affair, its invasion in novel climatic areas elevate the financial investment as more and more areas could be invaded by it. It further raises an ecological conundrum of managing a species that is potentially evolving to the regional environment (Mungi and Qureshi, 2018). Many scholars suggest that if a species is evolving to the ecological settings of the landscape, and is being used by other species, one can categorize it as a novel 'native species' evolving in the times of global changes (e.g. Pearce, 2016). These arguments might prevent any control mechanisms to arrest the invasion and can potentially lead to decline in the native biodiversity. Hence, it is critical to understand the reasons for Lantana's potential adaptability and invasion success.

The observed success of invasion, like in many other cases, can be interpreted in the light of availability of suitable niche, inherent phenotypic plasticity that optimizes the fitness in the new environment, and/or contemporary adaptation to new conditions (Hulme and Barrett, 2013). In India, most of the forests are used by local communities for livelihood and many areas are degraded by ecologically unsustainable uses of varying degrees (DeFries et al., 2010; Agarwala et al., 2016). In such areas the threat of Lantana invasion is higher, as inferred from our occupancy and MaxEnt models. Besides Lantana occupancy being promoted by human disturbance-induced degradation of native forests, it was also enhanced by warmer and more humid climates. Thus, the success of Lantana invasion in India is likely attributed to increasing availability of suitable climate and facilitation by reduced competition through human induced degradation. Unlike other tropical developing countries, where forested areas are reducing due to increased developmental activities, forest area in India was reported to increase at a rate of 1120 km²/year over the last decade (FSI, 2019). We flag the increase shown in the forest cover, which differentiates between plantations and invasive plants should be a vital element for long-term monitoring. Currently, we believe that these distinction between native forest, forest plantations and forest dominated by invasive species are not differentiated appropriately to justify increase in forest cover. We show that forest degradation caused by anthropogenic activities and/or global climatic changes could be in fact converting the native forests into invaded green patches, which could be mistaken as forest (e.g., Koulgi et al., 2019). This confusion can mislead forest policy, investment in management actions and subsequently compromise conservation objectives.

The climatic niche is used as a proxy for the fundamental niche, which is bounded by the environmental tolerances of the species (Hutchinson, 1957). Hence, shifts in the realized climatic niche of species have been proposed as an indirect evidence for adaptation by invasive species to novel environments (Gallagher et al., 2010; Mandle et al., 2010). In the present case study, the climate in parts of Africa, Asia and Australia was analogous to that observed in Central America - the native range of Lantana. Within this analogous climatic space, Lantana's climatic niche has significantly expanded. The increase in climatic tolerance observed in invaded region could be due to either predator/pathogen/competition release or phenotypic plasticity or adaptive evolution. Considering the covariates representing climate, soil resources, dense canopies and disturbance by fire in India (analogous as well as novel) we found that Lantana has invaded an additional novel niche space on the axis of increasing temperature, lower soil fertility and loss of productivity of invaded forests.

Previous studies (Blossey and Notzold, 1995) suggested that escape from specialist natural enemies could result in increased competitiveness of invasive plants leading to contemporary evolution. The invaded population of Lantana was found to be more tolerant of denser canopies, which could possibly be due to its enhanced competitiveness. A phenotypic variant of Lantana in India, which is a climber, enables it to access sunlight even in dense canopied forests (Fig. 6). A recent study further demonstrated that such a phenotypic variant may increase the performance and success of Lantana invasion in forested areas (Goyal and Sharma, 2019). Moreover, as a result of global climate change, many areas are experiencing warmer summers (Sharmila et al., 2015) and increased soil acidity that results in low fertility (Bhattacharyya et al., 2015). For any invasive plant an ideal phenotypic optimum will be to exploit these changes (Corlett and Westcott, 2013; Richards et al., 2006), which was observed in the case of Lantana invasion. If the species shows a significant difference in traits between native and invaded areas it clearly indicates its phenotypic plasticity, which, if responsible for higher fitness of the species, could be considered adaptive (Sultan, 1987; Pigliucci, 2001). This adaptation could be due to inherent genetic plasticity or due to genotypic change (Sultan, 1987).

Genetic studies of Lantana in India (Ray and Quader, 2014) have found higher genetic diversity with private alleles and multiple genetic clusters across India, suggesting multiple introductions of Lantana with novel founders each time. This was further validated by naturalist records from the 19th century that indicated multiple introductions from various sources in India (Kannan et al., 2013). Another study (Ray and Ray, 2014) on Lantana in India suggested that the multiple genetic clusters could be responsible for local adaptation and it could represent early stages of ecological divergence. Thus, in addition to global climatic niche shift and shifts in response norms, both of which are suggested to be the evidence for rapid adaptation

(Pearman et al., 2008; Gallagher et al., 2010; Mandale et al., 2010), genetic evidence suggests high genetic diversity as a result of multiple introductions and probable hybridization after introduction of previously allopatric populations of *Lantana*. These genetic changes can also be considered as suggestive of adaptive plasticity in the introduced populations. The above evidence supports the hypothesis (De Jong, 2005) that phenotypic plasticity provides a rapid opportunity for natural selection to operate and facilitates first steps in the adaptive walk by a species, which otherwise would depend on new mutations (Travis, 1994; West-Eberhard, 2003). Nevertheless, further experiments comparing populations from native and invasive areas are required for confirming that these phenotypic changes have a genetic basis to show conclusive support of contemporary evolution.

Previous studies investigating the effects of climatic changes on invasion by *Lantana* assumed that *Lantana*-climate relation would be preserved across space and time (Kannan et al., 2013; Goncalves et al., 2014; Panda et al. 2018). Our study results flag a caution on the approach, which assumes that the niche of a species to be at equilibrium and retain its response to climate. Such assumptions could underestimate the actual threat potential of invasive species to ecosystems. *Lantana* has invaded around 75 countries and poses a serious threat to their native biodiversity. The methodological approach used in the current study could be adapted as a model for studying and managing *Lantana* and similar biological invasions elsewhere. It can lend support for encouraging national initiatives for large-scale intensive monitoring of ecosystems to inform policy and management decisions.

Declaration of competing interest

The authors declare no competing interests.

CRediT authorship contribution statement

Ninad Avinash Mungi: Writing - original draft, Data curation, Formal analysis. **Qamar Qureshi:** Conceptualization, Funding acquisition, Supervision. **Yadvendra V. Jhala:** Conceptualization, Funding acquisition, Project administration, Methodology, Supervision, Formal analysis, Writing - review & editing.

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Appendix A. Supplementary data

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RECONCILING RESILIENCE ACROSS ECOLOGICAL SYSTEMS, SPECIES AND SUBDISCIPLINES

Research Article

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Role of species richness and human impacts in resisting invasive species in tropical forests

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Abstract

1. The biotic resistance hypothesis suggests that biodiversity-rich areas should be resistant to biological invasions. Globally, conservationists use this hypothesis to protect diverse ecosystems. However, supporting data are often contradictory, possibly due to several confounding factors. Complexity in inferences increases in the tropics, which are sparsely studied.
2. We hypothesize that human impacts, forest type and climate would modulate the relationship between native and invasive plant richness. To understand these interacting and varying effects of native richness and human disturbance on plant invasions, we sampled 354 grids of 25 km² with equal representation of protected areas (PAs) and multi-use areas (MAs) to record abundance of native and non-native plants from 34 PAs across five forest types in tropical India. We used linear mixed effect models to investigate the occurrence and abundance of invasive plants with respect to varying native richness, human impacts, forest types and climate.
3. Human use of forests increased the richness and abundance of invasive plants across all forest types. After accounting for human use, native species richness of tropical wet forests had a negative relationship with invasive plants richness and abundance, while the relationship reversed with increasing aridity and temperature. Human infrastructure facilitated invasions within PAs.
4. *Synthesis.* The biotic resistance hypothesis explained a lower number of invasions within protected tropical wet forests but not within dry forests. Human-free protected areas had lower richness and abundance of invasive plants across all systems, especially in wet tropical forests. Our results support the contextual importance of the biotic resistance hypothesis, while stressing the importance of protected areas, insulated from human impacts, to preserve the integrity of vulnerable natural systems.

KEYWORDS

biotic resistance, India, invasive plants, multi-use areas, protected areas, tiger reserves

1 | INTRODUCTION

With the growth of human population and associated transformation of natural systems into agro-industrial urban systems, humans have restructured global biota. This trend is likely increasing as the Anthropocene progresses. Two indices that exemplify the magnitude of these global changes are the loss in native biodiversity (IPBES, 2019a; IPCC, 2014) and prevalence of invasive species (IPBES, 2019b). Introduction and spread of invasive species even in the least modified parts of the earth, such as the Antarctic (Hughes et al., 2020), deep oceans (Levin & Le Bris, 2015), tropical rain forests (Wells et al., 2014) and African deserts (Schachtschneider & February, 2013), have questioned the resistance of these ecosystems to human-induced changes. In invasion ecology, ecological integrity is often measured as the capacity of an ecosystem to retain its native assemblage and resist change (inertia) despite being surrounded by invasive species, and its ability to regain its native assemblage (resilience) and functioning despite being invaded by invasive species (Chambers et al., 2019; Cushman & McGarigal, 2019). The former is popularly known as 'biotic resistance' and the latter as 'biotic resilience', more recently, it has been placed under the umbrella concept of ecological resilience that refers to the system's capacity to self-maintain from changing into alternate states (Chambers et al., 2017; Hirota et al., 2011; Levine et al., 2016).

Scientists and conservationists worldwide have advocated conserving biodiverse areas by declaring them as protected, so as to retain their ecological resilience (Ghosh-Harihar et al., 2019; Pimm et al., 2014). However, a large number of invasive species are globally sprawling in protected areas (PAs, Mungi et al., 2020; Shackleton et al., 2020). This questions the premise of protecting biodiverse areas for retaining ecological resistance and resilience to biological invasions. The theory of biotic resistance suggests that species-rich native communities are less invasible (Elton, 1958; Fridley et al., 2007), since available niches are filled, and hence, the community offers a higher competition to invading species (Iannone et al., 2016; Shea & Chesson, 2002; Von Holle, 2013). However, evidence in support of the biotic resistance hypothesis is rare and data are often contradictory (Levine et al., 2004). It is hence important to understand if PAs serve as a relevant conservation strategy in controlling invasive species, particularly in the advent of global change. Simultaneously, we need to know if certain systems are more vulnerable to invasions compared to others, so as to prioritize the allocation of limited resources in effective control of invasive species.

Most studies on the biotic resistance hypothesis are restricted to temperate regions that have relatively simpler species assemblages (Smith & Côté, 2019; Tomasetto et al., 2019). Hyperdiverse tropics offer model systems, by sheer virtue of their diversity, to better explore the role of native species richness in biotic resistance. The lack of studies in tropical systems limits our understanding on the subject (Barlow et al., 2018). Tropics hold a disproportionately large amount of global biodiversity, which is at risk due to increasing demographic, socio-economic, climate change and environmental pressures (Edelman et al., 2014). Tropics are also experiencing a high

spread and impacts from invasive species, which adds to the above-mentioned threats (Barlow et al., 2018).

Contradictions in the theory of biotic resistance, also known as the invasion paradox (Brooks et al., 2013; Fridley et al., 2007), arise due to differences in ecological assumptions and statistical designs in experimental and observational studies (Clark & Johnston, 2009; Peng et al., 2019; Smith & Côté, 2019). Observational studies often contradict the biotic resistance hypothesis, since they show a positive correlation between native and invasive species richness (e.g. Peng et al., 2019; Smith & Côté, 2019). This observed increase in invasive species with native species is likely due to the lack of control for environmental and biotic covariates, as well as spatial heterogeneity (i.e. intersystem variations) in these studies (Denslow & DeWalt, 2008; Fridley et al., 2007; Nunez-Mir et al., 2017; Perelman et al., 2007). Recent studies (e.g. Beaury et al., 2020) that account for these effects have found biotic resistance to be ubiquitous. Thus, to decipher the relationship between native and invasive species, it is pertinent to account for environmental settings (Melbourne et al., 2007; Smith & Côté, 2019; Tomasetto et al., 2019). In addition to the influence of environmental covariates and spatial heterogeneity, we believe that human activities would have a profound and varied influence on the vulnerability of ecosystems to biological invasions (Pyšek et al., 2010). A study that enhances our understanding of different tropical systems' resistance and resilience to plant invasions, while accounting for environmental, biotic, and human impact covariates, would assist policy and management for effective conservation in a changing world.

We use data on plant communities (species richness and abundance) from five tropical forest types sampled from within PAs (least human impact) and pair them with data from the multi-use areas (MAs, high human impact) but having the same vegetation type. Within these areas, we explore how invasive plant richness and abundance correlate with climate, anthropogenic disturbance, forest type, protection regime and native plant richness. We hypothesize that after accounting for environmental covariates, the negative relationship in native and invasive plant richness (i.e. biotic resistance) should vary with forest type and human impacts. Our findings from across varied tropical forest systems show the importance of PAs in conserving native biodiversity from invasive species. Our study provides an enhanced understanding of the biotic resistance hypothesis in the tropics.

2 | MATERIALS AND METHODS

Tropical India is broadly divided into five forest types: dry thorn forest (i.e. savannas), dry deciduous forest, moist deciduous forest, semi-evergreen forest and evergreen forest (Champion & Seth, 1968). Across these forest types, least modified and maximum protected forests are found in the core region of the tiger reserves (Ghosh-Harihar et al., 2019). Hence, we selected these forest types to address our study hypotheses. Tiger reserves and many PAs in India are made up of a legally designated human-free core area and

a buffer (MA) surrounding this core (Jhala et al. 2021). In the buffer of a tiger reserve, local communities use the forests for their livelihoods that include agriculture, livestock grazing, collection of fuel wood and minor forest produce, but no timber-logging, polluting industries or mining are permitted (Narain et al., 2005). We sampled the core (PAs) and buffer (MAs) of 32 tiger reserves, one wildlife sanctuary and one national park (Figure S1) to encompass all of the above forest types to address our hypotheses. The wildlife sanctuary and national park sampled by us had large inviolate areas, with least human modifications surrounded by buffer forests (Ranjitsinh & Jhala, 2010). By sampling PAs and MAs at each site in all forest types, we addressed the effects of human impacts and variations due to forest types.

At each site, we systematically distributed sampling plots on randomly placed 2 km long transects laid in each administrative unit of the forest (beat ~16 km²). On every transect, concentric plots of 30 and 10 m diameter were sampled at every 400 m interval to record all tree species and signs of human impacts in the 30 m plot, and all shrub species in the 10 m plot (Jhala et al., 2017; Figure 1). Irrespective of being native or non-native, all trees were individually

counted in 30 m plots and shrubs were quantified as percent cover in the 10 m plot using a modification of the Daubenmire's scale (Daubenmire, 1968). We enumerated all angiosperms and gymnosperms, but did not record bryophytes, pteridophytes, epiphytes and members of family Poaceae. In the 30 m diameter plot, canopy density was visually estimated as percent cover. Simultaneously, human impacts were quantified as the (a) number of trees with lopped branches, (b) number of trees felled, (c) evidence of grass and bamboo cutting, (d) number of people seen from the plot, (e) number of livestock seen from the plot and (f) livestock-human foot trails within the plot. Sampling was conducted between November 2017 and January 2018, as maximum plant species were recorded during these post-monsoon months in India. Whenever required, regional floras and photographic guides were used to confirm taxonomy (e.g. Daniel et al., 2005; Krishen, 2013; Page, 2017; Sharma, 1993). We made herbaria and/or took digital photographs for species that could not be identified in the field and subsequently consulted plant taxonomists for their identification. At every plot, the geographic coordinates, date, data and photographs were recorded using a customized android app (viz. MStrIPES). Sampling details were

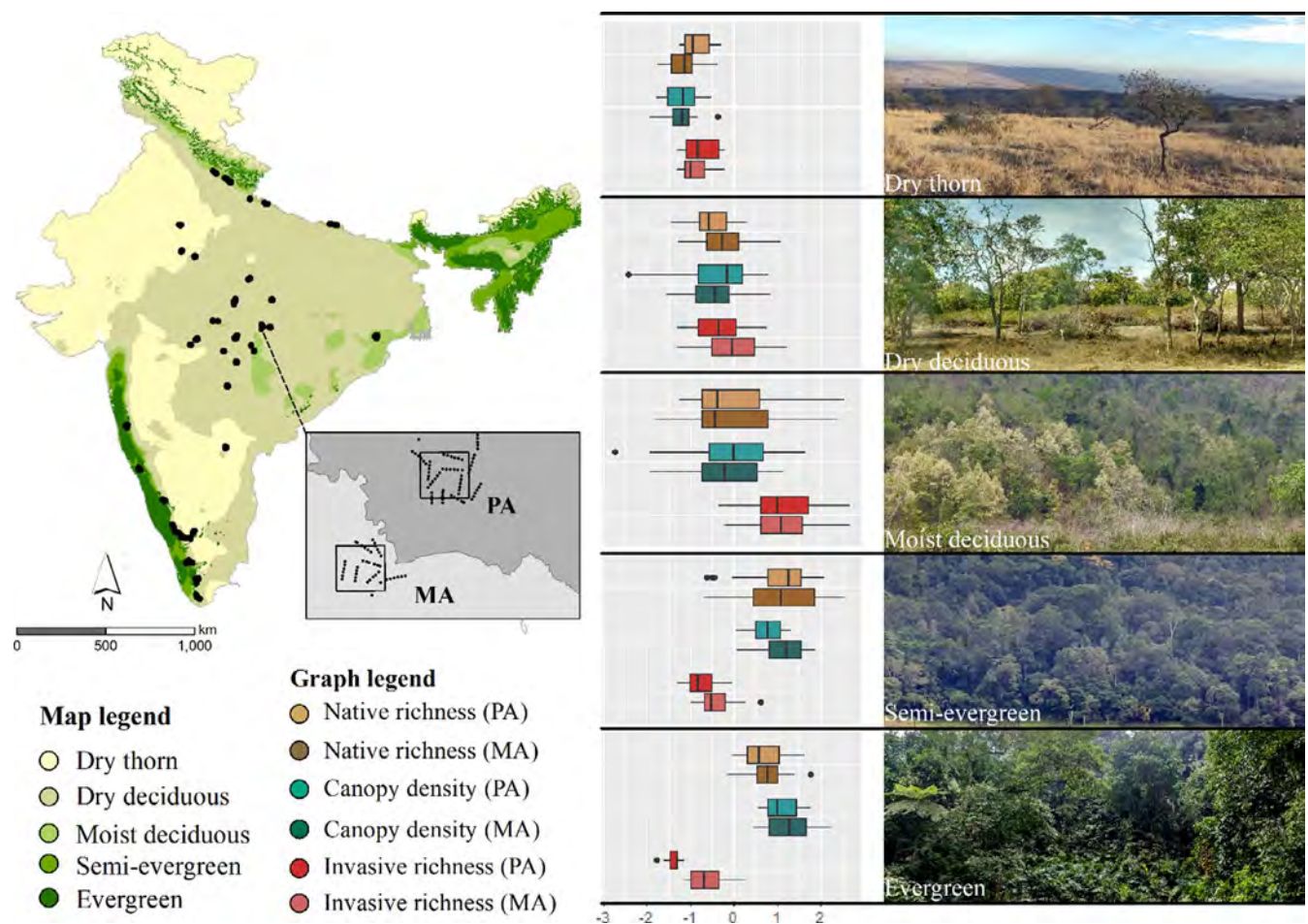


FIGURE 1 Location of vegetation survey grids ($n = 354$) in protected areas (PAs) and multi-use areas (MAs), across different forest types of India. For every PA, an equal number of grids (5×5 km) were sampled in PA and MA by sampling 22–55 plots per grid. Comparative native richness increased from dry thorn to evergreen forests, canopy was denser inside the PAs across all forest types, and highest number of invasive plants was recorded in moist deciduous forests

separately published in the form of a field guide (Jhala et al., 2017) in regional languages.

A spatial grid of 5 × 5 km was subsequently developed in the GIS domain and all data from the sampled plots were spatially attached to these grids in ArcGIS 10.6.1. This spatial scale (25 km²) was considered appropriate to understand ecological interactions as well as for managerial interventions for invasive plants in the region (Mungi et al., 2020). The information on human impacts, canopy, species occurrence and abundance was computed at this grid scale. In each grid, the number of plots ranged between 26 and 55 and was found to be adequate based on species accumulation curves, as observed in the five forest types (Figure S2). All native plant species were considered for estimating native plant richness, whereas all non-native plant species were considered for estimating invasive plant richness (Khuroo et al., 2012; Pergl et al., 2018).

For an in-depth understanding of the relationship between richness of native plants and abundance of invasive plants, we selected 10 non-native species that were considered as high-concern invasive plants in India (Mathur et al., 2015; Mungi et al., 2019). These invasive plants were *Ageratina adenophora*, *Ageratum conyzoides*, *Chromolaena odorata*, *Hyptis suaveolens*, *Lantana camara*, *Mikania micrantha*, *Parthenium hysterophorus*, *Prosopis juliflora*, *Senna tora* and *Xanthium strumarium*. These invasive plants encompassed a range of species that either occurred across all forest types (e.g. *L. camara* and *P. hysterophorus*) or were restricted to only a few (e.g. *M. micrantha* and *X. strumarium*) and varied in abundances between sites.

2.1 | Environmental covariates

Each grid was assigned to a forest type using a high-resolution forest type data (FSI, 2009). Within the PA grids, we used only those grids that had no signs of human impacts, tree felling and livestock grazing. Same number of grids was selected from multi-used areas paired with each PAs. Thus, addressing the variability caused by human use and habitat heterogeneity. Our sample consisted of 354 grids of 25 km² (44 in dry thorn forest, 106 in dry deciduous forest, 106 in moist deciduous forest, 48 in semi-evergreen forest and 50 in evergreen forest) resulting in a coverage of 8,850 km² of forests (Figure 1).

Although we control for several human impacts through ground sampling, we could not control for proximity to forest fires, roads, human settlements and forest loss; variables that may result in higher propagules making grids more conducive for invasive plants (Mungi et al., 2018, 2020). However, we account for the effects of these variables on invasive species richness and abundance in our analysis by including proximity of sampled grids to burnt forest patches, linear infrastructure, human settlements and cleared forest patches as covariates. We hypothesized that more invasive species occur near these disturbance drivers. We use fire occurrence data from Fire Information for Resource Management System (Giglio et al., 2003; Schroeder et al., 2014) and estimate the mean Euclidean

distance of each grid from fire occurrence. We also estimated the mean Euclidean distance of each grid from roads (Survey of India, 2011), railways (Survey of India, 2011) and urban settlements (Esch et al., 2017). Furthermore, we use forest loss information from the Global Forest Watch for the period 2001–2017 (Hansen et al., 2013), and calculated the mean Euclidean distance of each grid from lost forest patches. We use a square root transformation of these distances for our analysis so as to incorporate the biological threshold beyond which their impacts would be minimal. Apart from forest type and anthropogenic modifications, climate is also likely to influence richness and abundance of native as well as invasive plants (e.g. Adhikari et al., 2015; Joshi et al., 2020; Mungi et al., 2020). To account for the effect of climate, we used average annual precipitation and temperature of the warmest quarter from WorldClim (Fick & Hijmans, 2017). The data sources, scale and hypothesized effect of covariates on invasive species richness and abundance are explained in Table 1. Data used for analysis are available online (Mungi et al., 2021).

2.2 | Statistical analysis

We did not consider zero-inflated distribution since none of the sampled grids had zero native or invasive species. Furthermore, we assessed correlation within the environmental covariates using Pearson's correlation coefficient and found no substantial correlation amongst the variables (Table S1). All covariates were Z-transformed so as to convert them to comparable scales. Thereafter, we used these datasets to explore linear correlative relationships of (a) invasive plant richness and (b) invasive plant abundance with native plant richness, climatic variables and human impacts.

2.2.1 | Predictors of Invasive plant richness

Invasive plant richness was modelled using linear mixed effect models as a response to annual rainfall (R), temperature of warmest quarter (T), distance from human infrastructure (road, railways and urban settlements) (HD), distance from fire (FD) and distance from cleared forest patches (FLD) as fixed effects; while response to native richness (NR), canopy (C) and interaction between native richness and canopy was modelled as random effects conditional on forest type and protection regime (ForestPA). We first determined the best model for fixed effects and subsequently using the variables selected therein, added the random effects. The full model structure was:

$$\frac{\text{Invasive plant richness}}{\text{Response}} = \frac{(R + T + FD + FLD)}{\text{Fixed effect}} + \frac{((NR + C + NR \times C) | \text{ForestPA})}{\text{Random effect}}.$$

We fitted general LMM using the `lme4` package in R (ver. 1.1.4; Bates et al., 2018). Model statistics were estimated using the `nlme` package

TABLE 1 Effects of different environmental covariates on the richness and densities of invasive plants in India, along with their relevance, resolution, data source

Covariates	Relevance	Data source & resolution
<i>Fixed effects</i>		
Rainfall	Annual rainfall determines productivity and floral diversity across the tropics and the distribution of invasive plants in it (Goncalves et al., 2014; Mungi et al., 2020)	1 km (Fick & Hijmans, 2017)
Temperature	Higher summer temperature and low rainfall determines the xeric floral diversity and invasions in it (Kannan et al., 2013; Panda et al., 2018)	1 km (Fick & Hijmans, 2017)
Distance from human infrastructure (roads, railways and settlement)	Areas near human use have higher propagule pressure of invasive plants as humans are primary agents for introducing these species, as well as areas near roads and railways have higher probability of spreading invasive species (Dar et al., 2015; Sharma & Raghubanshi, 2009)	30 m (Esch et al., 2017; Survey of India, 2011)
Distance from fire	In wet forests, extensive fire causes loss of native plants and provides a window for establishment of invasive species, which act as a source of propagules (Hiremath & Sundaram, 2005; Mungi et al., 2018)	100 m (Schroeder et al., 2014)
Distance from cleared forest patches	Cleared forest provides unutilized resources that can facilitate establishment of invasive species that subsequently act as a source of propagules (Mungi et al., 2020). Used as an index of propagule proximity	30 m (Hansen et al., 2013)
Native plant richness	Higher native richness can deter the establishment of non-native species viz. the biotic resistance hypothesis (Beaury et al., 2020)	Ground sampled
Canopy density	Dense canopy reduces light availability to the understorey, thereby reducing the growth of many understorey plants (including invasive plants, Sharma & Raghubanshi, 2009)	Ground sampled
<i>Random effects</i>		
Forest type	Species assemblage and ecophysiology varies across different forest types, which can change the relationship of species with its environment (Beaury et al., 2020; Mungi et al., 2018)	30 m (FSI, 2009)
Protected area	By sampling within and outside protected areas, we control for several human impacts (Ratnam et al., 2019)	www.mstrips.in

(Pinheiro et al., 2020), while model fit was assessed by using the MuMIn package (Bartoń, 2018). We used Akaike information criterion (AIC; Akaike, 1973) to compare candidate models with different combinations of covariates for modelling invasive plant richness. Model with the least AIC was considered as the best model (Johnson & Omland, 2004). When models differed by <5 AIC, we used model average estimates weighted by AIC weights to incorporate model uncertainty in parameter estimates. Coefficients of the best LMM explained the differential effect of covariates on invasive species richness in different forest types, which were interpreted for their ecological relevance.

2.2.2 | Predictors of Invasive plant abundance

Invasive plants can colonize and increase in abundance only within a specified climatic niche (Mungi et al., 2020; Panda et al., 2018). Climatic variables and human impacts mask the influence of native plant richness on invasive species since models often extend beyond the climatic niche of the species and rarely control for human impacts. To control for the effect of human impacts and climatic niche, we selected only those grids that were within the core of PAs and the forest type within which the invasive species occurred for this analysis. For 10 high-concern invasive plants, we model the response

of their abundance to native plant richness, climatic variables and proximity to potential propagule sources, using multivariate linear regression. Model with the least AIC was considered as the best model. We used the 'lm' command in R for these linear models.

2.3 | Exploring niche space of high concern invasive plants

To understand how abundance of invasive plants respond to climatic variables and human impacts (source of propagules), we used data on abundance of 10 high concern invasive plants from within grids of PAs. We limit our analysis to PA grids, since in these grids, a multitude of human impacts were controlled (e.g. wood cutting, livestock grazing, extractive uses of forest produce etc.), so we could model the impact of proximity to roads, human habitation and forest loss (potential source of propagules) without confounding effects of other predictors.

We use canonical correspondence analysis (CCA) executed in package *VEGAN* in R (Oksanen et al., 2007) with abundance of invasive plants within 5×5 km grids and mean values of covariates of annual rainfall, maximum temperature of warmest month and proximity to source of propagules (proximity to human impacts, fire and cleared forest patches). We hypothesized that each invasive plant would differentially ordinate on the canonical components obtained from these climatic and propagule proximity covariates. Subsequently, we mapped the sampled PA grids on covariates that had the maximum loadings of significant CCA components to better understand their ecological correlates.

3 | RESULTS

Native species richness was high in semi-evergreen and evergreen forests, followed by moist and dry deciduous forest, while dry thorn forest had the least native species richness. Invasive species richness was highest in moist and dry deciduous forest, followed by dry thorn and semi-evergreen forest, whereas the least invasive species richness was observed in evergreen forest. Exploratory analysis revealed a positive trend in the native and invasive plant richness in dry thorn forest, dry and moist deciduous forest, while a negative trend was observed in semi-evergreen and evergreen forests (Figure 2). These correlations were significant only within PAs (Figure 2).

3.1 | Predictors of the invasive plant richness

Invasive plant richness was best explained by fixed effects of climatic variables consisting of temperature of the warmest month and annual rainfall, and disturbance variables comprising of distance from burnt forest patches, distance from cleared forest patches and distance from human infrastructure (Table S2). After incorporating random effects (Table S3), invasive plant richness across different forest

types was found to differ in their response to native plant richness, canopy cover and the interaction between these variables (Table 2). Fixed effects explained 5% variation in the data, while random effects conditional on forest types and protection explained 87% variation. Amongst random effects, canopy density was negatively related to invasive richness in semi-evergreen, moist deciduous and evergreen forests. Native plant richness was negatively related to invasive richness in PAs of semi-evergreen forests and all (protected and multi-use) areas of evergreen forests (Figure 3). The interaction between canopy cover and native plant richness was significant in most forest types, being positive in dry forests and negative in wet forests (Table 2; Figure 3).

3.2 | Predictors of the invasive plant abundance

Best models explaining the abundance of invasive plants had significant effects of climatic, forest and human impact variables (Table 3). Human impacts (proximity to human transmitted propagules) significantly increased abundance of invasive plants; this effect was not observed or was insignificant for *L. camara*, *P. hysterophorus* and *P. juliflora*. Native plant richness alone or in interaction with canopy density reduced abundance of invasive plants in wet forests (*M. micrantha*, *C. odorata*, *A. adenophora* and *A. conyzoides*). Native plant richness had no significant relationship with invasive plant density of dry forests (*P. juliflora*, *X. strumarium*, *H. suaveolens* and *S. tora*). The R-squared value for all these models varied from 0.19 to 0.53 (Table 3).

The primary ordination axis of CCA explained 79% of the variation in abundance of invasive plants (Tables S1.1 and S1.2). This axis had the highest loadings for annual rainfall (−0.85) and temperature of the warmest quarter (0.94, Table S1.3). The 10 invasive plants segregate along their niche space defined by annual rainfall and temperature of the warmest month across tropical India (Figure 4).

4 | DISCUSSION

Native species richness followed a moisture gradient being maximum in the wet forests (both semi-evergreen and evergreen) and least in the dry thorn forest. Whereas invasive richness had a parabolic relationship with moisture, being highest in moist deciduous forests and least in the wet evergreen and dry thorn forests. Native and invasive richness were positively correlated for dry forests (dry thorn, dry deciduous and moist deciduous) irrespective of their protection status. While in PAs of wet forests (semi-evergreen and evergreen) invasive plant richness was negatively correlated with native plant richness, MAs did not show any trends (Figure 2).

Across all forest types (moisture and temperature gradients) we found that PAs consistently had lower invasive plants compared to MAs (Figure 2). However, we had disparate results regarding the biotic resistance hypothesis. Patterns observed from wet forests were in consonance with the hypothesis, where invasive species

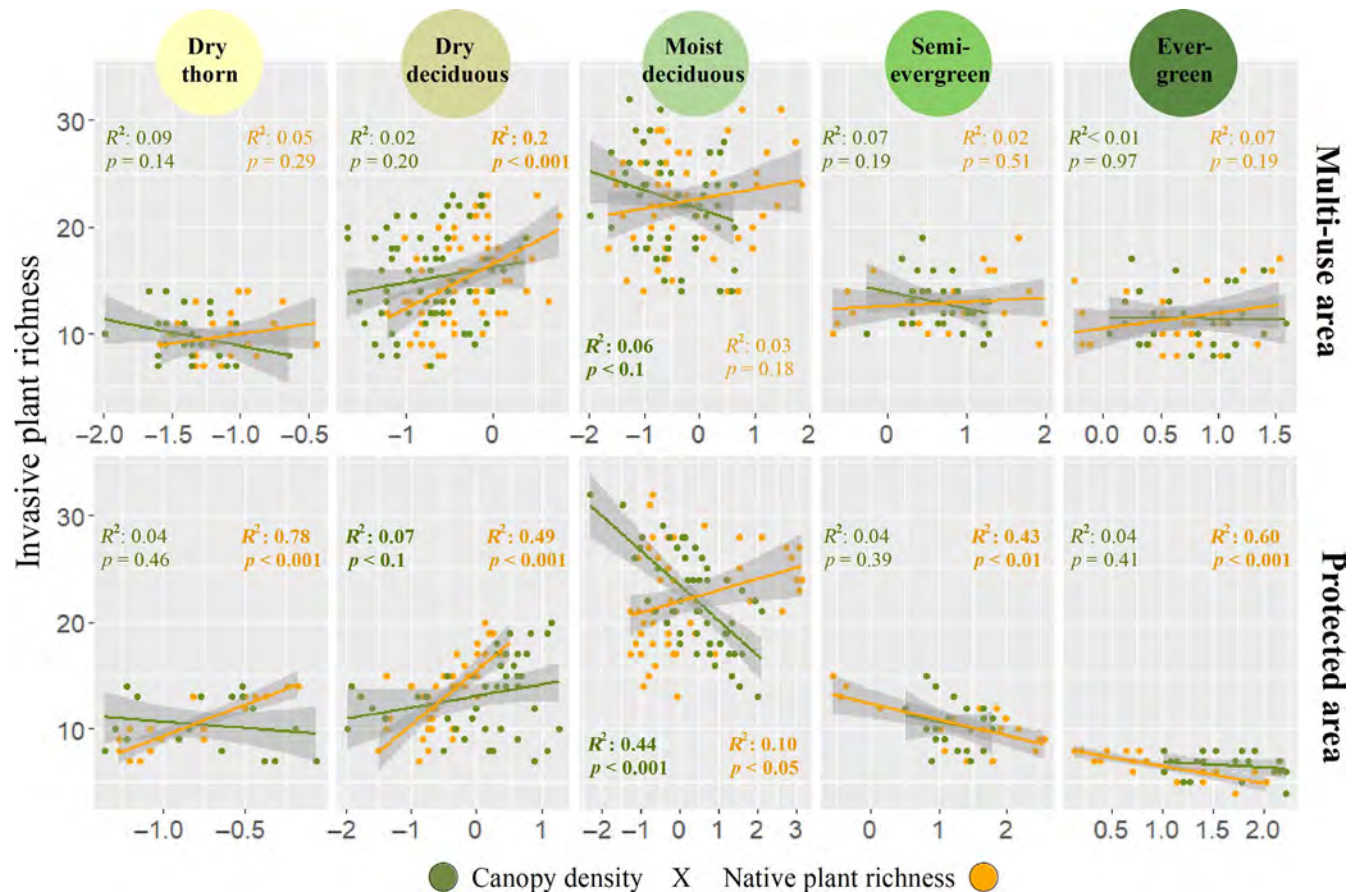


FIGURE 2 Relationship of invasive plant richness with canopy density and native plant richness in protected areas and multi-used areas across five tropical forest systems. Trend lines are plotted to show the directionality of these relationships, statistically significant relationships ($p < 0.1$) are shown in bold

richness declined with increasing native plant richness, while in dry forests, invasive species richness increased along with native species richness.

Tiger reserves in wet forests (Kalakkad-Mundanthurai, Periyar, Anamalai, Parambikulam, Bhadra, Kali and Similipal; Figure S1) resisted invasive plants by their species-rich communities and retained their ecological integrity. However, this relationship of biotic resistance was not significant for multi-use wet forests. This suggests that human use neutralizes the benevolent effect of native plant richness in resisting invasive plants. These results lend support to the creation of PAs in wet forest systems, where management activities restore native richness and reduce human use as a measure to arrest invasive species. Wet forest in the proximity of human disturbances (roads, railways, human settlements, burnt forest patches and cleared forest patches) had higher invasive species richness, possibly because these disturbed sites were sources of propagules. Forests around these disturbances were found to be densely invaded by *M. micrantha* and *C. odorata*, which were the major invasive species in wet forests. Developmental activities like linear infrastructure and clear felling (Nayak et al., 2020) in wet forests will likely result in fragmentation and subsequently reduce their biotic resistance and should therefore be curtailed within and in the proximity of PAs. Mitigation measures to maintain habitat connectivity for wildlife in

the form of engineering solutions (Clevenger & Huijser, 2011) often utilized to justify such developmental activities in PAs cannot mitigate the detrimental effects of fragmentation on biotic resistance.

While protected tropical wet forests ubiquitously displayed biotic resistance, drier forests had a contrasting positive relationship with native richness. These forests (moist and dry deciduous forests and dry thorn forests) had lower native plant richness and canopy compared to wet forests (Figure 1). Dry forests have also been historically exploited for timber extraction (even in PAs), are currently grazed by livestock, and fragmented by agriculture, monoculture plantations and linear infrastructure (Nayak et al., 2020). Additionally, these remaining forests are historically modified in their composition by forestry practices (Joshi et al., 2018) that promoted fast-growing woody species were for either timber production or greening of the landscape (e.g. *P. juliflora*, *Leucaena leucocephala*; Ratnam et al., 2011). Promoting monotonous woody plants depletes the regeneration of herbaceous vegetation under it and can facilitate the growth of invasive plants by altering edaphic characteristics (Parr et al., 2014). Therefore, in these drier forests, the manifestation of biotic resistance could have been curtailed by compounding effects of contemporary and historical human use.

Dry thorn forests were found to have naturally sparse trees (low canopy cover) and limited number of species. Native richness and

TABLE 2 Coefficients of covariates used to assess the determinants of invasive plant richness in different tropical forest types using linear mixed regression for every protected and multi-use forest type. Increasing wetness of the forest is represented by darker green shades. Values in bold are significant (p value <0.1)

Forest	I	NR	C	NR*C	R	T	FD	FLD	HD
Dry thorn MA	12.13	1.01 (± 4.13)	0.08 (± 1.21)	0.24 (± 0.63)	0.11 (± 0.23)	-0.42 (± 0.22)	-0.42 (± 0.16)	-0.39 (± 0.21)	-1.43 (± 0.15)
Dry thorn PA	16.36	5 (± 4.38)	0.85 (± 1.02)	0.71 (± 0.59)	0.11 (± 0.23)	-0.42 (± 0.22)	-0.42 (± 0.16)	-0.39 (± 0.21)	-1.43 (± 0.15)
Dry deciduous MA	16.12	2.86 (± 1.01)	0.21 (± 0.94)	0.36 (± 0.31)	0.11 (± 0.23)	-0.42 (± 0.22)	-0.42 (± 0.16)	-0.39 (± 0.21)	-1.43 (± 0.15)
Dry deciduous PA	16.95	6.92 (± 2.23)	0.45 (± 0.59)	1.17 (± 0.51)	0.11 (± 0.23)	-0.42 (± 0.22)	-0.42 (± 0.16)	-0.39 (± 0.21)	-1.43 (± 0.15)
Moist deciduous MA	21.56	1.64 (± 0.47)	-2.24 (± 0.88)	0.11 (± 0.19)	0.11 (± 0.23)	-0.42 (± 0.22)	-0.42 (± 0.16)	-0.39 (± 0.21)	-1.43 (± 0.15)
Moist deciduous PA	21.14	2 (± 0.52)	-3.75 (± 0.67)	0.46 (± 0.1)	0.11 (± 0.23)	-0.42 (± 0.22)	-0.42 (± 0.16)	-0.39 (± 0.21)	-1.43 (± 0.15)
Semi evergreen MA	12.25	0.46 (± 0.69)	-0.56 (± 2.16)	0.21 (± 0.22)	0.11 (± 0.23)	-0.42 (± 0.22)	-0.42 (± 0.16)	-0.39 (± 0.21)	-1.43 (± 0.15)
Semi evergreen PA	12.04	-1.87 (± 0.97)	-0.56 (± 2.22)	-0.31 (± 0.27)	0.11 (± 0.23)	-0.42 (± 0.22)	-0.42 (± 0.16)	-0.39 (± 0.21)	-1.43 (± 0.15)
Evergreen MA	13.09	-1.1 (± 1.01)	-0.68 (± 2.09)	-0.19 (± 0.2)	0.11 (± 0.23)	-0.42 (± 0.22)	-0.42 (± 0.16)	-0.39 (± 0.21)	-1.43 (± 0.15)
Evergreen PA	7.72	-2.02 (± 1.06)	0.67 (± 2.1)	-0.24 (± 0.19)	0.11 (± 0.23)	-0.42 (± 0.22)	-0.42 (± 0.16)	-0.39 (± 0.21)	-1.43 (± 0.15)

Abbreviations: C, average canopy density; FD, distance from fire; FLD, distance from lost forest; Forest, forest type and protection regime, for example, evergreen protected area (PA), evergreen multi-used area (MA), HD, distance from human infrastructure; I, intercept; NR, richness of native plants; R, annual rainfall; T, mean temperature of warmest quarter.

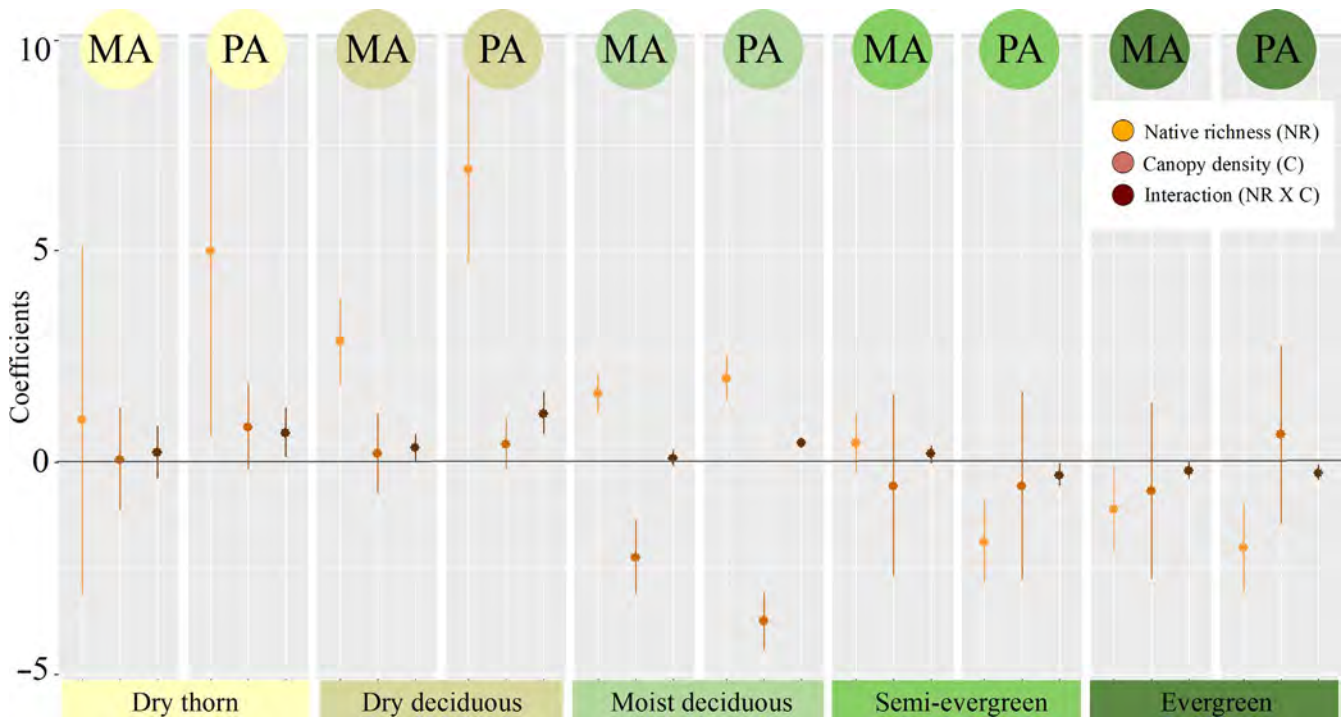


FIGURE 3 Independent and interactive effect of native plant richness and canopy density on invasive plant richness in multi-use areas (MAs) and protected areas (PAs) across different tropical forests in India

invasive richness were both likely limited by nutrients and moisture in these forests (Guttal & Jayaprakash, 2007). The woodlands in the dry thorn forests, which are a product of the historical plantation activities, were found to have higher invasive richness as well as higher abundance of invasive plants like *P. juliflora*, *X. strumarium* and *S. tora*. However, despite the above results, areas protected from contemporary human use (Ranthambhore, Sariska, Kuno, Nauradehi; Figure S1) were found to have less richness and abundance of invasive plants.

Moist and dry deciduous forests though categorized as woodland are functionally a spatial mosaic of broadleaf forests and savannas (Kumar et al., 2020; Ratnam et al., 2016, 2019). These forests are spread across central and peninsular India and are heavily fragmented by anthropogenic land uses (Roy et al., 2013) and degraded by high density livestock grazing (Dave & Jhala, 2011). Large tracts of these forests are now restricted to PAs, which are dominated by tree cover (Nayak et al., 2020). Particularly dry deciduous forests that were substantially modified by plantations of timber species (e.g. *Tectona grandis*, *Acacia* sp.) during the colonial rule had positive correlation of native and invasive plant richness. Many PAs in these forest types (Pench, Satpuda, Nagarhole) still retain these plantations and therefore also exhibit high invasive plant richness (Figure S1). Invasive plants like *L. camara*, *S. tora* and *H. suaveolens* were found in high densities across these forests. Invasive richness was higher in areas with open canopy (e.g. Rajaji and Dudhwa), and as canopy density increased, the invasive richness declined (e.g. Corbett and Valmiki; Figure S1). Dominant invasive species in these forests (*L. camara*, *A. adenophora* and *A. conyzoides*) were found at high density either in open canopy areas or around human disturbances.

We attribute the contrasting pattern of biotic resistance in wet and dry forests to the super abundance of propagules made available in and around dry forests by current and historical human impacts. Dry forests have been traditionally used more by people than the contemporary wet forests. The management activities in dry forests involved plantation of non-native species that had high invasiveness (e.g. *P. juliflora*; Mungi & Qureshi, 2018), or were brought in the proximity through imported seeds for agriculture (e.g. *Parthenium hysterophorus*, *S. tora* and *X. strumarium*). Anthropogenic disturbances like fire and forest loss facilitated invasive plant richness across all forest types, while disturbance like human infrastructure strongly influenced their richness in wet forests. Hence, irrespective of the forest types, PAs should be managed for minimal anthropogenic modifications, in terms of habitat change (e.g. plantation), changing natural fire regime, livestock grazing and infrastructure development (e.g. road, railways, power lines etc.).

A potential limitation of our study is our definition of native plant richness, wherein we include all trees, shrubs and herbs but exclude grasses. Our exclusion of grasses was because of our inability for definitive taxonomic identification in the absence of inflorescence during the sampling period. However, in our defence, we argue that large-scale field studies can rarely include all taxa of native flora that can potentially contribute to biotic resistance (inclusive of pteridophytes, bryophytes, etc.). We believe that by defining what constitutes native richness, we allow our study to remain relevant for comparisons with other studies. Besides, we interpret our results conservatively, inclusion of Poaceae would only strengthen the reported pattern on biotic resistance of different forest systems. A strong point of our study is that we take advantage of manipulative experiments wherein large

TABLE 3 The coefficients (standard error) of the best models explaining the relationship of invasive plant abundance and ecological covariates. Color shades are representative of the forest types in which these invasive plants are found, where increasing wetness of the forest is represented by darker green shades. Values in bold are statistically significant ($p < 0.1$)

Species, R^2 , p value	I	NR	C	NR*C	T	R	HD	FD	FLD
<i>Chromolaena odorata</i> (R^2 : 0.43; $p < 0.001$)	8.1 (± 11.31)	8.24 (± 9.85)	7.56 (± 11.99)	-10.41 (± 11.8)	-12.58 (± 6.76)	—	-15.38 (± 3.25)	—	—
<i>Mikania micrantha</i> (R^2 : 0.50; $p < 0.001$)	-18.73 (± 10.12)	9.02 (± 9.35)	27.02 (± 10.78)	-24.85 (± 11.62)	-20.26 (± 6.05)	—	-7.24 (± 2.97)	—	—
<i>Ageratina adenophora</i> (R^2 : 0.26; $p < 0.01$)	9.18 (± 2)	-2.13 (± 1.39)	—	—	—	9.17 (± 5.59)	—	-6.08 (± 2.73)	—
<i>Ageratum conyzoides</i> (R^2 : 0.19; $p < 0.001$)	8.09 (± 1.73)	-4.74 (± 1.61)	—	—	6.24 (± 2.35)	3.74 (± 1.96)	—	-6 (± 2.25)	-5.23 (± 2.23)
<i>Lantana camara</i> (R^2 : 0.13; $p < 0.01$)	12.64 (± 1.51)	6.82 (± 1.57)	-4.22 (± 1.69)	-4.46 (± 1.63)	-1.21 (± 1.53)	-2.01 (± 1.62)	—	—	—
<i>Senna tora</i> (R^2 : 0.53; $p < 0.001$)	8.08 (± 2.27)	—	-3.01 (± 1.72)	—	6.22 (± 2.28)	-8.56 (± 3.54)	—	3.75 (± 1.6)	7.22 (± 1.73)
<i>Parthenium hysterophorus</i> (R^2 : 0.23; $p < 0.001$)	3.91 (± 2.39)	-3.63 (± 1.93)	—	—	6.87 (± 2.48)	-10.81 (± 3.62)	-2.88 (± 1.82)	—	—
<i>Hyptis suaveolens</i> (R^2 : 0.26; $p < 0.001$)	5.41 (± 2.25)	5.05 (± 1.69)	—	—	5.75 (± 2.2)	-7.58 (± 3.48)	4.09 (± 1.67)	-4.35 (± 1.73)	—
<i>Prosopis juliflora</i> (R^2 : 0.38; $p < 0.001$)	-6.63 (± 5.05)	—	-5.99 (± 2.62)	—	9.18 (± 3.06)	-14.8 (± 5.22)	—	—	3.06 (± 2.06)
<i>Xanthium strumarium</i> (R^2 : 0.47; $p < 0.001$)	-9.1 (± 6.77)	—	-12.74 (± 3.47)	—	23.41 (± 3.94)	-14.11 (± 6.76)	-4.79 (± 2.66)	—	—

Abbreviations: C, average canopy density; FD, distance from fire; FLD, distance from lost forest; HD, distance from human infrastructure; I, intercept; NR, richness of native plants; R, annual rainfall; T, mean temperature of warmest quarter.

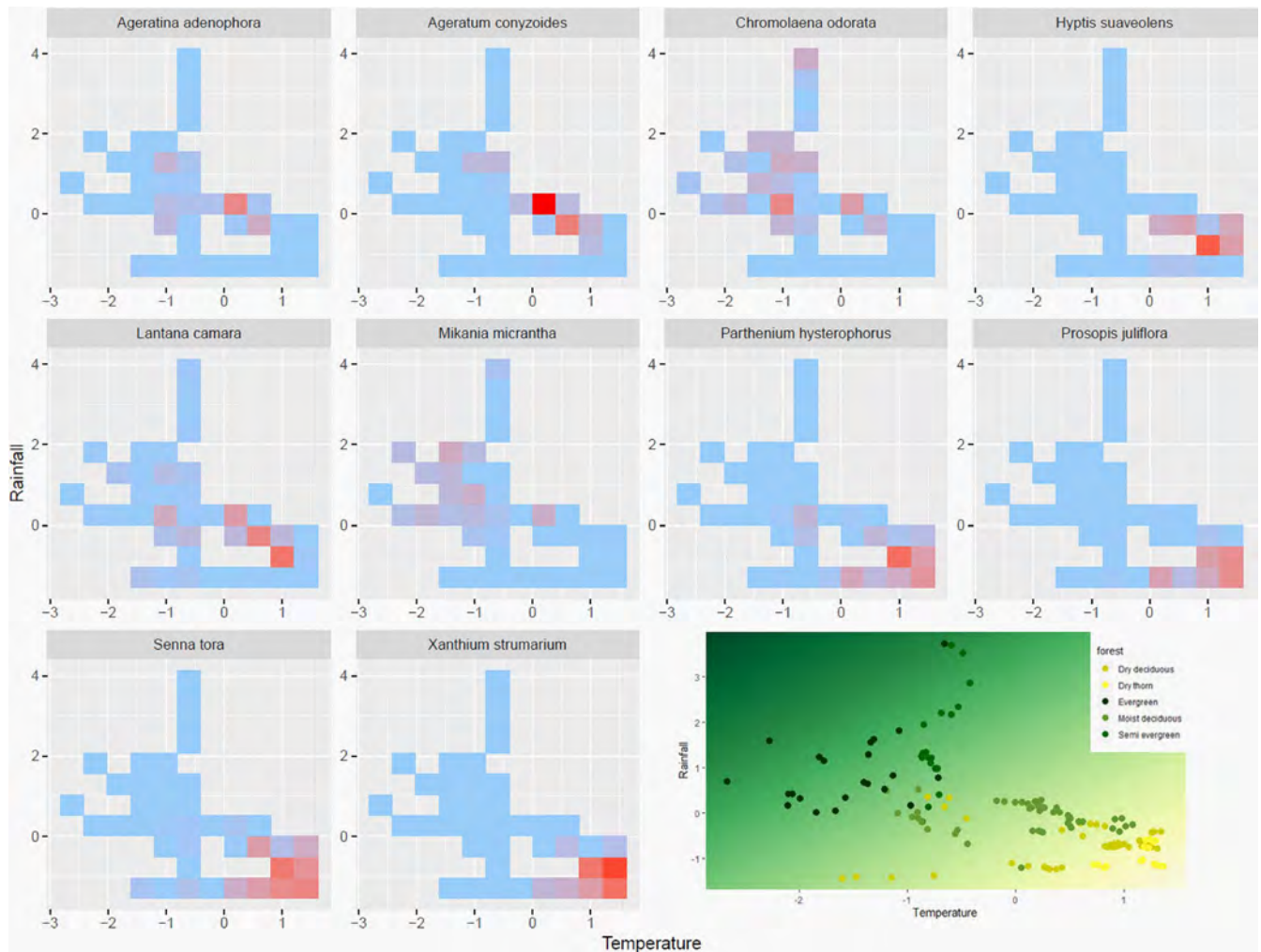


FIGURE 4 Using the canonical correspondence analysis, abundance of invasive plants was found to best ordinate along the rainfall and temperature gradient in tropical forests of India. The distribution of these species can be compared with the forest type gradient, which is also determined by the rainfall and temperature gradient

parts of forest systems were devoid of human use (PAs) and conclusively show the detrimental effect of human use by increasing invasive species richness and abundance. Our study could be further extended by quantifying and manipulating propagule availability and quantification of their establishment in florally rich versus impoverished forests and in protected versus multi-use forests.

Our results bring in a better comprehension of the theory of biotic resistance within tropical systems. We found that this hypothesis holds true in systems that had high resistance and low resilience (wet tropical forests; Isbell et al., 2015); areas that are of paramount importance for targeting conservation investments. Whereas the relationship between native plant richness and invasive plant richness and abundance was less pronounced or inverse within systems that were known to have low resistance but higher resilience (dry tropical forests; Isbell et al., 2015). This result was further compounded by high human impacts in these drier forests. Human impacts opened up all systems to invasive species. Our results show the importance of protecting forests from anthropogenic modifications. Protection of hyperdiverse tropical forests results in a positive feedback, since

they reduce biological invasions, which will in turn safeguard native species richness and abundance, ensuring their continued ecosystem services (IPBES, 2019b). Our results are timely, as tropical forests worldwide are being destroyed and degraded by unsustainable human uses and fragmented by infrastructure (Curtis et al., 2018; Song et al., 2018). Hence, there is an urgent need of making large tracts of tropical wet forests free of human modifications globally, to protect their ecological integrity and services.

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CONFLICT OF INTEREST

None of the authors have a conflict of interest.

AUTHORS' CONTRIBUTIONS

Q.Q., Y.V.J. and N.A.M. conceived the study, N.A.M. collated the data; Y.V.J. and N.A.M. analysed the data and wrote the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

Data available from the Dryad Digital Repository <https://doi.org/10.5061/dryad.866t1g1r4> (Mungi et al., 2021).

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How global climate change and regional disturbance can expand the invasion risk? Case study of *Lantana camara* invasion in the Himalaya

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Abstract Presently, it is debated if regional conservation efforts can alone resolve the ecological problems that global climatic changes could bring. Biological invasion is one of such concerns. In the present study, we modeled how change in global climate and regional anthropogenic pressure can impact the distribution of invasive *Lantana camara* in the Upper Ganga valley of the Western Himalaya (India). The forest in the study area was stratified into 1 km² grid and two 15 m radius plot were located in each of the forest types in the grid, for recording *Lantana* presence. In total, 2221 plots were sampled covering 22% of forest. We used predictors representing the climate, forest patch size, fire and natural

disaster variables for modeling the species distribution using maximum entropy algorithm. We further simulated 12 future landscape scenarios based on the global trends of these parameters. The present species—environment relationship was projected to these future landscape scenarios. *Lantana* was presently estimated to spread in 231 km² of the study area. It invaded larger forest patches in the subtropical region, and smaller disturbed forest patches in the warm and cold temperate region. Increased distribution of *Lantana* was projected across all the future scenarios. The study revealed how global climate changes and regional anthropogenic pressure can have a synergistic effect on the expansion of invasive species in the future. It thus questions the efficiency of conducting only regional efforts in absence of global initiative to reduce the greenhouse gases emission.

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s10530-018-1666-7>) contains supplementary material, which is available to authorized users.

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Keywords CCSM4 · MaxEnt · Range expansion · Species distribution model

Introduction

Given the unprecedented rate of global climate change and increasing anthropogenic pressures, it is increasingly important to understand how ecosystems and landscapes will adapt and respond to these drivers

(MEA Board 2005; Tylianakis et al. 2008). One of the most significant drivers of change under changing climate and disturbance regimes is biological invasion (Vitousek et al. 1997) that leads to proliferation of non-native plants and animals in terms of distribution and displacement of native species. Invasive plants pose threats to native biodiversity and various ecosystem services worldwide (Pimentel et al. 2000; Hejda et al. 2009) and often exploit the chances provided by increasingly suitable climate and loss of native species due to disturbances like fire and increased road connectivity (Kuhman et al. 2010).

The impact of anthropogenic disturbance and changing climate varies for native and invasive plants and depends on their plasticity and/or dispersal potential (Hampe and Petit 2005). Plasticity to the changing climate and dispersal to new habitat depends on the evolutionary histories of plants and their habitats. For example, the floral composition of the Western Himalaya was found to have low colonization rate and elevation specific speciation, which resulted in autochthonous species assemblage in the higher Himalaya (Mani 1974). This long-term colonization and climate specific speciation makes the native plants incapable of surviving in the changed climate or long-distance dispersal to the new habitat. Whereas, for invasive plants of continental distributions, their physiological plasticity and strategies to earn new dispersal agents can benefit them by the global changes (Sharma et al. 2011). As a result, for those native plants which are highly adapted to changing disturbance regime, colonization of recently disturbed areas is likely (Kubisch and Fronhofer 2014). While for other less adaptable species local extinction might prevail (Aitken et al. 2008).

Lantana camara species complex (Lantana henceforth) is a shrub native to tropical Central and Southern America and recognized as an invasive species of concern in India (Bhagwat et al. 2012). Lantana has high phenotypic plasticity (Sharma et al. 2011) and genetic diversity (Ray and Quader 2014) and as a result it has established in over 60 tropical and subtropical countries (Parsons and Cuthbertson 2001). Since its introduction in the early nineteenth century in India for ornamental purposes, Lantana has invaded climatically diverse landscapes covering the tropical rainforest of Western Ghats (Sankaran et al. 2014), sub-tropical Himalayan Mountains (Dobhal et al. 2010), semi-arid landscape of the Western India

(Bohra and Mishra 2012) and the mangroves (Panda et al. 2015). The distribution of Lantana is generally limited where winter temperature frequently falls below 5 °C resulting in defoliation and death of aerial woody branches (Day et al. 2003). Hence, the invasion range of Lantana is set by its physiological limits to the cold stress.

Lantana expands into new habitats following disturbances such as fires, landslides and floods, where native plants are stressed resulting from landscape degradation and fragmentation (Hiremath and Sundaram 2005; Raghubanshi and Tripathi 2009). Following disturbance, the forest canopy opens increasing the amount of light and freeing soil resources allowing the species to quickly colonize and invade. Lantana fruit attracts several bird species, which disperse its seeds far and wide (Sharma et al. 2005; Turner and Downey 2007). Moreover, the allelopathic characteristics of Lantana outcompetes the native plants and helps establish dense thickets (Gentle and Duggin 1997). Thus, changes in climatic conditions coupled with changes in disturbances regimes can act as drivers and significant predictors for future range expansion of Lantana.

Stakeholders are interested in understanding the current and likely future distribution of the species for prioritizing conservation efforts (Villemant et al. 2011). Species Distribution Models (SDMs) are often utilized as they provide a tool to predict the distribution quantitatively and spatially (Araújo and Peterson 2012). SDMs are useful for interpreting associated ecological interactions of a species and when utilized with spatially explicit climate and disturbance information can be used to better understand the geographic occurrence of the species and its environmental space. The global projection of the distribution of Lantana by 2050 differs depending on the analysis. A recent study predicted an increase in its distribution in response to climatic change alone (Qin et al. 2016), while another study found climatically suitable area to reduce in the future (Taylor et al. 2012). These studies suggest changes in the future range of the species but discrepancies in future projection are likely due to the different suitable habitat specifications and the role of disturbance in the simulations. It is crucial to understand how global climatic changes coupled with anthropogenic disturbance can influence the Lantana distribution in different parts of its range. In Himalaya, where Lantana is identified as high concern invasive

plant (Mathur et al. 2015), its distribution is not known; as well as, relying on global scale estimate of its invasion level and future expansion can be erroneous for management decisions. Hence, it is essential to include climate, habitat attributes (e.g. forest patch size, flood, etc.), and anthropogenic disturbances that change landscape characters (e.g. fire and landslides) at microscale to derive its present and future distribution.

In this paper, we apply a SDM approach to model the current and future distribution of *Lantana* across the study area which represents the species' climatic range limit in Northern India and a global biodiversity hotspot. To do so, we first utilize spatial representations of climate, fire occurrence, evidence of past landslides and floods, and current native forest patch sizes to model the current distribution of *Lantana*. Second, we develop a series of future scenarios by projecting climate, fire, and forest patch size distribution under different assumptions of global and regional changes and investigate the subsequent impact on *Lantana* distribution. Finally, we utilize our research to identify forest patches that are vulnerable to *Lantana* invasion, and draw key recommendations for stakeholders based on the model simulations.

Methods

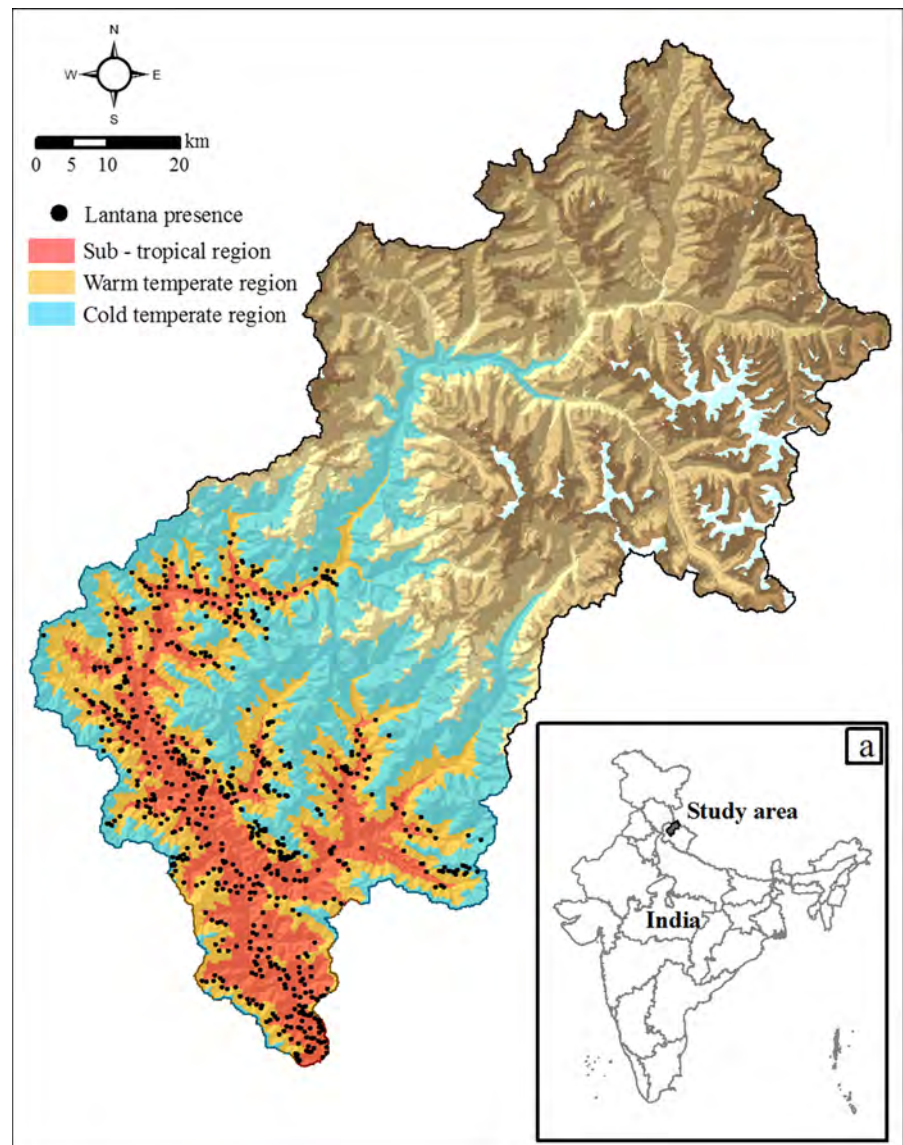
Study area

The study area lies in the catchment of Bhagirathi River in the Western Himalaya that extends from 30°07'N to 31°27'08"N and 78°08'29"E to 79°25'53"E covering 7644 km², in the state of Uttarakhand, India (Fig. 1). Winters in the area have become 1.5 °C warmer since 1982 and the summer precipitation has increased on average (Shrestha et al. 2012). The area is affected by climate change, which has retreated one of the biggest glacier (Gangotri) in the area (Kulkarni and Karyakarte 2014). These climatic changes are likely to influence the diverse array of vegetation types across various eco-climatic zones, viz., Tropical Moist Deciduous Forest (below 1500 m), Himalayan sub-tropical forests (elevation 1500–2000 m), Himalayan broadleaf forests (2000–2500 m), Himalayan conifer forest (2500–3000 m), Sub-alpine forest (3000–3600 m),

moist alpine meadows (3600–5000 m) and alpine arid pastures or Desert Steppe (above 5000 m) (Rawat 2017). Currently, these categories are further divisible into various sub-classes and seral types (Champion and Seth 1968). Generally the forests at the foot-hills and warm temperate belts are much more extensive and less patchy as compared to higher altitudes owing to climatic and topographic features (Singh and Rawat 2012; Singh et al. 2016). However, most of south facing gentle slopes and wider river valleys (< 2000 m) have been taken over for human habitation and agriculture. Most of the communities inhabiting such areas depend heavily on extracting forest resources for subsistence. As a result, areas around human habitations are heavily fragmented (Tiwari and Singh 1987).

The forests in the study area have been influenced by anthropogenic activities including livestock grazing, extraction of non-timber forest products and fuel wood since several centuries (Awasthi et al. 2003; Rana et al. 2010). The increased anthropogenic pressures can be correlated with increased abundance of invasive plants in the area (Singh et al. 2016). In addition, frequent burning of hill slopes to increase grass growth by the local communities have changed vegetation structure and composition in the area (Mehta 1996; Gurumni 2000). Often accidental fires escape to the surrounding forests area resulting in the loss of forest cover. In the past decade on average 90 fire occurrences per year were recorded in the region. The area has also seen significant growth in human population and as a result landuse patterns in the valley have been shifted from smaller agro-pastoral forest mosaics to commercial landuses and homogenous agriculture farms (Raman and Punia 2012). Rapid infrastructure development including construction and widening of roads have led to excessive soil erosion and loss of catchment capability in the region (Haigh et al. 1995). As a result, the area has witnessed increased frequency of landslides and flash floods (Sati et al. 2011; Sati and Gahalaut 2013; Kala 2014), which has further fragmented the forests. Thus, the native forests in the study area are fragmented due to anthropogenic modifications in the landscape, which will likely continue in the future and have consequences on the native and invasive plants in the area.

Fig. 1 Map depicting study area location in India (a) and Lantana presence in different climatic zones of the study area



Data collection

In order to explicitly model with behavior of Lantana across the very wide ecological environments in the study area we considered three ecological zones where it occurs: (1) Sub-tropical region (elevation < 1500 m) representing the lower warm valleys mainly dominated by *Shorea-Adina-Terminalia* deciduous broadleaf forest (Fig. 1, red color). (2) Warm temperate region (elevation 1500–2000 m) representing middle elevations that experience warmer summers as compared to the temperate area and cooler winters compared to sub-tropical area, mainly

dominated by *Pinus roxburghii-Olea-Bauhinia* forest (Fig. 1, orange color). (3) Cold temperate region (elevation 2000–2500 m) which is the coldest area in the Lantana range and dominated by *Cedrus deodara* and other conifer forest (Fig. 1, blue color and the northern area beyond it).

Each zone was divided into a 1×1 km grid. Using an existing forest cover map (India state of forest report 2010) each grid was classified as either forested or non-forested. In each forested cell, two 15 m radius plots were randomly located separated by at least 200 m in each of the 16 forest types present in the grid. On an average, a cell had maximum of two dominant

forest types and as a result between two to four plots were sampled in every cell of the grid. At each plot the presence of Lantana was visually assessed and recorded by a team of field biologists using a photographic field guide. Plots located in areas inaccessible due to difficult terrain were not sampled. During the sampling period of May–August 2016, 2221 plots were sampled in 802 grids, covering 22% (458 km²) of targeted forests in the study area.

Predictor data

Climate

Lantana is limited by cold temperature in the study area and thus, minimum temperature of coldest month (b6) and mean temperature of coldest quarter (b11) was presumed important. Previous research (Qin et al. 2016) demonstrated b6 to be significant predictor of Lantana in addition to annual precipitation (b12), precipitation of the warmest quarter (b18) and precipitation of the driest month (b14); while maximum temperature of the warmest month (b5) and mean diurnal range (b2) contributed insignificantly. In the present study area, b14 and b18 are substantially similar and of less ecological significance, as most of the vegetation responds to annual precipitation (Mani 1974; Rawat 2017); and hence b12 was included as a predictor. Moreover, ground sampling revealed that Lantana was predominantly present in lower valleys, where the annual temperature (b1) and b5 were higher, and hence b1 and b5 were included as predictors. These climatic predictors were downloaded from Worldclim (www.worldclim.org) that provides climate data derived from different global and regional weather stations information compiled for 1950–2000 period (Hijmans et al. 2005). It is downscaled by using geographic and elevation information at 1 km resolution. We further downscaled the Worldclim variables to 30 m spatial resolution using the PRISM approach (Daly et al. 1997) that utilizes elevation and location information. A 30 m digital elevation model (DEM), obtained from the Shuttle Radar Topography Mission (SRTM), was resampled to 1 km to provide the required elevation data at the same resolution as the climatic data. Comparing climate to elevation revealed more than 95% variation in climate explained by elevation alone. The regression coefficients and

intercepts were used to derive the climatic variables from 30 m DEM.

The same climate variables were obtained for 2050 conditions from the fifth Assessment Report of the International Panel of Climate Change (AR5, IPCC) (Stocker et al. 2013) for India. We used climatic scenarios for the four Representative Concentration Pathways (RCPs), which represent four greenhouse gas concentration scenarios based on the projection of human demographics and socio-economic conditions at end of this century (Moss et al. 2010). RCPs vary from the most optimistic scenario of reduced greenhouse gas emission after 2020 to the end of century, to the ‘business as usual’ scenario that assumes emission to increase with the present trend till 2100 (Van Vuuren et al. 2011). Every RCP results in climatic changes as shown in Table 1. The scenarios were developed under Community Climate System Model version 4 (CCSM4) released by the National Centre for Atmospheric Research (NCAR), which includes improvements in the treatment of clouds, aerosols, and land and sea surface temperatures (Gent et al. 2011). Downscaling of these climatic variables was also undertaken using 30 m DEM data and PRISM approaches.

Forest area

A forest type map showing the coverage of 16 forest types, derived from remotely sensed data and produced by the local state agency was available at 23.5 m scale and was resampled to a spatial resolution of 30 m for this study (India state of forest report 2010). The forest type map allowed individual forest patches to be mapped with a minimum mapping unit of 0.1 ha and patch area was subsequently used as predictor of Lantana distribution. In order to obtain future estimates of forest patch sizes across the study area we developed a climatic relationship between patch size, temperature and precipitation. Generally, every forest type has maximum patch size in the optimal climate, while at the trailing edge of the climatic range the stands get patchier and fragmented (Singh and Rawat 2012). Therefore, we modeled patch size at 30 m spatial resolution as a function of temperature and precipitation.

This relationship showed that across the study area, sub-tropical forest stands typically have larger patch sizes in humid-warm areas and more fragmented as

Table 1 Projected future scenarios by combining four global greenhouse gas emission scenes, which vary from the most optimistic reduced emission (RCP 2.5) to business as usual scene (RCP 8.5); with change in forest area and fire occurrences

Future scenario	RCP 2.5	RCP 4.5	RCP 6	RCP 8.5
Change in climate	Scenario 1 (1 °C rise in the temperature, active forest restoration and fire prevention)	Scenario 2 (1.4 °C rise in the temperature, active forest restoration and fire prevention)	Scenario 3 (1.3 °C rise in the temperature, active forest restoration and fire prevention)	Scenario 4 (2 °C rise in the temperature, active forest restoration and fire prevention)
Change in climate and forest area	Scenario 5 (1 °C rise in the temperature, forest area reduced by 426 km ² and fire prevention)	Scenario 6 (1.4 °C rise in the temperature, forest area reduced by 427 km ² and fire prevention)	Scenario 7 (1.3 °C rise in the temperature, forest area reduced by 866 km ² and fire prevention)	Scenario 8 (2 °C rise in the temperature, forest area reduced by 874 km ² and fire prevention)
Change in climate, forest area and fire	Scenario 9 (1 °C rise in the temperature, forest area reduced by 426 km ² and fire frequency reduced by half of present)	Scenario 10 (1.4 °C rise in the temperature, forest area reduced by 427 km ² and fire frequency similar to present)	Scenario 11 (1.3 °C rise in the temperature, forest area reduced by 866 km ² and fire frequency increased threefolds of the present)	Scenario 12 (2 °C rise in the temperature, forest area reduced by 874 km ² and fire frequency increased by fivefolds of the present)

climate gets colder. Temperate forest gets more fragmented as the climate gets dry-hotter or dry-cold (Rawat 2017). With future change in the climate regime, the distribution of forest patch distribution is likely to change. We used maximum temperature of hottest month, minimum temperature of coldest month and range of rainfall in a particular forest type to define its climatic range. Under climatic change, the range of each forest type will change; beyond which the native plants of that forest type will likely suffer heat stress or cold stress resulting in fragmentation and reduction of patch area (Allen et al. 2010; Kulakowski et al. 2011). Thus, we derived the climatic ranges of different forest type under each RCP and assigned the least forest area to the patches that fall out of the shifted climatic range. This adjusted forest areas for every RCP was used as scenario of future forest patch distribution for modeling future distribution of Lantana.

Landslides and flood affected areas

We derived disturbance due to landslides and flood areas from the 30 m SRTM data using slope length (LS factor) and the Topographic Wetness Index (TWI). LS factor is an index that considers steepness of a slope and its length of relative soil loss to derive the potential of soil erosion (Lee 2004). These

identified areas also represent the sites that mostly undergo different magnitudes of landslides (Poudyal et al. 2010). TWI quantifies the effect of topography on runoff generation and predicts the area subjected to overland flow i.e. floods (Beven and Kirkby 1979). Higher TWI values represent converging valleys or flat terrain that has high potential of water saturation (Schmidt and Persson 2003). We cross-validated the derived potential landslide and flood areas with landslide and flood occurrence data in the past five years based on observed disturbance events and observations. In total, 56 landslides and 33 flooded sites were recorded in the study area. We cross validated the derived indices by assessing the predictions for actual locations of an event, when $TWI > 15$ and $LS \text{ factor} > 5$ was considered as occurrence of an event. We assume that in 2050, excluding major topographic changes (such as earthquakes), landslide and flood areas will not change. Hence, the LS factor and TWI were kept constant for present and future projections.

Fire

We obtained information on fire occurrence from the Fire Information for Resource Management System (FIRMS) database, which consisted of daily MODIS

hotspots and Visible Infrared Imaging Radiometer Suite (VIIRS). The MODIS active fire product detects fires at 1 km resolution through middle—infrared and thermal infrared brightness temperature (Giglio et al. 2003). VIIRS detects fire at 375 m resolution using multispectral bands and complements MODIS for detecting fires of smaller extent (Schroeder et al. 2014). In total 1424 Fire occurrences that were larger than 375 m were recorded for the period of 2000–2016 in the study area. The majority (1173) of the fires were located around the lower valley i.e. in sub-tropical and warm temperate region, which had more human settlement compared to cold temperate. We used distance from the fire as a predictor of *Lantana*, as fire can burn nearby area or degrade it by spreading ashes and smoke that can support *Lantana* invasion (Hiremath and Sundaram 2005).

Climate change is likely to increase the natural fire frequency, which coupled with increased population will elevate the chances of fire. For projecting future fires, we used global fire projections (de Groot et al. 2013) and socio-economic assumptions of different RCPs. To do so, we calculated per year fire incidence (fire frequency) in different forest types since 2000–2016. Under RCP 2.6, we assumed the optimistic condition in socio-economic criteria, where the fire frequency is reduced by half due to preventative actions of concerned stakeholders and public awareness. Under RCP 4.5, we assumed that the fire frequency was stable. Under RCP 6.0, we used the global prediction of increase in the fire frequency by three folds, and under RCP 8.5 by fivefolds. The total number of deduced fire occurrences was simulated in every forest type and Euclidian distance from it was used for SDM.

Apart from the considered environmental covariates, *Lantana* is likely influenced by the edaphic parameters in the study area. Himalaya being predominantly metamorphic and sedimentary rock, has complex soil structure. Absence of soil data at desired scale or its future projections, restricted us to exclude soil parameters from the present study.

Species distribution modeling

We used the Maximum Entropy (MaxEnt) (Phillips et al. 2006) approach for modeling *Lantana* distribution under present and future scenarios. MaxEnt has been successful in accurately modeling the

distribution and forecasting similar invasive species (Pawar et al. 2007; Roger et al. 2015; Adhikari et al. 2015; Choudhury et al. 2016; Qin et al. 2016). The field dataset was divided in 80% of the data used for model development, and 20% used for testing.

Four model types in MaxEnt were tested (linear, quadratic, hinge, and threshold) with the model cross-validated using a 25% test sample drawn randomly from the presence locations. As the presence data was systematically surveyed throughout the region and the species was homogenously present, drawing random background points within the same climatic region was the most valid option (Phillips et al. 2009; Elith et al. 2010). In order to increase the number of absent cells we used 10,000 background points randomly drawn from within the region. 100 bootstrap resampling runs were performed and the mean logistic probability and AUC score (Area Under Curve) of the receiver operation characteristic (ROC) was reported for enhancing the modeling precision (Peterson et al. 2008). We used jackknifing for assessing the relative contribution of each variable on species presence. The regularization function was adjusted to 1, as the model it produced was visually most accurate (Elith et al. 2010). MaxEnt output for every scenario was converted into presence distribution based on the 10th percentile presence threshold (Radosavljevic and Anderson 2014). This model established the relation of *Lantana* to the environment and estimated its distribution in the study area.

Accuracy assessment of the model was undertaken using the 20% testing data not used in model development. For providing an overall assessment, we used the kappa statistics as it is a conservative measure of agreement when the classes to test are only two (Uebersax 1987).

Twelve future scenarios were developed based on a range of climatic, fire and forest patch scenarios discussed earlier. Under the four climatic scenarios we developed a set of scenarios based on fire and patch size distribution, stable fire yet decreased forest patch distribution set and an increasing fire and decreasing forest patch distribution (Table 1). The present species-environment relationship was used in each scenario as a comparison control. With these projections MaxEnt also estimated the effect of clamping (effect of covariate values beyond the range in the training data) on the output (Elith et al. 2010). We removed all the pixels where the clamping was more

than 0.8. This produced the projected area of Lantana for different future scenarios of the landscape.

All the analysis was done using R (ver 3.0.3), SAGA GIS and Arc GIS 10.2.

Result

From the field observations, Lantana was recorded in 1109/2221 plots, yielding naïve occupancy of 50%. Its invasion was recorded in six forest types: Moist Siwalik Sal forest, Northern dry mixed deciduous forest, Upper or Himalayan Chir Pine forest, Himalayan sub-tropical scrub, *Quercus leucotrichophora* forest and West Himalayan upper Oak/Fir forest. Hence, all scenarios were focused on these forest types. The highest elevation which had Lantana presence was 2112 m, whereas the minimum winter temperature of a plot with presence of Lantana was 5.6 °C. This plot was near the human settlement, where the forest was frequently burnt for fodder production. Lantana was not detected in plots ($n = 69$) geographically above this point. The LS factor and TWI could classify 96 and 92% of the landslide and flooded sites in the study area, indicating agreement to accurately index the landslide and flooded sites.

Forest patch size was found to be the most significant predictor of Lantana distribution through MaxEnt, where its invasion decreased with increase in patch size. Other covariates and their permutation importance to predict Lantana in the study area and their Jackknife test are depicted Table 2. In the sub-tropical area, Lantana was predicted to expand into colder and hotter areas (lower and higher mean winter

temperature), which are dry (low annual precipitation) and recently disturbed landslide sites away from fire. In warm temperate area, Lantana was predicted to expand into colder areas (low mean winter temperature), with less rainfall but near to the disturbed patches (fire, landslide and flood). In cold temperate area, the species preferentially was predicted to occur in hot (high mean winter temperature), humid (high annual precipitation) areas that are frequently burnt, but not disturbed by landslide or flood area (stable substrate). Differences in the predicted occurrence in relation to forest patch size, winter temperature and fire in three regions is depicted in Fig. 2. We selected these variables as they significantly differ in the response across its distribution, and provide insight into its ecology.

The potential area invaded by Lantana in the valley was 231 km²; out of which 217 km² was sub-tropical region, 11 km² was warm temperate region and 4 km² was cold temperate region (Fig. 3). The probability map of Lantana distribution is provided in Online Resource 1. The accuracy assessment under current conditions, using the 20% ($n = 222$) of the test data not used in model developed, resulted in kappa statistics of 0.86, 0.94 and 0.98 for sub-tropical, warm temperate and cold temperate area respectively. The area under the receiver operating curve (AUC) for the distribution models were 0.70 (± 0.09), 0.90 (± 0.05) and 0.94 (± 0.04) respectively. This suggests that MaxEnt has modeled Lantana invasion accurately for the study area (Elith et al. 2011).

The assumed fire occurrences in different forest types under future scenarios are given in Table 3. The projected distribution of Lantana against 12 future scenarios based on global and regional assumption

Table 2 Contribution of different environmental covariates to MaxEnt model of Lantana in sub-tropical, warm temperate and cold temperate regions of study area

Variable	Sub-tropics (% contribution)	Warm temperate (% contribution)	Cold temperate (% contribution)
Forest patch size	79.7	98.8	89.6
Mean winter temperature	14.1	0.2	2.5
Elevation	2	0	0.5
Distance from fire	3.2	0.5	0.1
Annual precipitation	0.2	0.2	5
Flood index	0	0	1.8
Landslide index	0.8	0.4	0.5

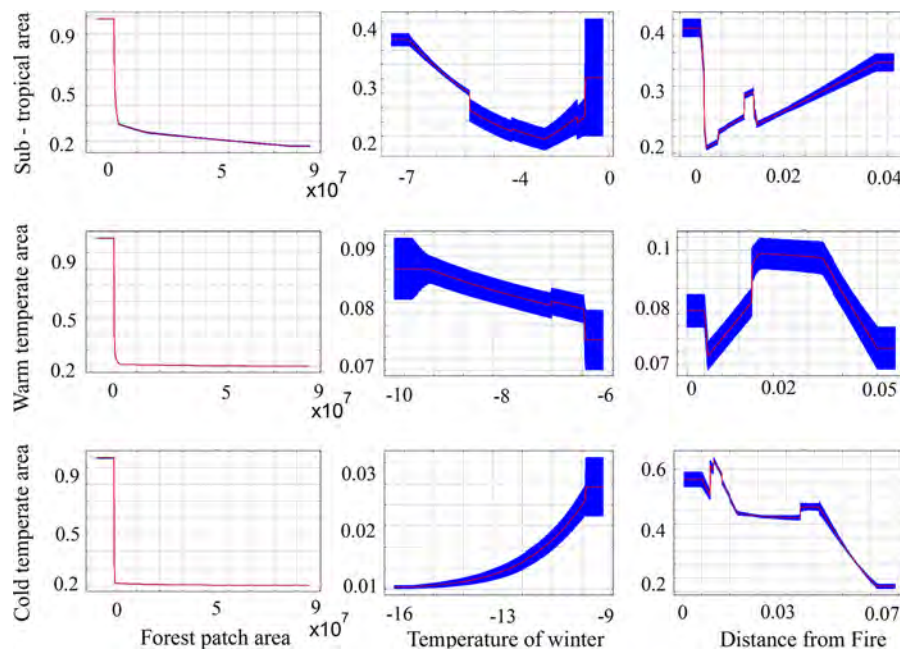


Fig. 2 Graphs depicting probability ($\pm$ SD) of Lantana occurrence as a response to forest patch size, temperature of winter and distance from fire in sub-tropical, warm temperate and cold temperate regions of the study area. In sub-tropical region, Lantana invaded moderately sized forest patches, decreased with higher winter temperature and was present around as well

as away from fire occurrence. In warm temperate region, Lantana invaded small forest patches, decreased moderately with increase in winter temperature and was present in proximity to fire occurrences. In cold temperate region, Lantana invaded smaller forest patches, increased with temperature of winters and fire occurrence

(Fig. 4) is shown in Table 4. The largest expansion in Lantana invasion range was up to 375 km² under scenario 4. The most conservative estimate given was 317 km², under scenario 3. Thus, the projected relationship to the future scenario revealed that Lantana will expand its distribution under a decrease in sustainability (increased emission) of the landscape. In addition, where the regional changes are actively managed by restoring forest area and preventing fire, the invasion range will expand due to global climatic changes. Forest patches vulnerable to Lantana invasion under each scenario are shown in Fig. 5.

Discussion

The results of this study provide managers with information on the present and future distribution of Lantana under changing regional disturbances and global climate change. Our study estimates that 94% of total Lantana distribution is recorded in the sub-tropical region of the valley, which provides an optimal climatic environment for this tropical shrub.

We found that the Lantana distribution decreased with increases in elevation and decreases in temperature, with the species distribution broadly limited by a mean winter temperature of less than 5.5 °C. Our results also indicate that native forest patch area was significantly negatively related to the Lantana distribution, with the influence of forest patch size more important at the edges of the species climatic range. Response of Lantana to these environmental parameters also affirms our apriori hypothesis of climatic extremities and anthropogenic disturbance explaining majority of Lantana invasion.

Despite the marked forest fragmentation in the sub-tropical portion of the study area, Lantana invaded larger forest patches away from disturbance events like fire and floods. This could be attributed to the favorable climatic conditions due to which resource utilization and competitive abilities (allelopathy, etc.) can be maximized. However, its distribution also increased with landslides in the area, which can be attributed to the construction of new roadways. In the warm temperate region, where the summer temperature is similar to the tropical region but winters are

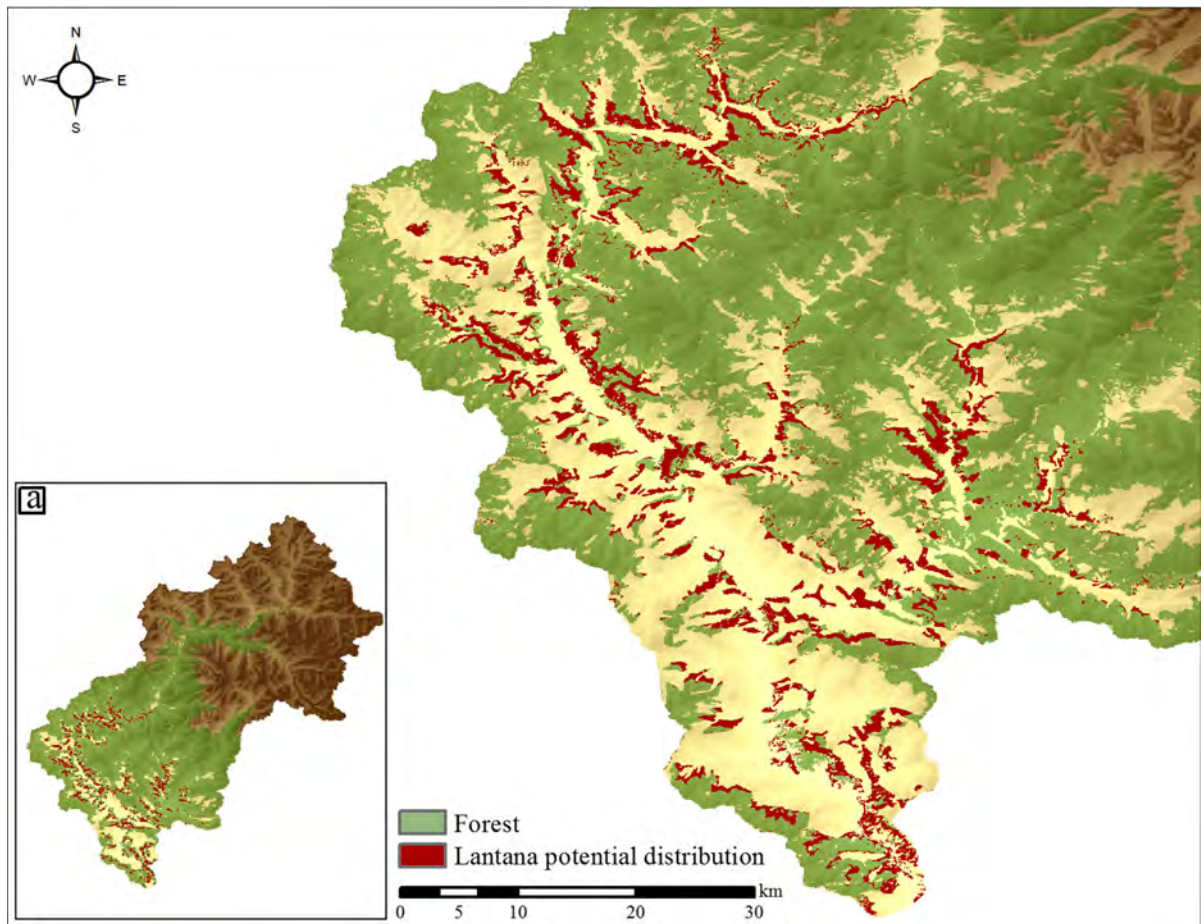


Fig. 3 Range of Lantana invasion in the study area (a) and its potential distribution in the forest

Table 3 Projected fire occurrence under the future scenario where the fire frequency is halved (RCP 2.5), unchanged (RCP 4.5), increased by threefolds (RCP 6.0) and increased by fivefolds (RCP 8.5) from the present fire frequency in different forest types

Forest type	RCP 2.5	RCP 4.5	RCP 6.0	RCP 8.5
<i>Quercus incana</i> forest	478	984	1350	2250
West Himalayan upper Oak/Fir forest	34	70	96	160
Moist Siwalik Sal forest	7	15	21	35
Himalayan Chir Pine forest	383	788	1080	1800
Himalayan sub-tropical scrub	30	61	84	140

colder, Lantana invaded small forest patches. In this region, the species occurred at a distance from fire disturbance yet closer to landslides and flood sites. However, in the cold temperate region, where Lantana distribution is chiefly constrained by the cold temperature, it occurred in warmer areas with higher rainfall

and stable substrate (away from landslides and floods). It invaded smaller forest patches that were burnt, which provides a niche opening with unutilized resources and minimum competition. Thus, climate, forest fragmentation and anthropogenic disturbances are significant predictors of Lantana presence that can

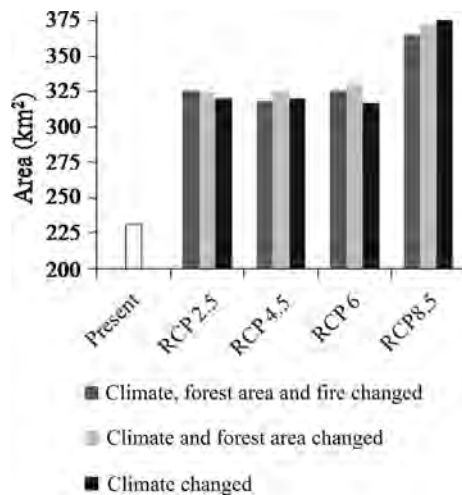


Fig. 4 Area invaded by Lantana under present and future environmental scenarios

substantially influence its future distribution and range expansion.

The future impacts of global climatic and regional anthropogenic changes were simulated in 12 different scenarios, which revealed differential increases in the distribution of the species throughout the valley. The projected greatest distribution area was solely due to changes in global climatic variables (scenario 4), despite regional efforts of forest restoration and fire prevention. However, a consistent increase in the area of Lantana distribution was projected by all the

scenarios (scenario 5, 6, 7 and 8) that considered climatic change coupled with regional forest area loss/fragmentation. The second consistent increase in species distribution was projected by all the scenarios (scenario 9, 10, 11 and 12) that considered climate and forest changes with addition of fire. The ‘worst-climate’ as projected under scenario 4 leaves no space for improvement or sustainability; and is globally prevented by making different emission regulation policies. The intermediate scenarios that are outcome of conservative climatic changes reduced the area of the distribution with increased forest restoration and fire prevention. The result of this study contradicts the global projection of Lantana distribution in the future (Taylor et al. 2012) and supports the increased invasion hypothesis (Qin et al. 2016).

Lantana’s future distribution is likely to be influenced by interaction of the considered covariates or additional factors not considered in this research. At the micro scale, the species is likely impacted by soil nutrient dynamics that are projected to change in the future (Clair and Lynch 2010) and community composition (Lavergne et al. 2010). Incorporating these processes into mechanistic models would be an improvement on the present correlative models, which only address effects of changes in environmental variables (Kearney and Porter 2009). These environmental future projections can have further issues due to assumptions of General Circulation Model (GCM)

Table 4 Projected Lantana invaded area under future environmental scenarios

Future scenario	Area invaded by Lantana (km ²)			
	RCP 2.5	RCP 4.5	RCP 6	RCP8.5
Change in climate	Scenario 1: 320	Scenario 2: 320	Scenario 3: 317	Scenario 4: 375
Change in climate and forest area	Scenario 5: 324	Scenario 6: 324	Scenario 7: 330	Scenario 8: 372
Change in climate, forest area and fire	Scenario 9: 326	Scenario 10: 318	Scenario 11: 325	Scenario 12: 365

Darkest color represents highest change

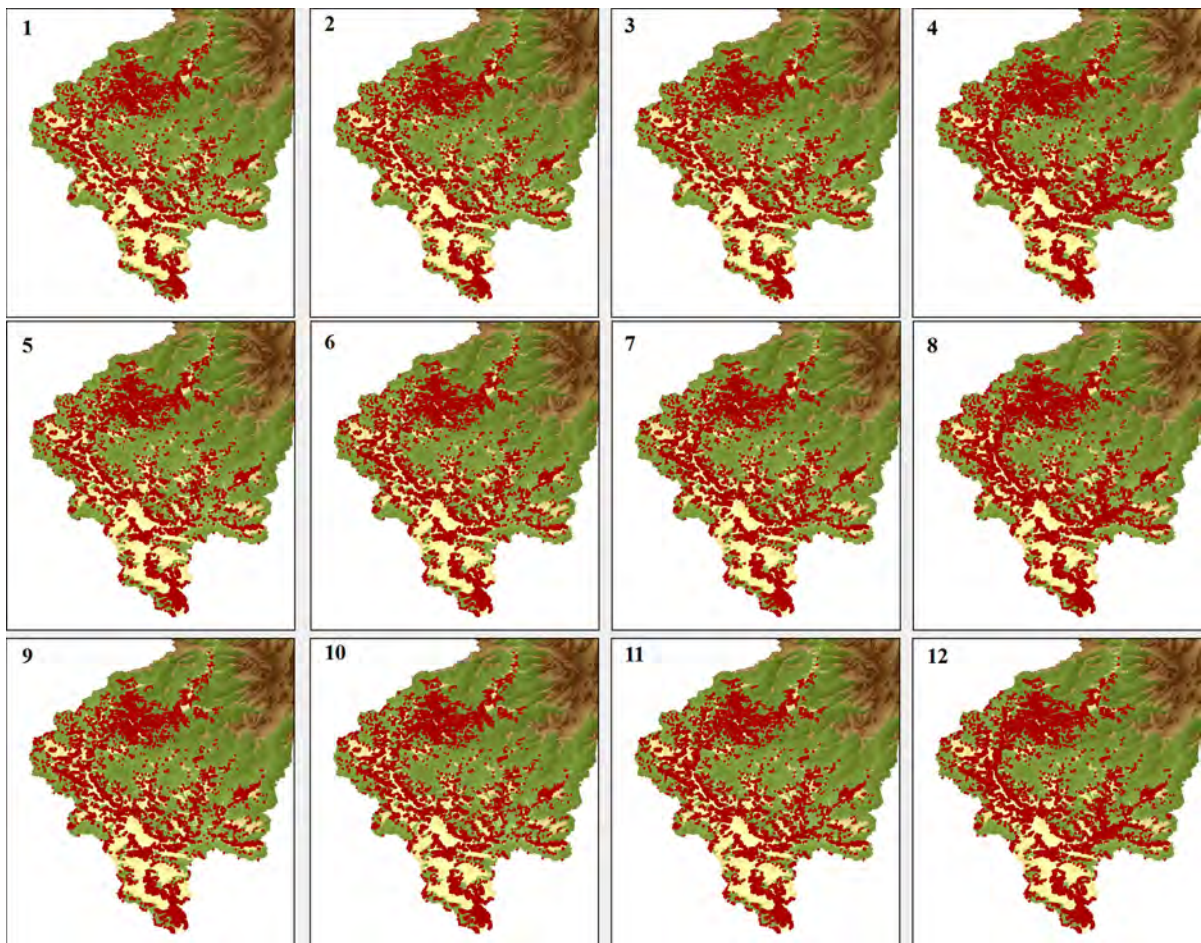


Fig. 5 Projected distribution of Lantana in the study area under different future environmental scenarios. Map number depicts the scenario number

used in the study, which is based on the global conditions that may differ from the study area conditions; and hence caution should be made while interpreting results based on such models.

This climate-disturbance induced invasion can form a positive feedback loop in which invasive species exert a competitive pressure on the native plants and degrade the forest patches which further helps invasion (Didham et al. 2005). Native tree species in the valley, which are affected by the climatic changes and human extractions (e.g. *Quercus leucotrichophora*, *Cedrus deodara*) can become further vulnerable to Lantana invasion (Tiwari and Singh 1987; Singh et al. 2016). This will impact the ecosystem services like soil moisture, fuel wood, carbon regularization and habitat for many species in the valley (Rana et al. 2010). Study results shows fire

to be the important factor in facilitating Lantana invasion in cold temperate areas. Thus, we suggest that minimizing fire frequencies in cold temperate can potentially control the future invasion of Lantana in these forests. The study can be used to identify the forest patches that are currently invaded by Lantana and require active managerial actions to eradicate the species. We also identify forest patches that are vulnerable to Lantana invasion in the future, these forest patches should be monitored for any colonization evidence of Lantana. Any seedling and sapling of Lantana in these patches should be removed to avoid the future expansion of species. It indicates the necessity of continuous monitoring of the landscape by combining remote sensing and ecological surveys.

The future projection also revealed that regional actions for mitigating the increased invasion may not

be adequate as the majority of the range expansion occurs as a response to change in global climatic scenarios. As recent global climatic changes are manifestation of human induced local disturbances, adopting a proactive control measures for such disturbances in place of reactive mitigation measures is globally needed to sustain the ecological integrity and allied services. Thus, more policy actions are needed at the global scale for reduction in the greenhouse gasses emission to avoid similar range expansion and collapse of native ecological communities worldwide.

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In search of Aliens: Factors influencing the distribution of *Chromolaena odorata* L. and *Mikania micrantha* Kunth in the Terai grasslands of Manas National Park, India

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ABSTRACT

Protected areas are essential for both conservation of biodiversity and provisioning of dynamic ecosystem services. In recent years, invasive plant species have had devastating impacts on the sustenance of natural habitat for the in-situ conservation of threatened species. In the present study, we investigated the distribution pattern of *Chromolaena odorata* and *Mikania micrantha* and factors governing their spread in the grassland of Manas National Park. We carried out extensive field sampling and modeled the distribution of invasives using a suite of algorithms. Model predictions differed with respect to AUC, sensitivity, specificity and TSS range, largely in classification performance. Final risk maps were produced averaging the model outputs of Random Forest and MaxEnt for both the species. Subsequently, we also emphasized that the niche/SDM modelling studies should instigate by testing a suite of algorithms for predictive ability under the specific conditions of the study since no single optimization approach would be best under all circumstances. Proximity to the road and human settlement, elevation, fire occurrence and precipitation of driest quarter were the key predictors for both the invasive. The potential area invaded by the *C. odorata* was 74.87 sq. km and *M. micrantha* 81.82 sq. km, and a high degree of overlap found between the distributions of both the species. Invasion risk maps can be used as an early detection tool for the management of invasive species, which could help in minimizing the ecological significance and economic cost of invasions. The findings of the present study will help the forest authorities to manage, take the necessary steps in the identified area to chalk out a comprehensive strategy for control of invasive.

1. Introduction

Biological invasions are impairing the changes in global biodiversity, leading to a decline as well as the extinction of native species (Mack et al., 2000; Pimentel et al., 2000). The Convention on Biological Diversity (CBD), stresses that the biological invasion of alien species is the second worst intimidation after habitat destruction. Thus, preventive measures subjecting to invasive species havoc, turns out to be a prime priority in biodiversity conservation (Hulme, 2009). Invasion process is accelerated by major drivers of global change such as deforestation, population explosion, changes in land use land cover, rapid economic development, urbanization, habitat fragmentation and climate warming (Hoffmeister et al., 2005; Ihlow et al., 2016). The biodiversity hotspot regions in India have the highest concentration of the country's forest cover and include most of the protected areas (Rodgers

and Panwar, 1988). However, increasing biotic pressure, encroachment and linear infrastructure creates a state of disequilibrium in the environmental conditions, which makes these areas vulnerable to invasion (Adhikari et al., 2015). Among the 100 worst invasive plant species of the world (Lowe et al., 2004), 11 species occur in India and most of these have invaded the protected areas (Hiremath and Sundaram, 2013). Invasive plant species in Indian protected areas have received reasonably diminutive attention until recently (Choudhury et al., 2016; Hiremath and Sundaram, 2013). Studies found that *Lantana camara* (Puyravaud et al., 1995; Mahajan and Azeez, 2001; Murali and Setty, 2001; Sahu and Singh, 2008; Babu et al., 2009; Shukla et al., 2009; Chandrasekaran and Swamy, 2010; Sundaram, 2011), *Chromolaena odorata* (Mahajan and Azeez, 2001; Chandrasekaran and Swamy, 2010; Lahkar et al., 2011), *Mimosa diplotricha* (Vattakkavan et al., 2002; Lahkar et al., 2011; Choudhury et al., 2016), *Mikania micrantha* (Lahkar

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et al., 2011; Choudhury et al., 2016) and *Prosopis juliflora* (Dayal, 2007; Waite et al., 2009) are the most noxious invasive species in the PAs of India (Hiremath and Sundaram, 2013). In addition, Adhikari et al. (2015) revealed that most of the ecosystems of the Western Ghats and northeast India were more prone to invasion compared to other parts of India.

The Manas National Park (MNP) represents one of the protected areas in the Indian Terai landscape. Uniquely crowned with five conservation statuses (Tiger Reserve, World Heritage Site, National Park, Biosphere Reserve and Elephant Reserve). This Indo-Bhutan trans-boundary protected area is home to around 37 threatened mammals and 28 threatened birds listed in the IUCN redlist (Ghosh et al., 2014). The grasslands in Manas are important for the conservation of threatened species like greater one-horned rhinoceros (*Rhinoceros unicornis*), tiger (*Panthera tigris*), swamp deer (*Rucervus duvaucelii*), hispid hare (*Caprolagus hispidus*), pygmy hog (*Porcula salvinus*), hog deer (*Axis porcinus*), Asiatic wild buffalo (*Bubalus arnee*), Asian elephant (*Elephas maximus*), and Bengal florican (*Houbaropsis bengalensis*). However, the spread of invasive species predominated by *Chromolaena odorata* and *Mikania micrantha* along with livestock grazing and uncontrolled burning is the major threat in Manas (Lahkar et al., 2011). This has led to the strong recommendation from the UNESCO World Heritage Convention in 2005, 2008, 2011, 2016 mission for development and implementation of invasive species management for the park (WHC, 2017). The situation is alarming, and if remains unaddressed can impose threats to both grasslands and grassland-dependent faunal species (Lahkar et al., 2011).

Chromolaena odorata L. and *Mikania micrantha* Kunth, both invasive, originate from the Asteraceae family. *C. odorata* is a perennial herbaceous shrub native to Mexico, the West Indies and tropical South America (Holm et al., 1997). In 1845, *C. odorata* was first introduced to the Calcutta Botanic Garden in India as an ornamental plant, and Jamaica was considered as the likely geographic source to India (see McFadyen, 1989, 1993; Muniappan et al., 2005). Whereas *M. micrantha* being a perennial herbaceous weed vine native to tropical Central and South America (Cock, 1982) was introduced during the World War II to camouflage airfields of the British allied army (Poudel et al., 2005).

Species distribution models (SDMs) are widely applied to explore possible biogeographic scenarios, predict invasive species distributions and range shifts under climate change (Dark, 2004; Adhikari et al., 2015). Preponderant SDM/ENM users are accustomed to use one or a few algorithms, most frequently MaxEnt (Qiao et al., 2015). Studies also focus on the “no silver bullet” theorem, which suggests “no single optimization approach will prove to be best under all circumstances” (Qiao et al., 2015). A number of statistical methods are available for constructing species distribution models, which is typically done by estimating the probability of the occurrence of a species at given geographic coordinates based on presence/absence (or presence only) and corresponding environmental data (Guisan and Zimmermann, 2000).

It is well established that the basic requirement for successful invasion is the climatic similarity between the invaded and projected regions (Panetta and Mitchell, 1991; Scott and Panetta, 1993). Besides, the requirement is confirmed with evidence that the establishment and spread of alien plants are restricted by an insufficient climate match (Pyšek et al., 2003). As a result, climate matching approach has been used by several workers for predicting species distribution (Thuiller et al., 2005; O'Donnell et al., 2012) and invasion risk of invasive alien species (Curnutt, 2000). However, at micro scale few other non-climatic factors such as geology, land-use changes, competition, disturbance regime and proximity to sites of introductions in particular areas, can also play crucial role in determining the distribution of invasive species (Adhikari et al., 2015). Moreover, increasing the frequency, intensity and spatial patterns or scale of disturbances will most likely lead to paced up replacement of native by exotic species (Yan et al., 2001).

The management of invasive species requires knowledge of areas vulnerable to invasion. Lahkar (2008) conducted a preliminary study of

the invasive species in the grasslands of the Bansbari Range of MNP. However, a systematic study of invasive species in the park has not yet been conducted (Lahkar et al., 2011) and the current information on the spread of invasive and factors associated were not known. Owing to the severity of the threat posed by *C. odorata* and *M. micrantha* forecasting their habitat suitability is therefore important for the management approaches. Thus, in the present study, we attempt to assess the distribution of *C. odorata* and *M. micrantha* in MNP with special emphasis on the use of testing a suite of algorithm and steps in model selection procedure. Besides, we tried to explore the co-occurrence and overlap pattern of both the invasive in the grassland of Manas National Park.

2. Study area

The Manas National Park (MNP) located (26°35'–26°50'N, 90°45'–91°15'E; Baksa and Chirang districts of Assam) at the junction of Indo-Gangetic, Indo-Malayan and Indo-Bhutan realms is a strategic conservation area in the Jigme Dorji-Manas-Bumdeling conservation landscape in the eastern Himalayan eco-region (Wikramanayake et al., 2001). MNP occupies an area of 500 sq. km, which forms the core area of the Tiger Reserve (2837 sq. km) (Fig. 1). The park extends on both sides of the Manas River and is restricted to the north by the international border of Bhutan, to the south by densely populated villages and to the east and west by reserve forests. It is placed in the eastern duar and has extensive Bhabar and Terai grassland areas that are typical of Himalayan foothills. Altitude ranges from 50 m MSL on the southern boundary to 250 m MSL along the Bhutan hills. The Humidity levels are high and can reach up to 76%. The mean annual rainfall is 3330 mm. November to February is relatively dry when the smaller rivers dry up, and there is an acute water shortage in the Bhabhar areas. The mean temperature ranges from 5 °C to 37 °C. Floristic composition of the park based on studies carried out by Sarma et al. (2008) are as follows—woodland: comprises of tree species mostly belonging to the semi-evergreen forest and moist mixed deciduous forest. The area under the semi-evergreen category is 233.31 sq. km and it is distributed mostly in the northern part and the extreme south-west of the Park. Savannah grasslands: dominated by tall grasses such as *Narenga porphyrocoma*, *Imperata cylindrica*, *Phragmites karka*, *Arundo donax*, *Saccharum spontaneum*, *Themeda arundinacea*, *Saccharum procerum* and *Vetiveria zizanioides*, those are interspersed with trees such as *B. ceiba* and *Dillenia indica*. The total area under this category is 161.98 sq. km. alluvial grassland: 44.49 sq. km scattered over the Park and characterized by pure patches of grasslands and presence of water during the rainy season.

3. Methodology

3.1. Data collection

The study was carried out during 2013–2015 in the grasslands of MNP. A systematic grid-based (1 × 1 km) approach was followed to survey the presence of *C. odorata* and *M. micrantha*. We carried out extensive field sampling with the help of a five-member team. The surveys were done mostly on feet, seldom by elephant rides in the areas dominated by tall and thick grass patches. Subsequently, to quantify the spread of the invasive, ocular estimation was done on the basis of cover in terms of radius: 1–3 m, 3–5 m, 5–10 m, 10–20 m, 20–50 m and > 50 m. However, large patches of invasives were mapped (as polygon) on the ground using GPS map 62s. Altogether we have collected 1149 *C. odorata* and 1054 *M. micrantha* presence locations (see Fig. 1). We binned the presence locations of each species into 250 × 250 m grid cell by removing multiple presence points retaining only one presence location per grid.

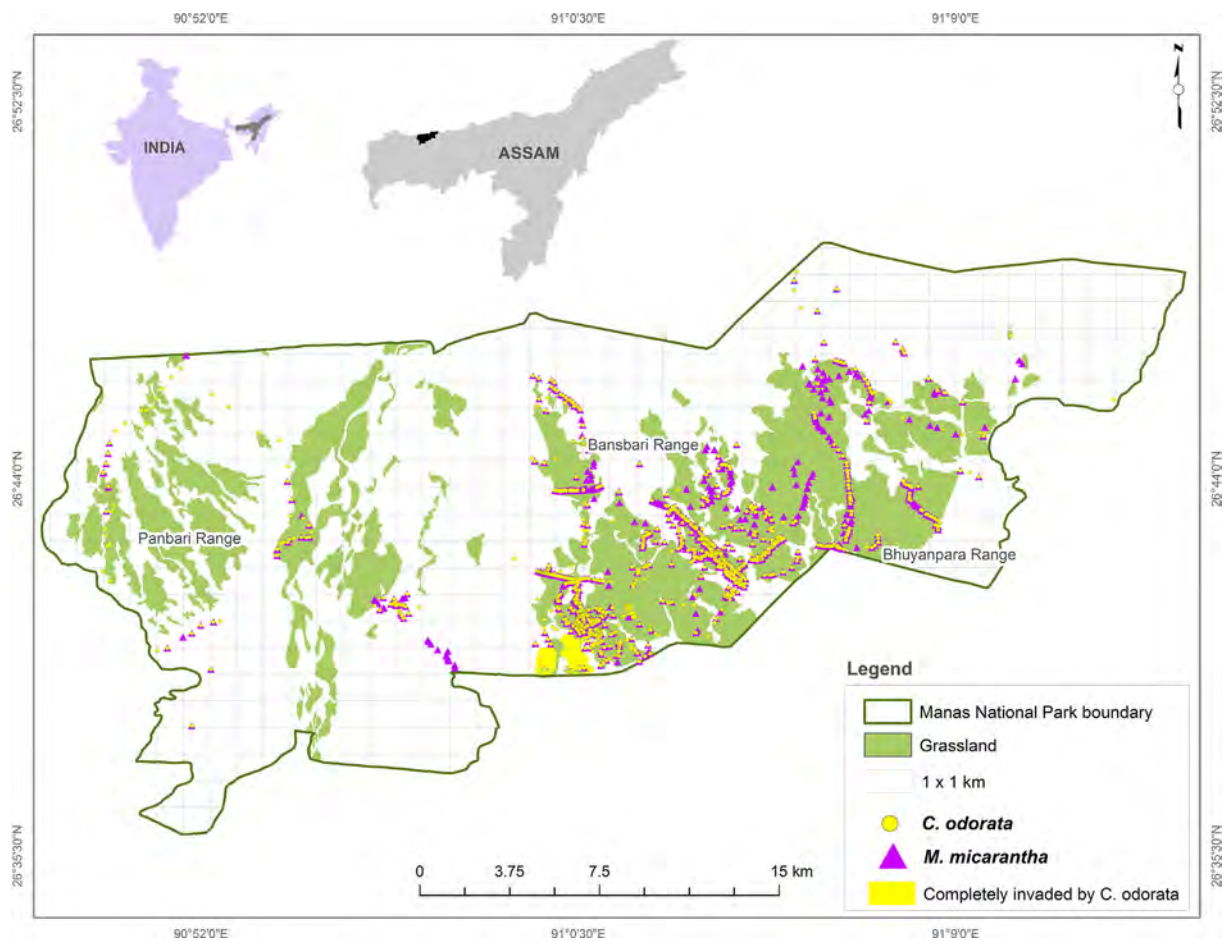


Fig. 1. Locality records of *Chromolaena odorata* and *Mikania micrantha* in Manas National Park, Assam.

3.2. Environmental & eco-geographical data

We used 19 bioclimatic variables obtained from WorldClim (Hijmans et al., 2005), eco-geographical variables such as: Distance to water sources (DisWator: Euclidean distance from river, streams and wetlands), Distance to human settlements (DisHuSet: Euclidean distance from human settlement and Agricultural land), Distance to road (DisRoad: Euclidean distance from road), Elevation (DEM: Digital elevation data from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Fire density using historical data on the incidences of fires in MNP during 2000 to –2015 (FSI, 2016). We performed correlation test among the variables and discarded one of the variables from the correlated pair with VIF > 3 (Variation Inflation Factor) (Zuur et al., 2010). Finally, the variables included in the niche models were: BIO7 = Temperature Annual Range, BIO9 = Mean Temperature of Driest Quarter, BIO12 = Annual Precipitation, BIO14 = Precipitation of Driest Month, BIO15 = Precipitation Seasonality, BIO17 = Precipitation of Driest Quarter, Elevation, DisWator, DisHuSet, DisRoad and Fire (Fig. 2).

3.3. Modeling technique

Initially, we explored the factors governing the distribution of invasive species using General Niche-Environment System Factor Analysis (GNESFA), which provided a flexible framework to tackle habitat use exploration (Calenge and Basille, 2008). GNESFA makes available the graphical displays of the niche within its environment which lead to a consistent knowledge of the system (Calenge and Basille, 2008). The basic principle of GNESFA consists of the choice of one of two distributions, the utilization units (in this case, the pixels with the presence

of *C. odoratum* & *M. micrantha*) as the ‘Focus Distribution’ and the environmental units (the set of pixels on which each environmental variable was measured) as the ‘Reference Distribution’. More specifically, GNESFA has properties that depend on the distribution chosen as a reference and uses two key concepts to describe the niche of the species: marginality and specialization (see Caruso et al., 2015). We used GNESFA’s variants FANTER (Factor Analysis of the Niche Taking the Environment as Reference), MADIFA (Mahalanobis Distance Factor Analysis) and ENFA (Ecological Niche Factor Analysis) as an exploratory tool for the comparative approach to understand the factors encouraging distribution of the studied invasive.

Finally, we used a suite of algorithms to model the distribution of invasive. BIOCLIM: calculates the similarity of environmental variables of a location comparing the values at any location to a percentile distribution (Booth et al., 2014). DOMAIN: algorithm computes the Gower distance between environmental variables at any location and those at any of the known locations of occurrence (Carpenter et al., 1993); Generalized Linear Model (GLM): algorithm uses maximum likelihood by allowing the linear model to be associated with the response variable via a link function and by allowing the degree of the variance of each measurement to be a function of its predictive value (see Guisan et al., 2002; McCullagh and Nelder, 1989). Random Forest (RF): an extension of classification and regression trees (Breiman et al., 1984; Breiman, 2001); MaxEnt: model expresses the probability of distribution of species by applying machine learning technique called maximum entropy modeling. Here, we used default settings for parameters such as prevalence, regularization multiplier, and density of background sampling, but created multiple replicate models and explored the implications of different combinations of environmental variables (see Jathar et al., 2015).

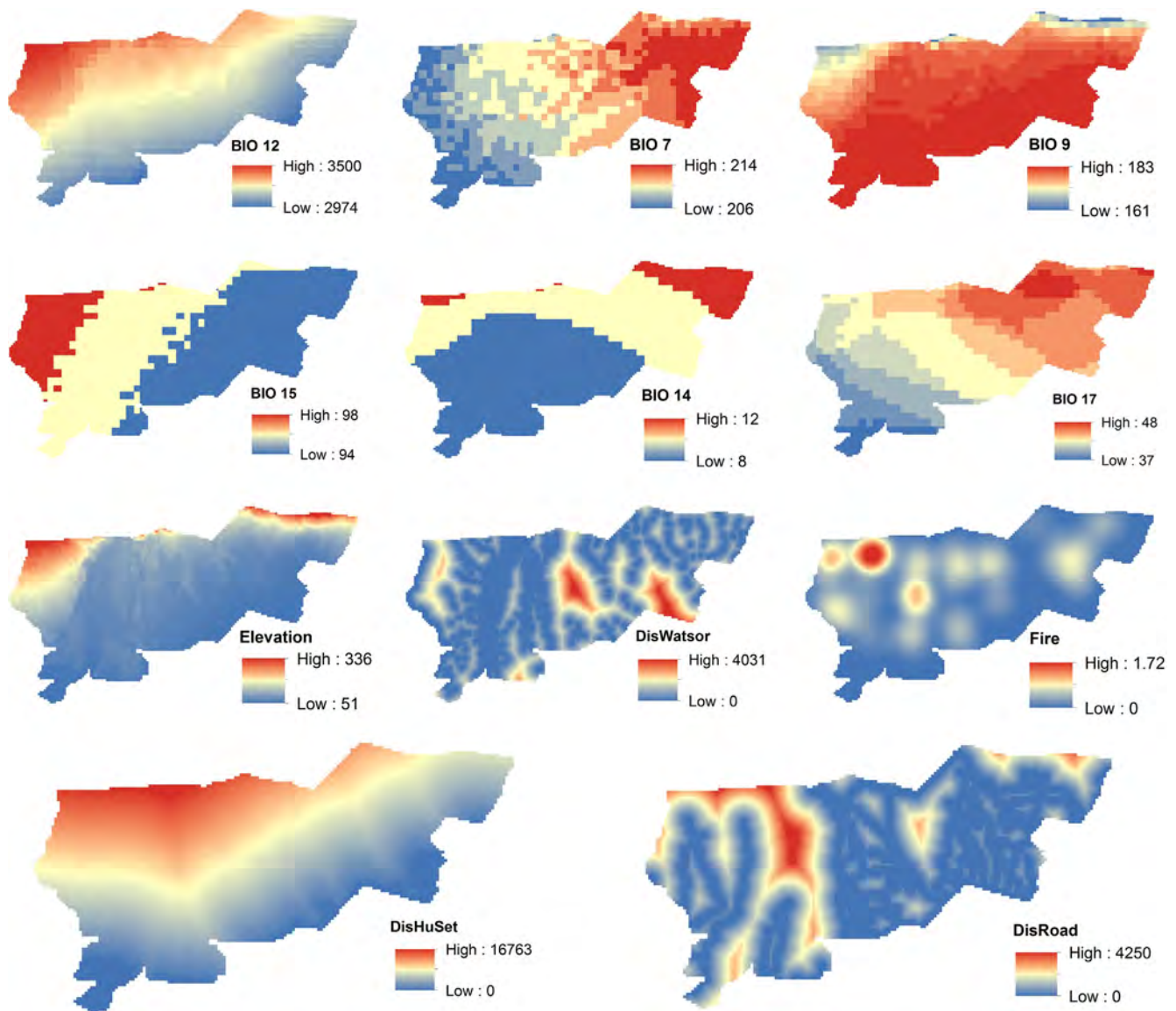


Fig. 2. Environmental and eco-geographical variables used to model the distribution of invasive in Manas National Park.

3.4. Model validation

We used occurrence data, and divided them at random into two sets for model calibration (70%) and evaluation (30%). We developed models based on each of the two random subsets of the occurrence points and tested each against the other random subset. To evaluate correspondence between model outputs and known true configurations, we calculated sensitivity, specificity and true skill statistics (TSS = 1 – sensitivity + specificity) (Fielding and Bell, 1997). TSS has significant compensations over kappa, which is not prevalence dependent (Allouche et al., 2006), both indices combination of contrasting performance of sensitivity and specificity.

We calculated overlap between the predicted habitats of *M. micrantha* and *C. odorata* using Schoener's *D* using the following formula in ENMTools (Warren et al., 2010). Measures of overlap was calculated comparing two normalized predicted distribution models output by MaxEnt using estimated values of habitat suitability for each grid (Warren et al., 2008).

$$D(p_x, p_y) = 1 - \frac{1}{2} \sum_{n=i} |p_{x,i} - p_{y,i}|$$

where $p_{x,i}$ and $p_{y,i}$ represent the probability assigned by distribution model to grid cell i for species x and y , respectively. The value of D ranges between 0, when two species have no overlap in the environmental space, and 1 when two species share the same environmental space (Warren et al., 2008).

4. Results

Both *C. odorata* and *M. micrantha* were found to invade in Bansbari, Bhuyanpara and Panbari ranges of MNP. However, *C. odorata* was found to occupy larger areas in the southern boundary of the park. Subsequently, almost 15% of the recorded locations had more than ~50 m radius coverage for both the species (Fig. 3). Additionally, 205.10 ha area of grassland has been completely invaded by *C. odorata* in the southern boundary of the Bansbari range.

The distributions of available/used RUs (resource units) for *C. odorata* and *M. micrantha* showed a high frequency of use of RUs (Fig. 4). Based on the eigenvalues obtained from the GNESFA “Focus = utilization” algorithm, we selected the first and the last component for both species in FANTER. The FANTER, results showed that the used RUs were distributed in a particular range of the first

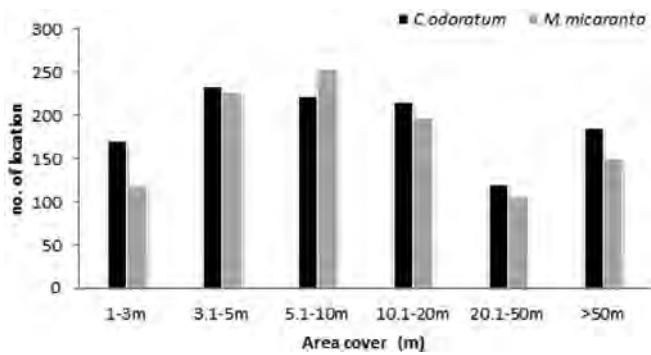


Fig. 3. Number of locations of *C. odorata* and *M. micrantha* recorded in Manas NP with respect to area covered.

factorial axis (Fig. 5). In contrast, we selected first two components (*C. odorata*: eigenvalue₁ = 8.46, eigenvalue₂ = 6.52; *M. micrantha*: eigenvalue₁ = 7.67, eigenvalue₂ = 5.47) for both the invasive in MADIFA and confirmed that this analysis found an interesting direction in the ecological space (Fig. 6). Furthermore, ENFA results (*C. odorata*: eigenvalue₁ = 6.52, eigenvalue₂ = 3.24; *M. micrantha*: eigenvalue₁ = 7.15, eigenvalue₂ = 4.15) indicated that *C. odorata* and *M. micrantha* were found to colonize nearby roadsides and human settlements. However, *M. micrantha* preferred areas with low elevation (swampy grasslands) compared to *C. odorata* (Fig. 7). The randomization test for the ENFA indicated significant specialization on at least one component (Monte-Carlo test, *C. odorata*: $p < 0.001$; *M. micrantha*: $p < 0.001$) for both the invasive.

4.1. Invasive risk mapping

Model predictions for both the invasive differed with respect to AUC, sensitivity, specificity and TSS range largely in classification performance space, indicating significant model-to-model difference in quality (Table 1). MaxEnt results showed that among the environmental & eco-geographical variables distance to road, elevation, distance to human settlement, fire occurrence, and precipitation of driest quarter

were the key predictors for both the invasive (Fig. 11). Occurrence of both the invasive was vastly influenced by the proximity to the roads. Annual temperature range was found to contribute more in predicting *C. odorata* compared to *M. micrantha*. On the contrary, areas with low elevation were found to be more vulnerable to *M. micrantha* invasion. For both the species, the algorithm that had large value of AUC and TSS were therefore used to draw the final distribution maps and to classify suitable areas of spread for the species. Final risk maps were created averaging the scores of RF and MaxENT for both the species (Figs. 8, 9 and 10) separately. We scaled the values of each model between 0 and 1 and then calculated the average score. Subsequently, we classified the output into low (0.25–0.5), moderate (0.5–0.75) and high (> 0.75) occurrence probability zones. The potential area invaded by the *C. odorata* was 74.87 (low: 60.93; moderate: 10.25; high: 3.68) sq. km and *M. micrantha* 81.82 (low: 70.31; moderate: 8.75; high: 2.75) sq. km. Schoener's *D* index value of 0.74 indicates a high level of overlap between the niches of *C. odorata* and *M. micrantha*.

5. Discussion

The results of this study provide the managers with valuable information on the present invasion of *C. odorata* and *M. micrantha* in the grassland of MNP. FANTER, ENFA and MADIFA results provided the graphical explanatory relationship among ecological variables and invasive. According to Calenge and Basille (2008), habitat selection is based on the measure of specialization on a particular direction of the ecological space. Therefore, in this study the strong specialization of few variables (e.g., distance to road and human settlements, annual precipitation, elevation) in determining the habitat selection implies that the variance of available RUs is large in comparison with the variance of used RUs. The overall results were comparable to those of former comparative modelling studies (e.g., Elith et al., 2006; Qiao et al., 2015). We generated the final risk maps using the algorithm which were most powerful (i.e., MaxEnt & Random Forest) in relations to predictive power, and at the same time which is also ecologically meaningful for the study area (pers. obs.). Use of a single statistic, such as TSS, can mask significant differences in performance between algorithms. RF algorithm for both the invasives showed greater specificity

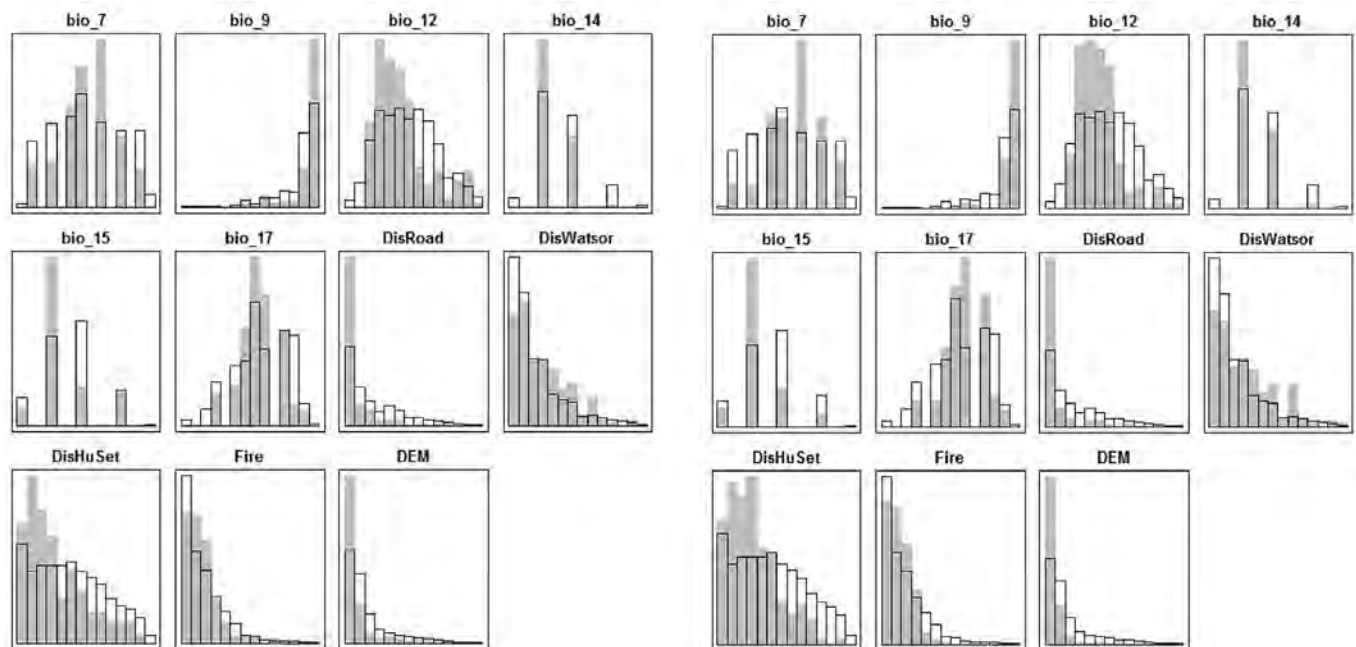


Fig. 4. RUs (Resource units) histograms for *C. odorata* (left) & *M. micrantha* (right), the white columns show the distributions of available RUs in MNP, whereas grey columns show the distributions of used RUs.

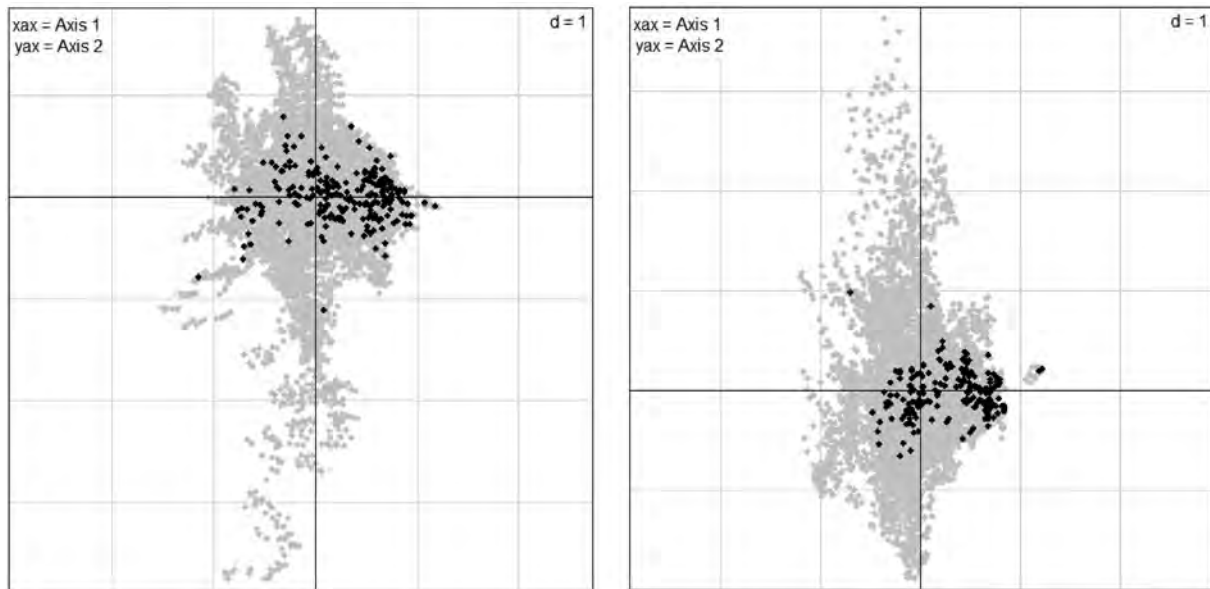


Fig. 5. Taking the Environment as the Reference (FANTER) for *C. odorata* (left) and *M. micrantha* (right), grey points show the distribution of the RUs (here the pixels) on the axes found by the analysis and black points correspond to the RUs used by the species.

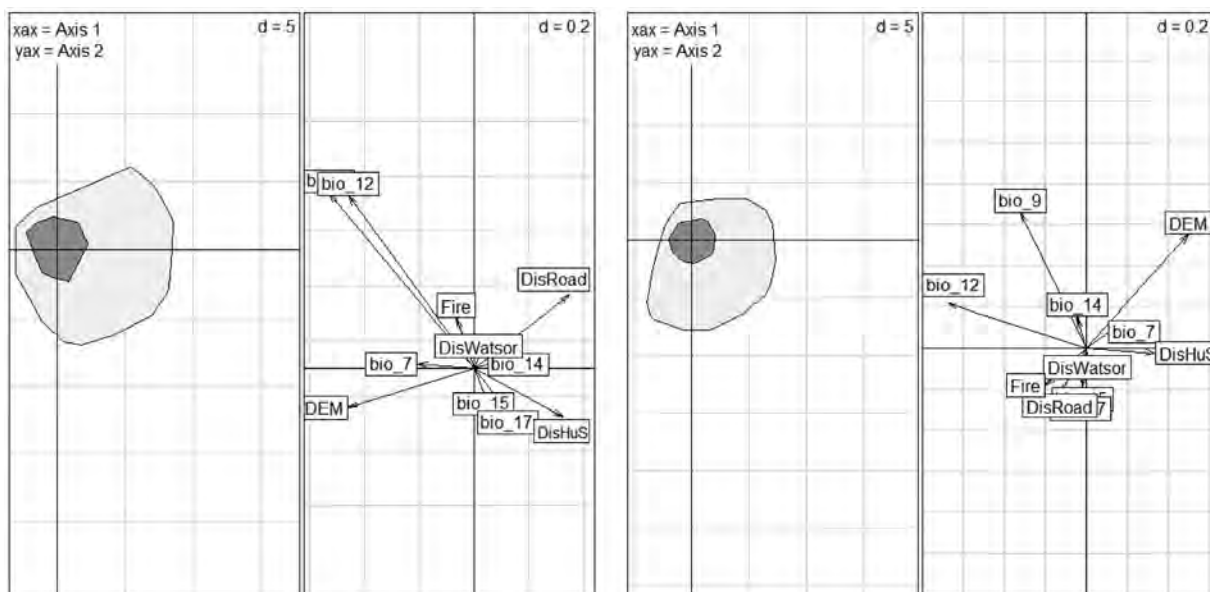


Fig. 6. Biplot of the Mahalanobis distance factor analysis (MADIFA) for *C. odorata* (left) and *M. micrantha* (right) in Manas National Park. The horizontal axis represents the first component taken, the vertical axis the second component taken.

and low sensitivity in comparison to MaxEnt results. However, AUC values calculated in MaxEnt were higher compared to RF. In contrast, RF algorithm well predicted the present distribution, whereas MaxEnt predicted the potential geographical distribution of both the invasives, should be considered as risk maps.

In recent years, most of the protected areas have converted into isolated islands due to ever-increasing anthropogenic pressure and the steady depletion of forest cover (Foxcroft et al., 2007). There are several pathways (e. g. human-dominated boundaries, connecting roads and rivers) for an invasive plant to pass in a protected ecosystem (Cowie and Werner, 1993; Alston and Richardson, 2006; Foxcroft et al., 2007; Adhikari et al., 2015). Both abiotic and biotic factors together with dispersal mechanism (e.g., road network) strongly influence spatial pattern of invasive. In MNP, roadside provide an open habitats that are disturbed by maintenance activities (e.g., vegetation mowing) and, highly connected nature of road networks facilitates the spread of

invasive. It is gradually recognized from several other studies that roads function as key habitats as well as a corridor for invasive plant species (Neubert and Parker, 2004; Roura-Pascual et al., 2009). Few studies also hypothesized that seeds from invasive were carried over short or long distances by vehicles visiting the park (Gabbard and Fowler, 2007; Lonsdale and Lane, 1994; von der Lippe and Kowarik, 2007).

Barik and Adhikari (2012) reported that temperature and precipitation, along with the physiographic variables were the key predictors in determining the potential distribution of *C. odorata* within India. However, our study revealed that at the micro-scale, both abiotic condition and localized factors were found to govern the distribution of the species. The intensity of light had a profound effect on the emergence, growth and reproduction in *C. odorata* (Ambika, 2007). This is in concordance with a previous study by Ambika and Jayachandra (1980), who observed that the seeds of this species require light for germination. Maximum germination of seeds occurred at 150 lx. However, light

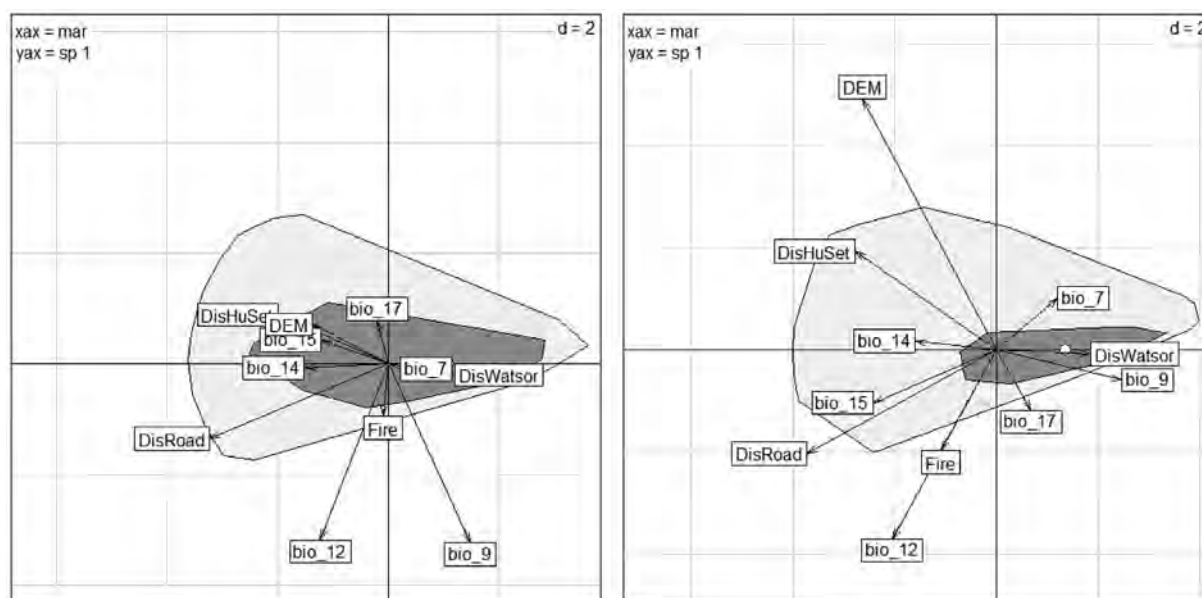


Fig. 7. Biplot of the ecological niche factor (ENFA) analysis for *C. odorata* (left) and *M. micrantha* (right). The horizontal axis represents the marginality component, the vertical axis the first specialization component.

Table 1
Classification performance measures of different SDM algorithms.

Species	Model	AUC	Sensitivity	Specificity	TSS
<i>Chromolaena odorata</i>	Bioclim	0.725	0.529	0.811	0.340
	Domain	0.735	0.720	0.644	0.364
	Mahal	0.811	0.735	0.787	0.523
	GLM	0.751	0.823	0.580	0.403
	RF	0.836	0.882	0.695	0.578
	MaxEnt	0.879	0.808	0.669	0.478
<i>Mikania micrantha</i>	Bioclim	0.729	0.758	0.600	0.358
	Domain	0.759	0.825	0.588	0.416
	Mahal	0.831	0.724	0.833	0.558
	GLM	0.795	0.741	0.769	0.510
	RF	0.839	0.827	0.791	0.620
	MaxEnt	0.887	0.724	0.788	0.512

Algorithm used for the final distribution map shown in bold.

intensities ranging from 50 to 4500 lx supported good germination. Because of the high light requirements of *C. odorata*, forest degradation generally allows this to colonize in the dense scrambling thicket which grows through over existing grassland patches (Bansbari and Bhuyanpara range) and along the roadsides of MNP. Few other studies also support the similar pattern of invasion by *C. odorata* suppressing other vegetation forming thick cover within the short period (Awanyo et al., 2011). In MNP, *C. odorata* has hardly invaded in the forest patches with dense canopy and thick tall grass cover, where light intensity is low (pers. Obs). Ambika (2007) also reported that filtered low-intensity light in dense canopy forest, less in red and blue light and rich in far-red, could not support maturation of *C. odorata* beyond the seedling stage, and they remain as non-reproductive populations. Soil nutrients play a key role in influencing the distribution of many invasive plant species (Dassonville et al., 2008; Mandal and Joshi, 2014). *C. odorata* is able to germinate over a wide pH range and is adapted to a wide range of soil conditions (Mandal and Joshi, 2014). Germination under a range of soil conditions aids the ability of *C. odorata* to invade diverse habitats (Anyasi, 2012). The absence of soil nutrients data was one of the limitations of the present study. *C. odorata* was found to occur in relatively moderate to high elevation areas within the study area in contrast to *M. micrantha*. An experiment conducted by Senarathne and Sangakkara (2007) proved that the emergence of *C. odorata* seedlings decreased

with increased duration of submergence under water. Their also noticed that the highest percentage of seed emerged from a depth of 1 cm when not exposed to flooded conditions. Their findings which suggest a reduced germination rate of *Chromolaena* seeds under maintained flooding, might be the reason for absence of the species from the swampy areas of MNP. On the other hand, the areas predicted suitable for *M. micrantha* were low elevation zones including roadsides and the southern boundary of the park. Rameshprabu and Swamy (2015) also reported highest distribution frequencies of *M. micrantha* in low altitudes and climatic zones of tropical wet areas. Similar with Chitwan National Park in Nepal, the lowland riverine forest was found to be the most affected by *M. micrantha* compared to Sal forest (Baidar et al., 2017). Therefore, at microscale the soil moisture content could be one of the predictors in the distribution of the species. Besides, precipitation, annual temperature range also had a bearing on the distribution of this species similar to the findings of Zhang et al. (2011). Zhang et al. (2009) also found that both the species prefer high light conditions, which may be one of the reasons for the high degree of overlap mostly in the roadsides of the study area. However, they do differ in their soil water preferences. *M. micrantha* was predominantly efficient at full soil water regimes and *C. odorata* at moderate soil water conditions. Hence, in our study area, FANTER and ENFA results showed that the niche is slightly narrow for *M. micrantha* compared to *C. odorata*, as soil moisture content was one of the specialized requirement for *M. micrantha*. Invasive plant species often out-compete native plant due to higher resource capture and utilization efficiency and stronger allelopathic effects (Callaway et al., 2005). It is well established that the abundance of *Mikania* and *Chromolaena* reduces the availability of native species particularly young plants (Sapkota, 2007 and pers. obs.). In comparison to conspecifics originated from the native range, *C. odorata* plants from the nonnative range are stronger competitors at high nutrient concentrations in the nonnative range (Qin et al., 2013). Therefore it would be interesting to understand how *Chromolaena* and *Mikania* compete with each other in the MNP where they occur in close association. As a part of management intervention, park authority burns the grassland during the dry season (Feb-March) to restrict the succession. However, in the *Chromolaena* dominated patches burning of grasses is often found to be constrained. As a result, few patches of grassland habitats near Puhu field and Rhino Camp have been altered with complete dominance of the invasive plant. Fire density has had a

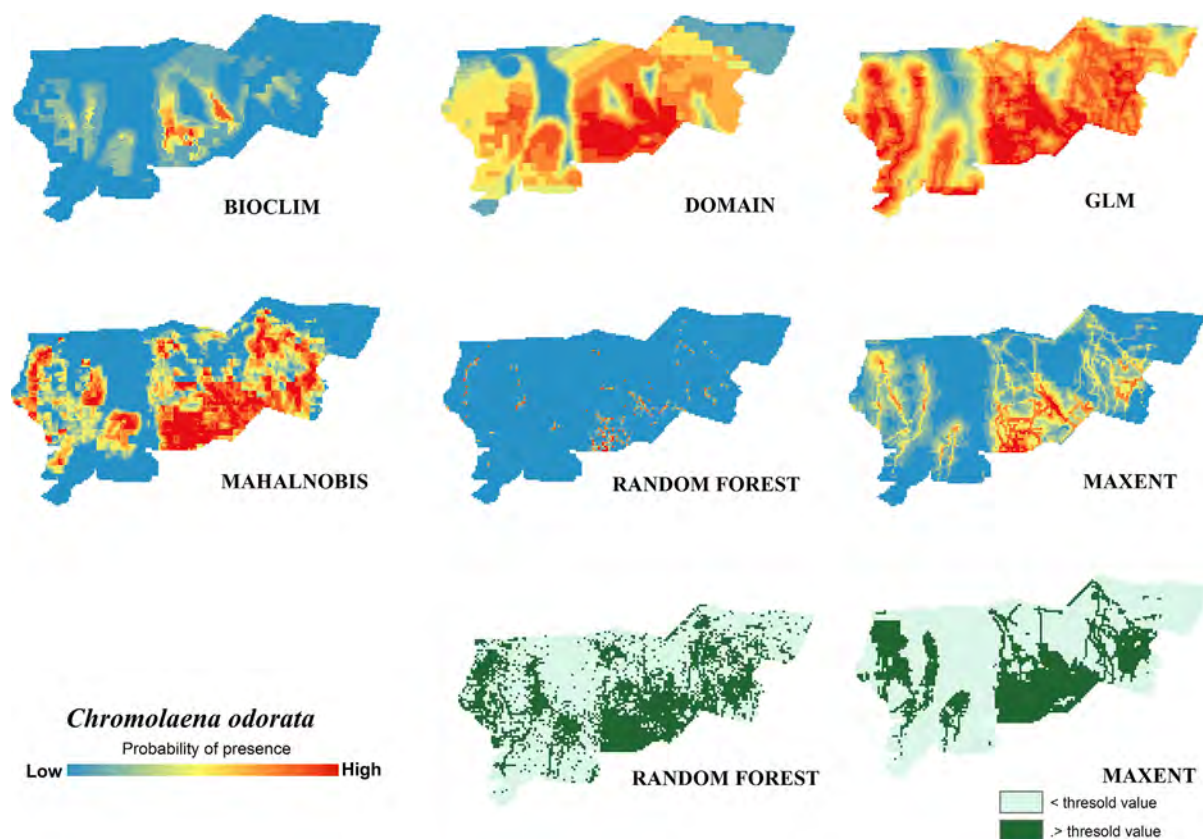


Fig. 8. Distribution maps of *C. odorata* in Manas National Park using different algorithms.

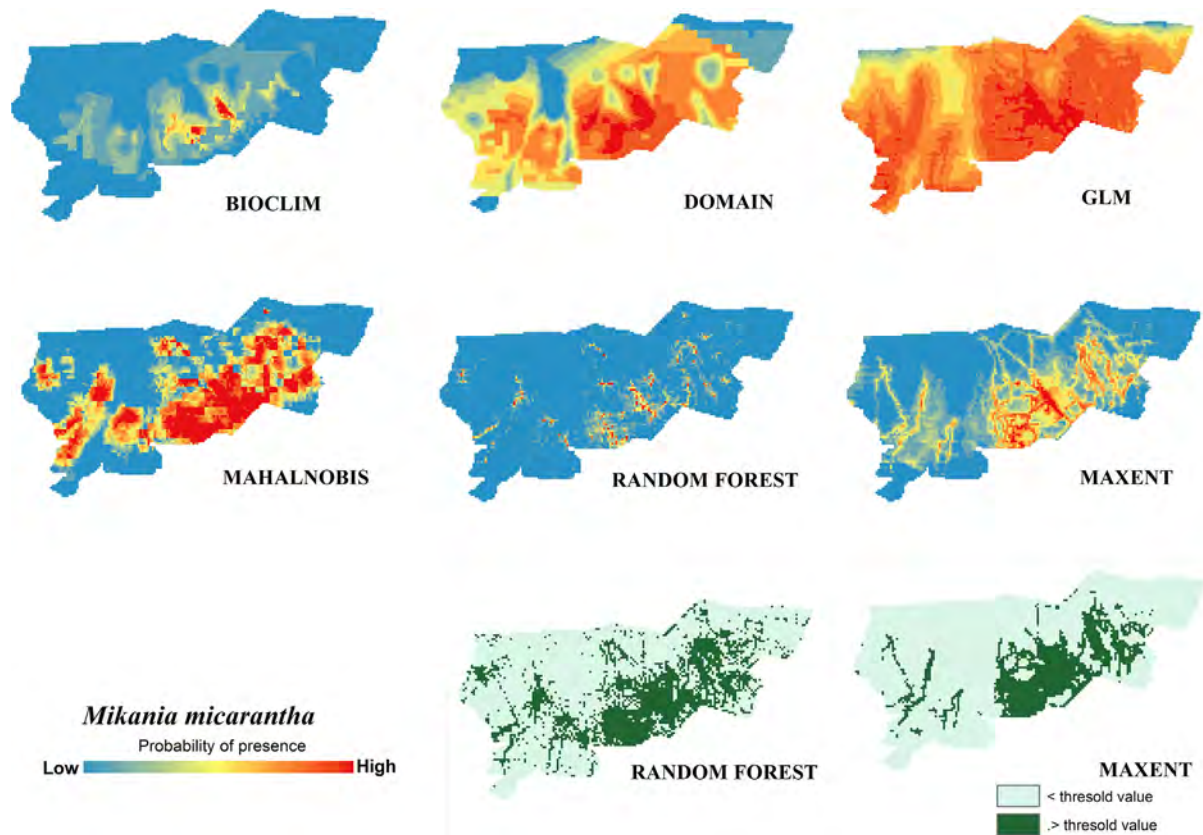


Fig. 9. Distribution maps of *M. micrantha* in Manas National Park using different algorithms.

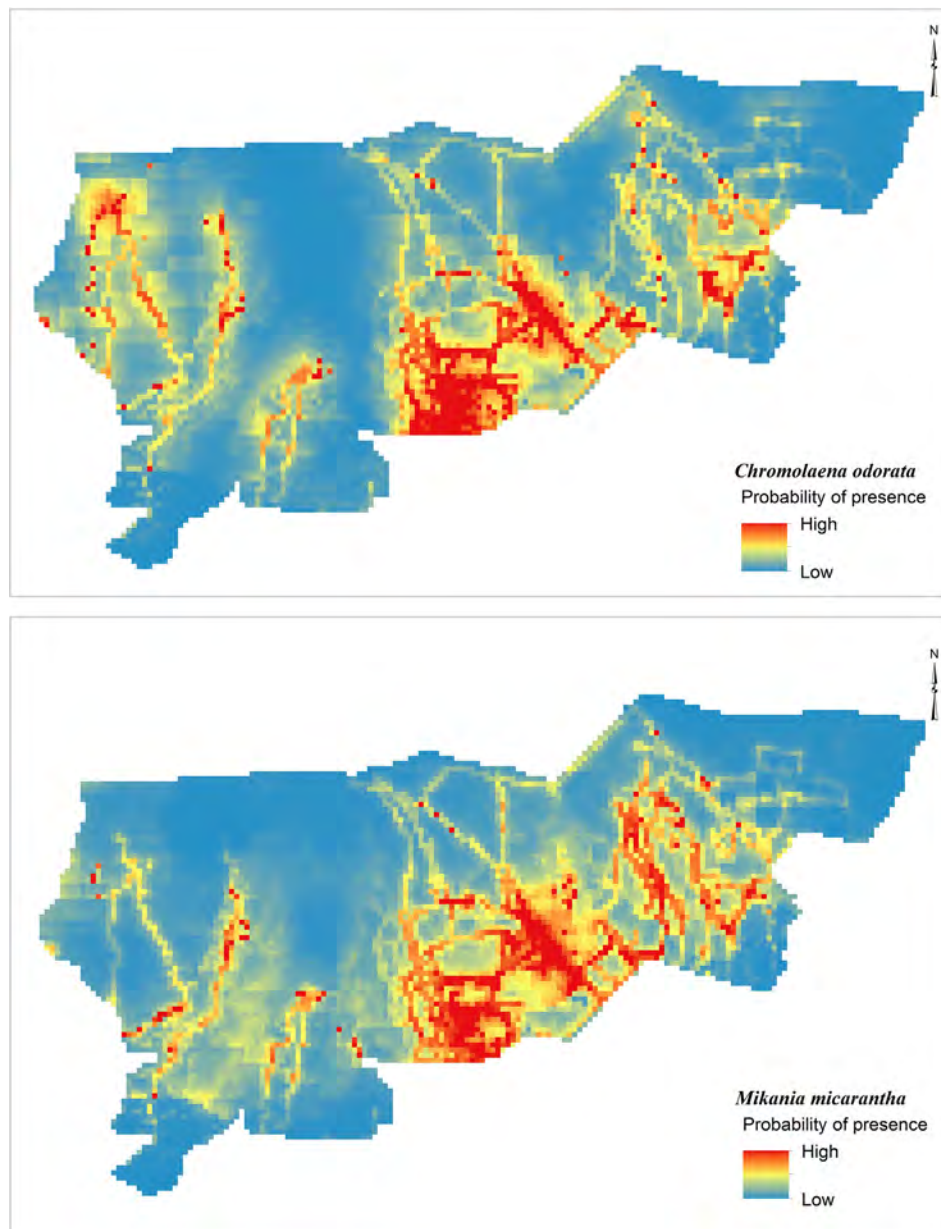


Fig. 10. Average score of MaxEnt and Random Forest algorithm for *C. odorata* (top) & *M. micrantha* (bottom) in Manas NP.

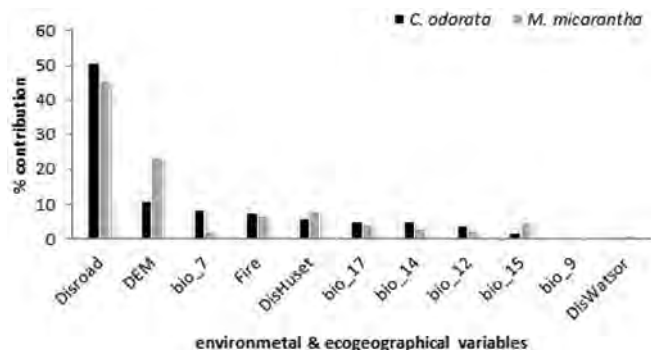


Fig. 11. Contributions provided by the environmental/eco-geographical variables considered to develop the MaxEnt model for invasive.

marginally negative influence on *M. micrantha* but the opposite for *C. odorata* (pers. obs.). Careful and systematic fire management in the grassland patches to some extent may limit the proliferation of *M.*

micrantha. The southern boundary of the MNP was highly invaded by both the invasive. A narrow road alongside the southern boundary of the park demarcates between human settlement and core area. In the absence of grazing reserves, the local people also let their cattle (cow, buffalo, and sheep) inside the park for grazing, which degrades most of the short grassland (dominated by *Imperata cylindrica*) habitat for wildlife. Moreover, overgrazing also results in compacting in soil and promotion of invasive species.

Lahkar et al. (2011) stated that invasive species had been changing the structure and function of grasslands in MNP. Also, speculated that the amount of habitat suitable for the reintroduction of rhinos, as outlined in IRV (Indian Rhino Vision) 2020 would be highly impacted. According to the present predicted distribution map, if both the invasive species continue to grow at its present rate, they will spread over entire grassland area of the park. The present study revealed almost 15–20% of the total park area and more than 30% of grassland area to be under the threat of *C. odorata* and *M. micrantha* invasion. Considering the present probable areas in which these two invasives are likely to invade, there are high chances that the majority of the

significant wildlife habitats will be affected and altered in the near future leading to habitat shrinkage of Asiatic Wild Buffalo, introduced One-horned rhino & Swamp deer and Hog deer. Also, invasive were found to proliferate and have completely encroached few grassland patches in Bansbari range which were critical habitat for endangered Pygmy hog, Hispid hare and Bengal Florican. Pygmy hog likely to be more susceptible to even minor modifications in its habitat compared to other species. It was speculated that there are less than 100 individuals remaining in the MNP (Ghosh et al., 2014). A rapid survey carried out by Ghosh et al. (2014) found 19 active nests of pygmy hog in Kuribeel, New Buraburi and Uchila camps of Bansbari range. The present study revealed all these areas to be partly invaded by both *C. odorata* and *M. micrantha*. Apart from that, the Bengal Florican population in MNP also is alarming, and few established male territories dominated by *Imperata cylindrica* were invaded by *C. odorata* (pers. obs.) in recent years. Owing to the small size of the park area, highly connected road network and uncontrolled burning may provide further opportunity to the invasive plants to invade the greater area of the national park. We highly recommend that the forest department should strictly prohibit the use of random paths/trails in the grassland areas, since *C. odorata* found to invade vigorously in open areas (e.g., southernmost part of Bansbari range; pers. obs.) Beyond the park boundary, the invasive may also have a greater impact on the overall ecosystem services and livelihood of the people. Park manager needs to take account of an ecosystem approach which ponders drivers of invasion. Moreover, anthropogenic disturbances such as fifteen-year-long ethnic and political battle starting in the mid-1980s disrupted the ongoing conservation and management activities, thus, largely impacting the wildlife and habitat of MNP (Goswami and Ganesh, 2014). Therefore, community awareness programmes can play a major role to minimize the proliferation of invasive. Alternative livelihood and stall feeding of domestic cattle may restrict the grazing pressure to some extent. Education and capacity building of frontline forest staff may help to carry out the long-term monitoring protocol for the invasive in MNP.

Recent experimentation with the restoration of grassland ecosystem in the study area revealed that mechanical removal was the most effective method to minimize the proliferation of both the invasive (unpublished data). Therefore, the areas predicted suitable but currently not invaded by the invasive are the critical zones along with invaded areas to be considered for adopting prevention measures. Invasion risk maps can be used as an early detection tool and for the management of invasive species, which could help in minimizing the ecological significance and economic cost of invasions.

Furthermore, our present findings support the need of testing a multiple SDM/ENM algorithms, and we strongly recommend the use of an initial suite of model predictions from a variety of algorithms under a diversity of parameter settings as indicated by Warren and Seifert (2011) and Qiao et al. (2015). Henceforth, the algorithm that is most powerful in terms of ground reality with precise ecological inferences can be used.

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PERSPECTIVE

On the History, Politics and Science of Invasion Ecology

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Abstract

The socio-political influence on conservation science has always been contested. One such arena, which has aroused much interest, is of biological invasions. Owing to the inherent paradoxes and dilemmas in defining geographies and impacts, invasion ecology was criticized for being value-driven. The present study explores value-judgements in the evolution of invasion ecology, by reviewing the historical and modern opinions that identified species with their geographic origin or perceived impacts. We found ‘weediness’ to be the primitive term that identified species as inherently ‘bad’ and was rooted in the biblical thoughts of the Dark Age. Western enlightenment and oriental connectivity questioned such claim of species being inherently ‘bad’. Particularly, naturalist and geological expeditions after the 15th century observed that the species that were transferred out of their range, induce negative impacts on the native ecosystem. We found this phenomenon politicized during the late 19th and 20th century, where species were identified with political boundaries, leading to malpractices of ‘exotic introduction’ and extreme ‘bio-nativism’. ‘Biological invasion’ was a scientific term of the 1950s, but the post-World War society perceived this ‘invasion’ with its martial influence. In the subsequent years, a quantitative and technological revolution in long-term ecological monitoring challenged the normative way of perceiving an ecosystem equilibrium or identifying changes brought to it by an invasive species. With the current science-values interface in the subject, we conclude that value-judgements about managing invasive species can help achieve conservation goals; however, its influence on the conceptualization of ecology can distort the scientific premise and should be avoided.

Keywords. Bio-nativism; exotic introduction; postmodern ecology; value-neutrality.

Introduction

Biological invasion is declared as the second most pervasive threat to biodiversity after habitat destruction ([Sala *et al* 2000](#)). It is perceived as a threat to global biodiversity, agriculture and human health, and has hence attracted attention from diverse sectors ([Pimentel *et al* 2001](#); [McGeoch *et al* 2010](#)). Defining an invasive species thus becomes pertinent for categorizing a species or taking any action against it. Popularly, an invasive species is defined as a widespread non-native species that has a negative impact on a native ecosystem. Owing to subjective terms like ‘non-native’ and ‘negative’ in the definition, invasion ecology has been criticized for its ambiguous nature ([Peters 1991](#)). Although these terms refer to biogeography and effect on non-human systems, their rationalization is influenced by human perceptions ([Richardson *et al* 2000](#)). When a term that explains a phenomenon is influenced by human perceptions, it can overtake the rational understanding; and in extreme cases, can influence the conceptualization of a value-laden science like Ecology ([Pyšek 1995](#); [Richardson *et al* 2000](#)). For example, interpretation of invasion-related terms has perpetually produced metaphors like ‘alien’, ‘noxious’, and ‘exotic’ that carry an innate sense of wrongness and are extensively used in ecology ([Chew and Laubichler 2003](#)). Though studies have argued that such innate wrongness helps to manage the ill-effects caused by an invasive species; it can influence science and societal opinions about the environment. Cognitive linguists have inferred that a metaphor is not just a matter of words but also triggers the intended thought process, with the immediate comparative perception of facts ([Lakoff and Johnson 1999](#)).

As a result, scholars tried to make a value-neutral definition (e.g., [Colautti and MacIsaac 2004](#)) of an invasive species by trying to eliminate the human perception. However, owing to its popularity, value-driven metaphors and adjectives are retained in invasion ecology ([MacIsaac *et al* 2011](#)). Different opinions of scholars regarding the identity of invasive species have divided the academicians into two visible groups, one proclaiming the value-neutrality of invasion science ([Richardson *et al* 2000](#); [Holle and Simberloff 2005](#); [Richardson and Ricciardi 2013](#)) and another questioning the necessity of value-neutrality ([Brown and Sax 2004](#); [Davis *et al* 2011](#); [Schlaepfer *et al* 2011](#)). These extreme opinions highlight the importance of a question that the subject must raise: how strong is the science-value interface in invasion ecology and why? There have been numerous attempts to rationalize the terminologies associated with invasion ecology and biology ([Blackburn *et al* 2011](#); [Jeschke *et al* 2014](#)). In fact, a few scholars argue that limiting or standardizing the terminologies can impede the development of the field of invasion ecology in different sections of society ([Carlton 2002](#); [Hodges 2008](#)). The nature and reason of this argument polarity maybe explained by the science-value interface that has influenced the present-day conservation philosophy ([Proctor 2001](#)).

Since the notable mention of invasive species by the 19th century scientists, including Alphonse De Candolle, Charles Lyell and Charles Darwin ([Darwin 1859](#)), though not using the same term, there have been efforts to rationalize the definition of geographies and effects on non-human systems. Conceptualization of these geographies and non-human systems, in fact, traces back to the belief system before modern science, with its roots in the enlightenment era, mercantilism, Renaissance, middle ages and the historical agrarian societies. It is the idea of 'otherness' that has persisted in each of these identities. The rationale behind such identities is uncertain because issues like these are examined from a constructivist perspective and are, therefore, vulnerable to personal bias ([Warren 2007](#)). Recently, due to the influence of these metaphors on conceptualisation in ecology ([Davis 2009](#)), invasion ecology has been seen in the larger social milieu of values and politics and the 'wrongness' or the 'rightness' of biological invasion has been vehemently debated.

It is beyond the scope of the present study to review all these studies. The present study explores the influence of societal value in the development of the concept of invasion ecology. Resisting the temptation to accept invasion ecology as a value-neutral science, this article reviews multiple narratives about the epistemology of biological invasions and highlights the necessity of inter-disciplinary philosophies in the subject.

Weed and Weediness

The earliest known concept of invasive species was in regarding plants that affected food resources of primitive human societies as weeds. Weeds and weediness are two ideas that have been constructed since the start of agriculture ([Clayton 2003](#)). With the advent of agriculture, the people-nature relationship changed. Any species that damaged cultivable 'good species' were identified as 'bad species' ([White 1975](#)). It was not until the biblical ages that weediness was used as a metaphor for representing anything evil and 'unnatural'. Genesis (3:18) states Adam to be cursed with weeds ([Speiser 1964](#)), suggesting weediness to be equivalent to something evil (e.g. *"The one who sowed the good seed is the son of man. The weeds are the sons of the evil one, and the enemy who sows them is the devil."* Matthew 13:33). Because of biblical supremacy, contemporary scholars raised concern for the lost innocence by condemning the 'unnatural' weeds as its cause. This influence always persisted with the term and was even referred by Shakespeare, a scholar of Renaissance Europe (*"tis (world) an unweeded Garden..."* Hamlet 1.2.6).

The theological overtone of unnaturalness in weeds was questioned by different philosophers (e.g. Heraclitus, Zeno of Citium, and Plutarch). Such ideas challenged the dichotomy of 'natural' and 'unnatural' since historic times. These voices were heard with the fall in biblical supremacy. But the visible arguments were due to the growing global connectivity of European scholars during the Renaissance, particularly with the eco-centric oriental societies, who influenced the redefinition of human-nature relation ([Kelly 2012](#)). The scholars during the

Enlightenment era found otherness of weeds to be an outcome of human artifice ([King 1957](#)). For example, in the 18th century, botanists argued that weeds were not the cause, but rather, an effect of soil impoverishment ([McDonald 1941](#)). Many post-Renaissance scholars, including Wolfgang Goethe and Russell Lowell, romanticized weeds as ‘wilderness that rebelled against human regulation’ ([Clayton 2003](#)). However, the majority of society was still driven by biblical supremacy that treated few species as innately evil and supported the dominance of what they considered as good species.

Exotic Introduction

Scholars influenced by the idea of European supremacy over others took the advantage of biblical references. For example, Sir Matthew Hale (1667), an English barrister, stated that man is superior to nature and hence must have control to change it (influenced by “*Thou hast given him dominion over the works of thy hands; thou hast put all things under his feet*” Psalm 8:6) ([Clayton 2003](#)). Similarly, Raynal (1713–1796), a French writer, believed that modifying wild nature to a garden was what distinguished civilized Europeans from uncivilised Indians ([Gilderson 1996](#)). Nevertheless, with the growth of the positivist movement in Europe, science was advocated for any political decision and was reflected by the arguments of scholars advocating species introductions. For example, Walter Buller, a 19th century naturalist from New Zealand, invoked Darwinism for the displacement of native flora and fauna (including people) by superior European species ([Clayton 2003](#)). This attitude of ‘European gardens better than wilderness’ was further backed by the vast improvement in navigation technique and diversity of available modification tools, which helped in transferring the species across the globe and modifying the native biota for economic and political purposes. Amidst the positivist movement, using science for justifying species transfer during the imperial era was thus biblical rooted and was enhanced by capitalist mercantilism and the navigation technology ([Beghin and Potier 1997](#); [Hulme 2009](#)).

The transfer of crop plants out of their native areas was an important step in world history, as it facilitated the expansion of societies and empires ([Peretti 1998](#)). Most of the non-European societies, particularly Oriental and native Americans were constrained to using and breeding the available species in their area ([DiZerega 1996](#); [Kalland and Persoon 1998](#)). However, colonial rule tried to modify the new countries by introducing exotic species, to make the ambience depict their homeland (e.g. introduction of oak, pheasants and rabbits in New Zealand ([Wells 2006](#))) and for economic resources (e.g. introductions of *Prosopis juliflora* in South Africa ([Bennett and Kruger 2013](#))). Perception of native people to such introductions was varied. People fascinated with the imperial lifestyle tried to accept the changes. Those who revolted against the rule led to the movement of conserving the native values and biota.

Hence, 'exotic' was used both as a metaphor for appreciating a unique difference, as well as for criticizing an alien entity.

Nativism

Few of the introduced species escaped in the wild, spreading at an alarming and outcompeting the native cultivable and natural species. As a response to this damage, farmers and forest managers started removing such species. For example, Noxious Weeds Act (1900) was established in New Zealand to eradicate harmful introduced species (Chapin et al 2010); and *Lantana camara* (introduced species) management was initiated (1912) in parts of India (Bhagwat et al 2012). An extreme version of this idea was to remove any entity that didn't belong to the political extent of a particular society; an idea that led to biotic nativism. 'Native', before the 19th century, meant anything that was not a direct output of human artifice (Chew and Hamilton 2011). It was later related to the purism of landscape, and such purism was perceived to be free from any foreign invasions. As species were segregated based on the political boundaries and the human race in it, biological nativism was the historical outcome of apartheid cultures. For example, in pre-World War II Germany, strict biological nativism was supported by Nazism. Ideologically and ecologically, the Nazis attempted to purify their nation and nature, by eliminating people and biota that were supposedly non-native (Peretti 1998). For example, Reinhold Tuxen, head of the Reich Central Office for Vegetation Mapping, announced a fight against the 'Mongolian invader' *Impatiens parviflora*. Such decisions converted the wilderness into 'natural gardens', as all the ecological selections were controlled and manipulated by human interventions (Pollan 1994).

Scholars suggest that the emergence of biological nativism could also be a product of newly emerged, democratic, less-developed countries, who suffered due to (political) invasions during the World War II (Peretti 1998; Nunez and Pauchard 2010). The approach adopted by such countries usually relies on eradicating non-native species based on political boundaries. Not surprisingly, the Leopold Report (1963), a scientific document to manage national parks in the United States of America, stated that management should aim to protect and recreate native nature that was present before invasion and degradation by the first white man and biota brought by them (Hecht and Cockburn 2010). Such perspectives were based on a myth of an idealized primitive society living in harmony with the environment (Katz 2014).

Although environmental purism is not inherently racist, there are compelling arguments that nativist purism is undesirable in all spheres-political, cultural and ecological (Peretti 1998). Species ranges and extents are driven by how far they can disperse and how far back in time they did so; political boundaries are proximate, ever-changing and artificial and do not match up with the time scales at which species ranges expand. Hence, political boundaries should not be considered for assigning species with their identities. All the same, contemporary attempts to preserve differing cultures and small-town community life by limiting foreign influence

need not be racist or xenophobic, but rather, an attempt to preserve the spectacular diversity on earth (Hettinger 2001). However, if human modification of ecosystems is left unchecked for natural selection to happen, it will lead to the completely human-controlled ecosystems (Katz 2014).

Biological Invasion

The experience of few species being harmful to the ecosystem, their geographic identities, need to control their impacts and emerging quantitative ecology of the 20th century led to the rationalization of the concept of biological invasions. The species out of their geographies were recorded by naturalists of the 18th and 19th century including Pehr Kalm, Alexander Humboldt and many others (Davis 2009; Chew 2011). Charles Darwin considered this phenomenon when he observed that non-native species could threaten native species on islands (Darwin 1859; Richardson and Pyšek 2008). As described by the previous study (Davis 2009), the influence of geographies on species was also motivated by Wallace's six distinct bioregions of earth that inspired the contemporary biogeographers to explore the biology of species outside their bioregion. To geographers and voyagers of the 19th century, this was all about human introductions that affected the species of distinct geographies. One of the first few published records of invasive species, was for species (native or non-native) that burgeoned, resulting in the rarity of other species (Brandis 1891). Subsequently, ecological knowledge accumulated as a product of geological and naturalists' expeditions. Early ecologists observed the ecological difference brought by the species that got out of its native area (Spalding 1909; Thomson 1922; Egler 1942). The impacts that these species can have on the introduced area started getting the attention, particularly with non-native plants (Campbell 1926).

It was not until the 1950s that the subject gained ground in the scientific community. Marston Bates 1956, in his chapter, 'Man as an agent in the spread of organisms', reported that the species which spread with human movement can become 'Neobiota' in different regions. Another contribution was by Charles Elton (popularly known as the father of invasion biology) in 'The Ecology of Invasions by Animals and Plants' (1958). Elton flagged the concern on biological invasions using radio broadcast and used general language to convey the seriousness of the topic. Unlike many other scientific publications by Elton, the starting paragraph of his book 'The Ecology of Invasions by Animals and Plants' dramatically claimed "*It is not just nuclear bombs and war that threatens us. There are other sorts of explosions, and this book is about ecological explosions*" (Elton 1958). Based on the ecological observations for more than a decade, Elton warned that the loss of biodiversity due to invasive species would be so severe that "*Instead of six continental realms of life, there will only be one world...*" (Elton 1958). Scholars criticized Elton's idea as a product of his martial mindset and language

developed by the World War society ([Chew 2006](#)). However, Elton's work since the 1930s indicates that his monograph was the output of long-term ecological observations that lead to the concept of biological invasion in 1958 ([Kitching 2011](#)). Although Elton's idea was not influenced by the post-war martial mindset, the society that was habituated with everyday war news could have perceived these martial metaphors literally. And hence, out of two contemporary metaphors of 'neobiota' and 'biological invasion,' it was only the latter that eventually became the highest cited term ([Richardson and Pyšek 2008](#); [MacIsaac *et al* 2011](#)).

Modern Invasion Ecology

Modern invasion ecology that constituted itself somewhere in the 1980s, owes its presence to the advancement in quantitative ecology ([Davis 2006](#)). The global awareness for biological invasions was reflected in the SCOPE program ([Macdonald and Jarman 1984](#)) that resulted in an exponential increase in quantitative data about the spread and effects of biological invasions ([Richardson and Pyšek 2008](#)). Association of the impacts with ecosystem services and biological extinctions enabled the subject to gain strength for raising funds and carrying long-term research. The post-1980 rise in scientific publication and citations on biological invasions symbolizes a modern rationalization of the subject ([Pyšek 1995](#)). As evident from the adjective 'modern', the new version of invasion ecology was based on induction (ecological surveys, lab experiments, etc.) and deduction through statistical hypothesis testing. But the ultimate objective of biodiversity management was to maintain the 'balance of nature' by managing invasions. Definition of the geographies and 'negativity' associated with the identified species is only partially addressed by such modern approaches. Thus, the workable modern definition for an invasive species was widespread non-native species whose introduction is mainly attributed to humans and which negatively impact the ecological integrity ([Colautti and MacIsaac 2004](#)). The meaning of 'non-native', 'human-induced' and 'negative impact' are left to interpretation by the scholars and the stage of invasion in the ecosystem.

In the modern definition of biological invasion, anthropogenic activity ([Hulme 2009](#)) is popularly considered responsible for introducing a species out of its evolutionary range, where it might turn invasive due to a release from controlling agents (competitors, predators and disease). Such assumptions suffer from ecological limitations as one cannot be definitive about the evolutionary history, or about the conservatism of this evolutionary niche of a species. Species' distributions are dynamic; each species originated somewhere, had subsequent changes in its life histories that has resulted in its current distribution and will determine further speciation within the geographic barriers ([Walther *et al* 2002](#)). With increased human transport available, humans are spreading many species out of the geographic barrier, will all these species become invasive? There have been evidences suggesting that distinct geographic origin of a species cannot be the only reason for its invasiveness elsewhere ([Davis *et al* 2011](#); [Hassan and Ricciardi 2014](#)). Hence, the duration for which a species be present in a particular

location to be classified as native is more of a philosophical issue (Westman 1990) and then an ecological one. The second criterion of ‘negative’ impacts was developed keeping in mind that not all human-induced non-native species turnout to be harmful. According to this criterion, invasive species are not integrated into the ecological community but are the ones that degrade it. Paradoxically, recent studies show that natural communities are dynamic and hence, constantly prone to change (Lavergne et al 2010). Moreover, scholars have been challenged with providing a principled distinction between harming a natural system and changing it (Gunn and Throop 2002). When the harm is to a non-human system, the justification for negative impact is complex, and scholars have recently proposed to incorporate human-values in the framework of defining negativity of impacts (Jeschke et al 2014). Biological invasion is a special case where all the criteria are the same, except that it enforces immediate changes on the ecosystem, which in an ideal evolutionary time would give equal opportunity to the native species to respond. These imminent changes are manifested into the localized extinction of native species, loss in functional diversity and gradual homogenization of the global biota (McGeoch et al 2010).

Further, as climate change unfolds, species will change their current distributions to survive (Peterson et al 2002; Mungi et al 2018). Will such species then be considered as invasive? It is inevitable that differential changes in any community will lead to the introduction of hitherto unknown species and can even result in them becoming abundant. If we want the natural processes to occur without human intervention, then the ecosystems will be invaded. And if we intervene, the processes will be no longer ‘human-free’; this alarms the onset of Anthropocene (Crutzen 2006; Steffen et al 2007). The recent culture in conservation science that denotes a native ecosystem as a stable equilibrium and invasive species as something that disrupts that equilibrium is thus, no longer tenable. With the fall of the Clementsian concept of climax in modern ecology, thoughts began to appear that challenged balance-of-nature paradigms regarding ecosystems. Scholars highlighted that ‘species move freely on all geographical scales’ (Hengeveld 1989). Such thoughts that challenged the ecological constructions of species, communities, and nativity, were very outcome of postmodern science (White 1998; Warren 2007).

Contemporary Invasion Ecology

Invasion ecology, as a subject, has evolved from the normative binary of ‘good’ and ‘bad’ species to a modern thought of the abrupt state of ecological equilibrium. The upsurging era of postmodernity (Lyotard 1984) is questioning the ‘balance of nature’ and perceiving it as multiple states based on chaotic processes (White 1998). Postmodernity, as a state of society, might be yet debated but, increased references of chaotic processes in ecology (Evans et al 2013) and the new paradigms of multiple stable states (Fukami and Nakajima 2011) allude to a common reference of postmodern thoughts. Ecosystems states can be defined in multiple ways

and that complicates the utility of this concept. What state – structural or functional – must one prioritize is still a deeply subjective choice. An ecosystem is now perceived as a dynamic response to the changes in the environment, and a complex interaction explanation of which is beyond the scope of present study but can be found elsewhere (Scheffer and Carpenter 2003; Hobbs and Norton 2004). This criterion does not weigh the geographic origin of a species or negativity of its impacts as important. The first important factor is the potential regime shift in a non-ecological time and second, the anthropogenic base of such shifts. The alternate stable state is a product of human manipulation of the ecosystem, in an era of biodiversity crises due to anthropogenic influence, and thus it induces concern. Secondly, biological invasions claim to accelerate biological extinctions and economic loss (e.g. loss of US\$ 314 billion per year for six nations (Pimentel et al 2011)), and hence could be perceived as a risk (Burgman 2005). Hence, accounting human as a causal agent within a system, and not an external entity, serves the purpose of conservation. However, the potential alternate stable state poses an interesting conundrum for managerial action as removing an invader from the new regime of the ecosystem can disturb the newly established ecological networks and processes. This loss of interaction could further move the system into other chaotic states (Hughes et al 2013). Reverting back the ecosystem to its pre-invasion state, which in itself is subjective, needs control on all micro-parameters of the ecosystem. Moreover, waiting for an ecosystem to cross the existing regime and then reverting it back consumes resources with uncertain ecological gain. The way science can help is by providing early warning signals of ecological regime shift by biological invasions, so that strategies to resist it or adapt to it, could be timely availed. This needs continuous monitoring at an optimal scale and observing any indicators of such abrupt shifts, which is yet a challenging science.

The contemporary conservation strategies propose restoration of lost ecological regimes rather than the only removal of invasive species. Owing to small sizes of protected areas and human influence on its ecology, the probability of ecosystem reverting back to its original regimes on its own is minuscule. Although humans would regulate transformation to such a system, thereby making it anthropogenic selection; it would minimize the relative damage caused to the biodiversity. The current postmodernist views, alluding to their placement of human as a part of nature will support interventions in such cases (Robertson and Hull 2001) but should be freed from the xenophobic base. There is an urgent need to modify certain thoughts to compliment scientific decision in dealing with such conservation strategies. Many conservation biologists emphasize the importance and pervasiveness of species migration while maintaining a nativist ideology (Peretti 1998). This clash, many a time, has resulted in deactivating the management of some harmful invasions, while sometimes having resulted in the removal of native species (Sagoff 2000) and has also ended up terming threatened species as exotic and alien (e.g. Thapar 2013). Secondly, conservationists often target species that have visibly altered the landscape to an extent that adaptation to the change is costlier than removing the species. Such dissonance could be overcome by multi-disciplinary studies that have already been demanded (Larson et al 2011).

It is a time where, scholars from ecology, sociology and quantitative science come together to address the conceptualization and actions regarding biological invasions. Multi-disciplinary initiatives are showing success in using value-judgements without influencing the scientific premise. For example, considering opinions of the animal rights group resulted in successful control of feral pigs in Texas USA ([Perry and Perry 2008](#)), public participation for controlling invasive plants spread in Australia ([Williams and West 2000](#)). Invasion, in its entire context, is part of ecological science and not a different science in itself as indicated by few. Additionally, acknowledging socio-political and cultural values while addressing this conservation-oriented issue is crucial. Science in its positivist form is inept to solve such problems alone as “*meanings cannot be measured, only understood*” ([Bhaskar 2005](#)). Meaning could be multi-narratives and should not be feared; as our study demonstrates, including the contradictions in existing views, environmental conservation has always been a heterogeneous mixture of ecology, politics, sociology and culture.

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Proceedings of the International Conference on Invasive Alien Species Management



National Trust for Nature Conservation
Biodiversity Conservation Centre
Sauraha, Chitwan, Nepal

March 25 – 27, 2014

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Dignitaries of the inaugural session on the dais



Proceedings of the

International Conference on
Invasive Alien Species
Management

**National Trust for Nature Conservation
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Foreword

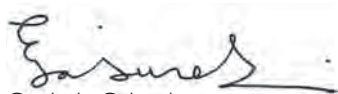
Alien species that become invasive are considered to be main direct drivers of biodiversity loss across the globe. Management of invasive alien species (IAS) is seen as major challenge in the field of biodiversity conservation. IAS, the non-native species threaten ecosystems, destroy habitats and create problems to other native species through invasion. It is considered as the second greatest agent of species endangerment and extinction. The ecological cost is often the irretrievable loss of native species and ecosystems. It also causes heavy economic loss, in terms of reduced crop and livestock production, reduced native biodiversity, increased production costs and so forth.

Nepal is also suffering from the introduction of IAS. Chitwan National Park, the first national park in the country listed in the world heritage site has been invaded with *Miconia macarantia* in the last decade threatening the habitat of some of the global significant species inhabiting the park. It is degrading the habitat of rhinoceros and prey species of tiger, thus reducing the resource base of these keystone species. Similar problems of invasion of non-native alien species are witnessed in eastern Terai, mid-hills and even in the high Himalayas. The protected areas (PA) in Nepal are under huge pressure from poaching and illegal activities and the invasion have further compounded pressure to the PA management. Research, monitoring, and management of biological invasions have not yet been a priority in Nepal. Very limited works have been initiated but these activities are not well coordinated.

In this context, NTNC initiated to organize the International Conference on Invasive Alien Species Management (ICIASM) with an aim to provide valuable input while revising National Biodiversity Strategy (NBS). We are thankful to Asian Development Bank (ADB) and the USAID funded Hariyo Ban Program for providing financial support for the conference. The conference, through the Chitwan Declaration attracted attention of global community for the effective management of IAS in a coordinated manner. The conference has also noticed the negative impacts of IAS not only in agriculture, livestock productivity, forests, wetlands, and water scarcity but also in fisheries, wildlife conservation, and human health. The conference has urged for the urgent need of comprehensive national strategies for prevention. It has been a special platform to discuss over the IAS issues in the globe and needs to be continued in the days to come.

At the end, I would like to extend our sincere thanks to all of the agencies and individuals involved to make the conference successful. Thanks to NTNC's BCC, technical committee, and management committee for the effective management of the conference. Special thanks to all of the delegates from Australia, India, Nepal, Pakistan, South Africa, United Kingdom, and United States of America for their valuable presence and sharing.

Thank you,



Govinda Gajurel
Member Secretary
National Trust for Nature Conservation

Preface

Invasive Alien Species (IAS) pose a profound impact on humans as well as on the ecosystems as it can be a cause of heavy economic loss, in terms of reduced crop and livestock production, reduced native biodiversity, costs involved to control their rapid spread and impacts on human health. Thus, these non-native species destroy ecosystems, habitat, or species and are also the second greatest agent of species endangerment and extinction after habitat destruction. Flora and fauna have entered an age of globalization just like economic globalization. Species are being moved around the planet at a rate much greater than we ever expected. The issue of IAS is caused by human activities associated with global linkages, network and ease of access by road, rail or air. In order to control their spread, measures have to be taken at national and local level. Realizing the threat of biological invasion, more attention has been given on research, monitoring, control and management of invasive species in the recent years by global communities. The Convention on Biological Diversity (CBD) calls for its signatory nations to prevent the introduction, control or eradication of those alien species.

The different bioclimatic zones of Nepal favor the introduction of several alien species. Research, monitoring and management of biological invasions have not yet been a priority in Nepal. Very limited works have been initiated and, moreover, these activities are not well coordinated. On the other hand, there is no national strategy document for the scientific management and control of invasive species. In this context, National Trust for Nature Conservation (NTNC) organized the International Conference on Invasive Alien Species Management (ICIASM) at NTNC's Biodiversity Conservation Center (BCC), Sauraha, Chitwan National Park from March 25–27, 2014 with an aim to provide valuable inputs while revising National Biodiversity Strategy (NBS) and implementing other biodiversity conservation and management initiatives. Major financial support for the conference was provided by the Asian Development Bank (ADB) and the USAID funded Hariyo Ban Program.

The conference provided a good platform and opportunity to present and share research findings, outcomes, recommendations and innovative ideas regarding IAS management all over the globe. The international character of this conference is illustrated by the participation of representatives from Australia, India, Nepal, Pakistan, South Africa, United Kingdom and United States of America. 27 research papers were presented by the participants in the conference. In addition, the conference, through Chitwan Declaration, agreed to draw attention of global community to initiate joint management to control spread of IAS. The conference also drew attention to the negative impacts of IAS not only in agriculture, livestock productivity, forests, wetlands, and water scarcity but also for fisheries, wildlife conservation and human health and urged for the urgent need of a comprehensive national strategy for prevention.

This proceeding contains the collection of key note paper and technical papers presented at the conference and it is intended to demonstrate how different dimensions of IAS problems impinge on each other and to provide recommendations to counteract and deal with the current and future IAS management problems and challenges. Opinions and statistics included in the technical papers do not necessarily reflect the opinion and views of organizer and supporting agencies.

Last, but not the least, I would like to extend my sincere gratitude to all the conference participants, agencies and individuals, institutions who provided financial support, members of technical and management committees and entire NTNC team for their support and cooperation to make this conference successful.

Thank you.



- Ganga Jang Thapa
Conference Coordinator
Executive Director - National Trust for Nature Conservation (NTNC)

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KEY NOTE PAPER

Galvanizing Action for the Management of Invasive Alien Species

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Abstract

Invasive Alien Species (IAS) are widely recognized as one of the major global change factors; they now affect all major economic sectors within and between countries. The estimated impacts of IAS nationally can be colossal and run into billions of US\$ annually. There has been much international response to the threats of IAS and suggested management frameworks (prevention and control) and tools are freely available. However, responses at national, local and even regional levels have been patchy or non-existent across the globe. In large part, this is because the broader impacts of IAS have been championed by environment sectors since the 1980s that traditionally do not house the frameworks for addressing such threats to economies. Other factors are also important such as the lack of detailed studies on the impacts of IAS particularly on rural livelihoods and the lack of inter-ministerial discussion and collaboration over the IAS issue within countries. Because of this, important tools for the control of IAS such as introduction of biological control are underutilized. There is now an urgent need for fully comprehensive management packages to be developed and implemented at national levels across the globe. These should include major stakeholder engagements and inputs.

Keywords: Invasive alien species, impacts, gaps in management frameworks, biological control.

Introduction: the global situation of invasive alien species

We live in a time of global change to our environment – what some have dubbed the ‘Anthropocene and earth’s sixth mass extinction of species’. Invasive alien species (IAS) are widely recognized as one of the major agents of change (Mack *et al.*, 2000). Recently the issue has been highlighted in the Convention on Biological Diversity strategic Plan for Biodiversity, 2011–2020 but also now reflected in other international agreements; for example the International Plant Protection Convention (IPPC) under the Food and Agriculture Organization (FAO) of the United Nations (UN).

Agricultural sectors have long been very familiar with IAS where individual invaders (largely pathogens and insects) have almost wiped out entire crops or livestock and thus threaten livelihoods and national economies. So what is different now about IAS and why has the issue become so prominent? The difference – that has been happening slowly but now accentuated – is in the diversity of species taxa and volume of IAS species threatening economies, livelihoods and the environment. This has largely been through increased trade and travel which have both dramatically increased in the last 40 years or so. But climate change and landscape change are exacerbating the situation, especially with the IAS already established in the early 20th century. It should be noted that people and organizations introducing species internationally a while back did not know then that some species could become highly invasive; e.g. water hyacinth (*Eichhornia crassipes*) a major IAS globally and a familiar site here at Chitwan.

Where has IAS come from? Most intentional introductions of species have been for the benefit of livelihoods and economic growth and most

have been ‘harmless’, but some have become IAS. However, a more major issue in terms of number of species causing problems has been the accidental introductions of ‘hitchhikers’ in relation to trade or travel pathways. Overall, some species from both types of introductions have established reproductive populations and spread aggressively and this has and still is a massive problem globally. Many IAS have been via the agricultural horticultural sectors: some intentionally, e.g. *Mikania micrantha* from the New to the Old World; and some accidentally, e.g. the red palm mite (*Raoiella indica*) from the Old to the New World where the mite is a major problem for the palm industries. And in the case of *Mikania micrantha*, the problems it can cause are well illustrated by the situation in Nepal. In the region of Chitwan National Park and also further east it now has a wide and expanding distribution and is having a negative impact on native flora, mammals of conservation importance and local livelihoods (Murphy *et al.*, 2013).

The negative impacts of IAS can be on a massive scale. Some generic examples include: the homogenization of floras and faunas within and between countries and regions which is a direct result of trade and movement of people; the local extinction or displacement of native species, e.g. in the case of *Mikania micrantha* as a factor in the local extinction of fodder grasses in Nepal; losses to the agricultural crops and livestock, e.g. foot and mouth disease; changes in ecosystem process, e.g. water catchments as in the South African fynbos ecosystem; genetic changes; e.g. hybridization shown to be important in plants, and mammals and birds; and the impacts on industrial processes, e.g. the classic case of zebra mussel (*Dreissena polymorpha*), an Old World species that now infests the Great Lakes of North America. The annual costs of IAS to some national economies have been estimated; e.g. USA US\$ 118 billion, Brazil, US\$ 6.9 billion (non-indigenous plant pathogens only) and the UK, nearly US\$ 3 billion (Pimental, 2002) But much of the data used for these estimates are

from the agricultural sector as this has been easier to quantify.

Responses to the IAS issue

At the international level there have been several responses. Only a selection of the more important responses is covered here. IAS are formally recognized by the Convention on Biological Diversity (CBD) as a major threat to habitat and biodiversity. Indeed, IAS are a major article of the 1992 CBD framework and, as mentioned, included in the Strategic Plan for Biodiversity, 2011–2020. The World Conservation Union (IUCN) established the Invasive Species Specialist Group (ISSG) in 1994 and its main function is to act as an advocacy body giving the environment sector a 'voice' on IAS. In Trondheim, Norway, in 1996, an International Conference on IAS (including 96 countries) debated the global issue of IAS and in 1997 the formation of the Global Invasive Species Programme (GISP) was underway (Mooney *et al.*, 2005). GISP produced a number of technical review documents on IAS (e.g. impacts, social dimensions, management) although unfortunately the GISP closed in 2012.

Various information (products, management guidelines and tools) have also been produced by international organizations. ISSG is home to the Global Invasive Species Database (GISD), which contains information about most of the World's major IAS. CAB International has produced the free, online Invasive Species Compendium (www.cabi.org/isc) giving all kinds of useful information about species across the globe; the current coverage is over 1600 species. And an international standard for phytosanitary measures on 'pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms' was produced under the International Plant Protection Convention (IPPC) of FAO (FAO, 2004).

Nonetheless, responses and actions at the national, local and regional levels have been somewhat different. For sure, actions and investments continue to be made in the agricultural sectors of many countries against pathogen, weed and pest threats (e.g. the South American cassava mealybug (*Phenacoccus manihoti*) which devastated cassava in Africa in the late 1970s and 1980s). But actions in this tend to be 'crop specific' and only a handful of widely distributed IAS have been addressed. Thus, in general, these responses do not take IAS impacts in the environment and other sectors into account. Responses and actions to protect the environment have been taken in some regions under Global Environment Facility funding and other funding mechanisms but there are still many gaps to fill, especially in the developing world.

Thus despite international responses to the IAS issue, responses, actions and investment in management at national, local and regional levels is very patchy; and in some cases, non-existent. There is now need to develop a 'comprehensive response' at various levels that truly crosses boundaries between different sectors.

The paucity of investment and action and what can we learn?

Why is there a paucity of investment and action at ground level and what can we learn from experiences of countries to date? Someway to understand these questions can be gained by looking at the history of the development of recognition of the IAS issues and the outcomes.

As we have seen IAS have been an issue for agriculture for centuries but these species were not always termed 'Invasive Alien Species'. And, many management methods and tools have been devised internationally (e.g. under the IPPC) and nationally for agricultural plant health.

However, turning to the environment sector, concerns about IAS and their impacts did not manifest until about the 1980s and a large factor in this was the long programme on the assessment of IAS under the 'Scientific Committee for Problems of the Environment' (SCOPE). This was global perspective and generally brought attention to the world of the scale of IAS impacts in the environment (Mooney *et al.*, 2005). Out of SCOPE and other programmes such as GISP, there developed much ecological knowledge on IAS, the process of invasion, the human dimensions of the problem and the collation of information about experiences with management. In particular, it emerged that IAS are a cross-cutting issue, affecting many major economic sectors of countries: agriculture, environment and trade; and the human dimensions in all of this both as 'drivers' and victims of IAS. Interestingly, some of this knowledge was new to the agricultural sector e.g. the variety of pathways of movement of IAS. Thus in summary, from the 1980's the environment sector was the main force championing the calls for actions against the increasing tide of invasions of aggressive alien species.

In all of this, some critical issues have emerged that have affected investment in actions across the globe. As we have seen, by and large, the agricultural sector has focused on the narrow subject of weed and pest issues, but IAS issues are larger and broader ranging. The main points are as follows:

- The reported impacts of IAS in environment sectors were for many years qualitative. Many papers were published on the 'extent' of IAS distributions but data on effects on native species, ecosystem functions, and rural livelihoods was largely absent. Because of this, there has been mixed perceptions of true impact. There are situations where IAS invasions will
- deteriorate over time but these are few. As a result, many involved in general natural resource strategies have concluded that IAS is a secondary problem.
- Most of the world's rural poor rely on natural resources which are also important conservation issues (e.g. local biodiversity) – little is known about the specific impacts of IAS on rural livelihoods but many funding streams now see natural resource management integral to livelihood issues.
- There has been a lack of awareness raising in the right sectors and /or lacking the right type of information (as per above point). Much has been written and debated within scientific and resource management circles but other critical stakeholders have been missed, e.g., the general public and key national Ministries.
- The governance of the natural environment at a national level usually comes under a 'Ministry of Environment' or the equivalent. However, traditionally, frameworks for addressing 'pest' issues lie within Agricultural Ministries and associated institutions. More generally, much in-country consultation over the last 15 years or so has shown that there is frequently poor information flow on issues such as IAS within country.
- Related to the last point is that countries who are signatories to the CBD have in reconciling actions under the CDB (which are legally binding) with national legislation.
- Finally, a key 'action' for IAS management is to regulate pathways of movement and this touches on the subject of trade; some species that are IAS are livelihoods for some but cause misery and cost to others.

Conclusion: building a comprehensive response and management framework for IAS

What is the way forward? How do we build a comprehensive response and management framework for IAS? The most urgent is to take actions now. The magnitude and threats of IAS to national economies and the environment are now very real and thus actions must be taken.

The main components of any IAS comprehensive response and management framework for policy and actions would involve at least the following:

- Inventories of IAS;
- Risk assessment that includes pathways and spread, and ecosystems at risk (agricultural and environment);
- Awareness raising, surveillance and rapid response measures;
- Eradication and control measures including extension support to those working in the field.

There is plenty of guidance on framework and tools for IAS that can be put to use; e.g. as good starting point there are the international standards for phytosanitary measures guidelines under the IPPC for plants. But other methods and tools are available and several 'best practices' published e.g. 'toolkits' for best management practices that were produced by GISP (Wittenberg and Cock, 2001) and more recently a resource kit for invasive plant management freely available on the web (PII, 2014).

However, more than this needs to be done to achieve a comprehensive response and management framework for IAS. Critically, we

need to learn from the national and local issues that we have reviewed and use the experiences to build future plans. Thus, at the practical level, the experiences to date of countries trying to strengthen policy on IAS threats or to develop fuller management frameworks are a very useful platform on which to base framework developments in the future. None of the issues highlighted in this talk are un-solvable; but they are significant issues and need to be taken into account and need investment of time and resources. As a priority, an emphasis should be placed on national inter-ministerial/ inter-sector experience and knowledge sharing and co-operation on IAS to address the threats and impacts. There is also need for greater public engagement on the IAS issues.

The need for agricultural, environmental and other sectors to work together is well illustrated by the experiences of trying to implement biological control in countries severely affected by IAS. Introduction of biological control or use of host specific natural enemies from the area of origin of the IAS has proved a valuable tool for managing IAS especially invasive plants (Murphy and Evans, 2009). This technology is particularly useful for IAS in protected and rural areas where other controls are not practical or may have side effects such as herbicide applications. The implementation of biological control requires quarantine and host target testing frameworks and these are frequently the responsibilities of the agricultural sector. But as we have seen, many IAS affect the environment as well as agriculture.

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Invasive Plant Threats to Forests in the Humid Tropics: A Case Study from Kerala State, India

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Abstract

Invasive alien species (IAS) cause a little recognized, but very substantial impact to forest ecosystems worldwide. Increased trade and travel across countries and continents especially after the recent advent of globalization has helped promote the process of spread of IAS more than ever before. Introductions of IAS can be either intentional or inadvertent. All invasive species possess certain biological attributes which contribute to their success as invaders in a new habitat. For invasive alien plants (IAPs), these traits include production of a large number of easily dispersible seeds, faster growth and better competitive resource capture and utilization abilities compared to native plants. IAS cause economic damage to the tune of 1.4 trillion dollars globally; overall loss in many countries is over 1% of GDP. IAPs are known to displace native plants, alter ecosystems processes, hydrology, primary productivity, nutrient cycling and soil structure and most importantly reduce native biodiversity. There is evidence to suggest that the threats due to IAS may increase with climate change and associated changes in habitats. Likewise, land use change promotes new incursions and faster spread of IAS.

In this paper, we assess the threat of IAPs to natural forests in Kerala State, India, situated in the humid tropics. Kerala has a long history of maritime trade with Europe, the Middle-East and other continents/countries which paved way for early introduction of alien species. Based on intensive field surveys and using a risk assessment protocol, we identified 38 IAPs in the forests of Kerala. These included trees, shrubs, herbs and climbers. Of these, 10 species are of high risk, 12 pose medium risk, 10 of low risk and the rest are of insignificant risk. Thirty species were introduced intentionally and the land of origin of majority of the species was South and Central America. This observation underlines the hypothesis that invasive species move along the latitudes. The survey revealed that apart from the ecological harm, invasive plants adversely affect the livelihood of all those who are dependent on forests in Kerala. The paper identifies early detection and rapid control, prevention of spread and habitat restoration as urgent measures for combating the threats. Improvement of provisions in quarantine regulations and strict adoption of these will help to prevent new incursions.

Keywords: Invasive alien plants, risk assessment, forests of Kerala.

Introduction

Invasive alien species (animal pests, viruses, pathogens and plants) have become one of the most serious threats to the ecological and economic well-being of every habitat and region on the Earth (Boy and Witt, 2013).

The introduction of alien species to a new location can either be accidental or intentional (Enserink, 1999). Accidental introductions are helped by travel across countries and continents and import of various items such as timber, food grains, fodder etc (Shimono and Konuma, 2008). Intentional introductions are for a variety of purposes such as agriculture, horticulture, forestry and ornamental (Cremer, 2003). All invasive species possess certain biological attributes which contribute to their success as invaders in a new habitat. For invasive alien plants (IAPs), these attributes include production of a large number of easily dispersible, light weight seeds, fast growth rate and better competitive resource capture and utilization abilities compared to native plants (Enserink, 1999; Burns, 2006). The economic damage due to IAS is estimated to be to the tune of 1.4 trillion dollars globally. In many countries, the overall loss due to invasions is over 1% of the GDP. In the United States alone, for example, the annual costs of containing the spread of IAS are reported to be more than US\$ 135 billion (Boy and Witt, 2013).

The impacts of IAPs include displacement of native plant species, change of soil chemical profile, rewarding pollinators better than the native species thereby reducing the reproductive success of local species, changing hydrological regimes, making the new habitat fire prone and limiting the photosynthetic efficiency of the local species by reducing light availability (Nilsson and Grelsson, 1995). Subsequent impacts would happen by reduced availability of forest resources like medicinal plants from natural forests and timber

from forest plantations. As in the classical case of Kaziranga National Park (Assam, India) wherein the movement of the endangered one horned rhinoceros was limited by thickets of *Mimosa diploticha* var. *diplotricha*, the impact on fauna would also be critical (Vattakkavan et al., 2002). Indirect impacts occur by way of complete elimination of food plants of the fauna and by making the habitat fire prone.

It was believed that the threat of IAS would be much low in natural habitats as compared to disturbed habitats. Forests were considered to be immune to large scale plant invasions. However, recent studies have shown that this may not be true. The diversity of survival strategies adopted by invasive species has been shown to help them adapt to natural ecosystems including closed canopy forests. It has been predicted that owing to the high adaptability of IAS to new environments, their threat would increase in the context of global climate change and associated changes in local habitats.

Kerala State, south-west India, with a humid tropical climate, has a long history of maritime trade with Europe, the Middle East and other continents/countries which paved way for the early introduction of invasive species to the State. It may be noted that most of the IAPs in Kerala are native to tropical America which is in tune with the hypothesis that invasive species move along the latitudes. The recent opening up of the global markets and subsequent increase in the types and amount of goods imported has helped invasion by IAS more than ever before. In this context, the main objective of this study was to survey and assess threats due to IAPs in the natural forests of Kerala State. It was also envisaged to identify suitable methods to manage the existing threats and to prevent future incursions.

Methods

The data on the presence IAPs in forests was collected through road surveys conducted in the State of Kerala (lying between north latitudes 8°.17'.30" N and 12°. 47'.40" N and east longitudes 74°.27'47" E and 77°.37'.12" E). The survey conducted during 2012–2013 covered evergreen, moist deciduous and dry deciduous forests and grasslands. There were a total of 655 observations points which were distributed throughout the State. At each location, information on the IAPs in the area, intensity of their infestation and the native species and habitats impacted by these were collected. The data were then subjected to an Invasive Species Assessment Protocol (Morse *et al.*, 2004) to ascribe an invasive rank (Insignificant to High) to the species in question. Details on the invasive ranks used in the study are given in Table 1. According to Morse *et al.* (2004), the factors that contribute to rank a species as High risk are its ability to change ecosystem processes, to invade relatively undisturbed ecological communities, to cause substantial impacts on rare or vulnerable species, to disperse to new areas readily, wide distribution and general abundance wherever present and difficulty to

control. Conversely, species with minimal impacts on ecosystem processes, native species, and ecological communities will generally be ranked as Low or Insignificant. Other factors that can push a species as insignificant are lack of potential to spread beyond a small existing range, stable or decreasing abundance within the current range and ease of control.

Results and Discussion

A total of 38 IAPs were located in the forests of Kerala. Of these, 10 are of high risk, 12 pose medium risk, 10 low risk and the rest 6 are of insignificant risk as per the risk assessment conducted (Table 2). These include 5 trees, 10 shrubs, 4 sub-shrubs, 13 herbs and 6 climbers. The land of origin of majority of the species was Central and South America. Three species were of Asian origin 2 were from Africa and 1 from Australia. It is also important to note that most of the introductions into the forests of Kerala were intentional (30 species). Seven species were accidentally introduced and the motive and mode of introduction of one species viz, *Alternanthera philoxeroides*, could not be deciphered.

Table 1. Description of Invasive Ranks assigned to invasive alien plants in the study

Rank	Description
High	Species represents a severe threat to native species and ecological communities
Medium	Species represents moderate threat to native species and ecological communities
Low	Species represents a significant but relatively low threat to native species and ecological communities
Insignificant	Species represents an insignificant threat to native species and ecological communities

Table 2. Risk classes of invasive alien plants identified in the forests of Kerala

S. N.	Species	Introduction	Purpose	Rank	Habit	Origin
1	<i>Acacia mearnsii</i> De Wild.	Intentional	Afforestation	High	Tree	South-eastern Australia
2	<i>Ageratina adenophora</i> (Spreng.) R. M. King & H. Robinson	Intentional	Ornamental	Medium	Subshrub	Central America
3	<i>Ageratum conyzoides</i> L.	Intentional	Ornamental	Low	Herb	Central America
4	<i>Alternanthera bettzickiana</i> (Regel) G. Nichols.	Accidental	NA	Insignificant	Herb	Tropical America
5	<i>Alternanthera brasiliana</i> (L.) Kuntze	Intentional	Ornamental	Low	Subshrub	Central and South America
6	<i>Alternanthera philoxeroides</i> (Mart.) Griseb.	Unknown	Unknown	Insignificant	Herb	South America
7	<i>Amaranthus spinosus</i> L.	Accidental	NA	Low	Herb	South and Central America
8	<i>Asclepias curassavica</i> L.	Intentional	Ornamental	Insignificant	Herb	Tropical America
9	<i>Centrosema molle</i> Mart. ex Benth.	Intentional	Cover crop	Low	Climber	Central and South America
10	<i>Cestrum aurantiacum</i> Lindley	Intentional	Ornamental	Medium	Shrub	North and South America
11	<i>Chromolaena odorata</i> (L.) R. M. King and H. Robinson	Accidental	NA	High	Shrub	Tropical and subtropical America
12	<i>Clidemia hirta</i> (L.) D. Don	Accidental	NA	Low	Shrub	Central and South America
13	<i>Erigeron karvinskianus</i> DC.	Intentional	Ornamental	Low	Herb	South America
14	<i>Hyptis capitata</i> Jacq.	Intentional	Medicinal?	Medium	Herb	Central America
15	<i>Hyptis suaveolens</i> (L.) Poit.	Intentional	Medicinal?	Medium	Subshrub	Central and Tropical South America
16	<i>Ipomoea purpurea</i> (L.) Roth	Intentional	Ornamental	Medium	Climber	Central America
17	<i>Jatropha gossypifolia</i> L.	Intentional	Hedge plant	Insignificant	Shrub	Tropical America
18	<i>Lantana camara</i> L.	Intentional	Ornamental	High	Shrub	Central and South America
19	<i>Leucaena leucocephala</i> (Lam.) de Wit	Intentional	Social forestry	Low	Tree	Mexico and Central America
20	<i>Measopsis eminii</i> Engler	Intentional	Shade tree	Medium	Tree	West and Central Africa

S. N.	Species	Introduction	Purpose	Rank	Habit	Origin
21	<i>Merremia vitifolia</i> (Burm.f.) Hallier f.	Accidental	NA	High	Climber	South Asia
22	<i>Mikania micrantha</i> Kunth	Intentional	Cover crop	High	Climber	Tropical and subtropical America
23	<i>Mimosa diplotricha</i> var. <i>diplotricha</i> C.Wight ex Sauvalle	Intentional	Cover crop	High	Shrub	Central and South America
24	<i>Mimosa diplotricha</i> var. <i>inermis</i> (Adelb.) Veldk.	Intentional	Cover crop	Low	Shrub	Central and South America
25	<i>Mimosa pudica</i> L.	Intentional	Ornamental	Low	Herb	Tropical America
26	<i>Mucuna breacteata</i> DC.	Intentional	Cover crop	High	Climber	South and South-east Asia
27	<i>Parthenium hysterophorus</i> L.	Accidental	NA	Medium	Herb	North and South America
28	<i>Pennisetum polystachion</i> (L.) Schult.	Intentional	Ornamental	Medium	Herb (grass)	Tropical Africa
29	<i>Phytolacca octandra</i> L.	Intentional	Ornamental	Insignificant	Herb	Central and tropical South America
30	<i>Prosopis juliflora</i> (Sw.) DC.	Intentional	Fire wood	High	Tree	Central and South America
31	<i>Pueraria phaseoloides</i> (Roxb.) Benth.	Intentional	Cover crop	High	Climber	South and South-east Asia
32	<i>Senna hirsuta</i> (L.) Irwin & Barneby	Intentional	Ornamental	Medium	Shrub	Central and South America
33	<i>Senna occidentalis</i> (L.) Link	Intentional	Unknown	Low	Shrub	Tropical and subtropical America
34	<i>Senna spectabilis</i> (DC.) Irwin & Barneby	Intentional	Ornamental	Medium	Tree	Tropical America
35	<i>Senna tora</i> (L.) Roxb.	Intentional	Unknown	Medium	Subshrub	Asia and the Pacific
36	<i>Sphagneticola trilobata</i> (L.) Pruski	Intentional	Ornamental	High	Herb	South America and West Indies
37	<i>Synedrella nodiflora</i> (L.) Gaertn.	Accidental	NA	Insignificant	Herb	Tropical America
38	<i>Tithonia diversifolia</i> (Hemsl.) Grey	Intentional	Ornamental	Medium	Shrub	Mexico and Central America

*NA stands for Not Available

Distribution and the risk posed by plants belonging to different risk classes are discussed below.

High risk species

1. *Acacia mearnsii* (Black wattle)

Black wattle is a fast growing, evergreen, nitrogen fixing tree introduced in to Kerala in the 1980's for afforesting grasslands in high altitude areas. It is highly invasive in shola forests (tropical montane forests) viz., Mannavanshola, Pambadumshola and the Eravikulam National Park in Idukki district (above 2000 m asl) posing a big threat to several rare, endangered and threatened species in the forests (Sankaran *et al.*, 2005). The tree is an aggressive colonizer with the ability to invade warm temperate and moist tropical habitats alike. It produces a large amount of long-lived seeds which are triggered to germinate *en masse* by fire. The tree prevents establishment of native species by producing allelochemicals. The impacts due to the species include decrease in stream flow, loss of biodiversity, increased soil erosion, reduced carrying capacity and destabilization of river banks (Sankaran *et al.*, 2013). The distribution of the species is restricted to areas above 1500 m asl.

2. *Chromolaena odorata* (Siam weed)

The plant was accidentally introduced in to Kerala from Assam in 1940's where it was introduced from Tropical America much earlier. This fast growing, upright or scrambling perennial shrub is one among 100 of the world's worst invaders. It is widely distributed in the forests of Kerala especially in the fringes and wherever canopy is open due to disturbance or felling of trees. Having got naturalized in a variety of habitats, it can grow in dense stands and smother plants up to a height of 20 m (Sankaran *et al.*, 2013). Growth, development and yield of several native plants and crops are affected by chromolaena due its

aggressive growth, efficient root system, allelopathic effect, competition for light and water and capacity to establish under a wide variety of agro-ecological conditions. Control of chromolaena demands restoration strategies wherein the removal of the species needs to be supplemented with assisted regeneration of native plants.

3. *Lantana camara*

Introduced as an ornamental plant, this low, erect and vigorous shrub grows very dense in open un-shaded habitats such as wastelands, rain forest edges and forests recovering from fire and logging. Wherever invaded, it mainly grows as a dominant understorey species disrupting succession of native plants and decreases biodiversity. The plant is so persistent that it can completely stall regeneration of rain forests for several years. In Kerala, it is a big threat to disturbed forests especially moist-deciduous forests wherein large expanses of the forest area have been occupied by just this species. Mechanical removal of lantana and subsequent planting of indigenous species is the best option to control lantana infestations (Chandrashekar, 2001).

4. *Merremia vitifolia*

Commonly found in forest fringes and gaps, this twining climber has the ability to smother native flora by cutting sunlight to plants growing underneath. It grows vigorously and spreads aggressively which makes manual removal difficult. The plant is widely distributed in the forests of Kerala (Sankaran *et al.*, 2013). In situations where it grows up to the forest canopy, cutting the main stem would lead to drying of the plant but it increases fuel load leading to canopy fires. Considering this, new incursions of the plant may have to be controlled by cutting at the base at the seedling stage.

5. *Mikania micrantha*

Mikania is a fast growing perennial climber introduced from tropical America as a cover crop for tea plantations in Assam. Its introduction to Kerala is apparently through import of timber from countries in South America. It is one of the main invaders in natural forests and plantations in the State and is widespread (Sankaran *et al.*, 2001) causing extensive damage. Moist deciduous forests and young plantations of teak (*Tectona grandis* L.) are the worst affected. The species can climb up to the canopy, penetrate crowns and choke and pull over even large trees. It aggressively colonizes tree fall gaps in natural forests but cannot penetrate undisturbed forests with closed canopy. Also, the alleopathic substances produced by the plant affects growth of native species. Mikania reproduces both sexually and asexually and its flowers attract a large number of pollinators including butterflies creating competitive pressure on the regeneration of native flora.

Livelihood of tribal people living inside forests of Kerala has been affected by mikania invasion since their efficiency in collecting reeds and bamboos, their only means of income, is hampered by the weed (Sankaran *et al.*, 2001). Mechanical removal of seedlings of mikania, followed by planting fast growing native species and assisted regeneration are suggested methods of control of the weed. A biocontrol program using a rust fungus viz., *Puccinia spegazzinii* imported from Trinidad is reported to be successful in Papua New Guinea and Taiwan. Preliminary trials of biocontrol using this fungus in Kerala were encouraging but sustained infection on mikania could not be obtained in the field (Sankaran and Suresh, 2013). Re-release of the pathogen is currently being planned.

6. *Mimosa diplotricha* var. *diplotricha*

The plant was intentionally introduced as a nitrogen fixing cover crop in coffee plantations. It is a fast growing prickly shrub which can

scramble vigorously over other plants forming dense tangled thickets up to 3 m in height and prevent regeneration, reproduction and growth of indigenous species. It also impacts growth and establishment of other invasive weeds such as mikania, chromolaena and lantana. The plant is widespread in Kerala and is commonly seen in wastelands, fringes of disturbed forests, plantations, agricultural systems and along roadsides and railway tracks (Sankaran *et al.*, 2013). Mechanical control is difficult due to the presence of prickles and hence herbicidal application is commonly practiced. The species is currently rampant in non-forest areas but the possibility of invasion in to forests is very high. Early detection and rapid control is the only possible way to protect forests from this species.

7. *Mucuna bracteata*

Mucuna is a fast growing, perennial, creeping and aggressively climbing vine introduced as a nitrogen fixing cover crop mainly in rubber plantations in Kerala. The plant is drought and shade tolerant. It can choke, smother and pull down native trees by its gregarious growth and climbing behavior. Mucuna is a gregarious colonizer in all forest areas surveyed especially if these are close to plantations with this cover crop. Propagation is through seeds and fibrous roots which arise from nodes. It is one species which has escaped the confines of plantations and has started to invade forests from its fringes. It is extremely difficult to remove the plant once it is established. Planting this climber in plantations near forests needs to be prevented through legislation.

8. *Prosopis juliflora*

Prosopis, a spiny, fast growing, small to medium sized evergreen tree with a short, crooked trunk and large crown is a much debated species in India. While many consider it as a wonder tree which caters to the fuel wood and animal feed needs of

people in the arid and semi-arid zones, it has also been considered as a tough and resilient invasive species which can reduce the carrying capacity of invaded habitats (Sankaran *et al.*, 2005). While it is widespread in the neighboring Tamil Nadu, in Kerala, it is found only in the dry deciduous forests of Chinnar Wildlife Sanctuary. If the spread is unchecked, it can form dense, impenetrable thickets which can pose serious threat to native flora and fauna. It can also dry out the soil and compete with other plants for water especially in dry areas. The invasiveness and spread of *Prosopis* need to be carefully monitored in the context of climate change. The control measures are to be planned based on this information.

9. *Pueraria phaseoloides*

Introduced as a cover crop in rubber plantations for its capacity to fix atmospheric nitrogen, this shade tolerant, aggressive, deep rooted, twining and climbing legume has adapted to a variety of habitats and soil types. It grows gregariously in vacant lands and forest fringes and has the ability to climb up the canopy and smother medium sized trees (Sankaran *et al.*, 2013). The species warrants legislative control for its use in plantations adjacent to natural forests.

10. *Sphagneticola trilobata* (Singapore daisy)

It is a creeping, mat forming perennial herb planted widely as an ornamental for its beautiful yellow flowers contrasting with the thick green leaves. It has a wide ecological tolerance and can thrive well in open and shaded areas. The plant can easily displace native species and reduce biodiversity. It is a noxious weed in agricultural areas, coastlands, planted forests, urban areas and waste places and is widespread in the State (Sankaran *et al.*, 2013). The plant is common in the fringes of natural forests in the State and the chances of invasion deep into forests are imminent. Although very few viable

seeds are produced, the flowers are rich in nectar attracting pollinators from native species. Care need be taken not to introduce the species into gardens within forests since its control may require long term restoration work.

Medium risk species

Invasion is a dynamic process preceded by stages of introduction, establishment, spread and naturalization and hence at any given point of time, a set of invasive species would be at any one or more of these stages. Risk assessment is a useful tool to predict the possibility of a medium risk species to break off into a high risk species. However, continuous monitoring and adoption of suitable control measures is necessary to avoid this cross over. There are 12 IAPs in Kerala which fall under the medium risk category. These include shrubs like *Cestrum aurantiacum*, *Hyptis capitata*, *Senna hirsuta* and *Tithonia diversifolia* which were intentionally introduced mainly for ornamental purposes. While *C. aurantiacum* and *T. diversifolia* are seen invading medium to high altitude forests, others are limited to lowland forests. The medium risk species also include sub-shrubs such as *Ageratina adenophora*, *Hyptis suaveolens* and *Senna tora* which were also intentionally introduced. Of these, *Ageratina* is observed only in high altitude areas where it is an aggressive invader. *Ipomoea purpurea*, a medium risk climber, introduced from Central America for its beautiful flowers, is currently an invader of forest fringes especially in areas above 1500 m asl. Though *Parthenium hysterophorus* is only a medium risk invader in Kerala because of the unsuitable climatic conditions for its proliferation, elsewhere in India it is noxious weed occupying over 5 m ha of land in the country. Among other species, *Measopsis eminii*, though introduced only recently, has emerged as a medium risk species in high altitude areas in Wayanad (Sankaran *et al.*, 2013).

All medium risk species need be monitored regularly for expanding their territory. The forest staff is to be trained to identify these species and selectively cull them. Tracing of fire lines close to the boundary of forests during summer helps arresting the spread of some species which invade forest fringes.

Low risk species

Of the 10 low risk IAPs, 4 are herbs, 3 shrubs and one each belongs to the categories subshrub, climber and tree. The only tree in the group viz., *Leucaena leucocephala*, commonly occurs in open lands outside forests but at two sites (Thattakkadu in Ernakulam District and Muthanga in Waynad District), it was observed within forests. However, the chances of *Leucaena* becoming a major invader in forests of Kerala are meager since the tree prefers less acidic soils which is uncommon in the State. But, the tree poses a major threat to different ecosystems elsewhere in India (Sankaran et al., 2005). *Mimosa pudica*, although an invader for several decades, has never been a serious threat to any ecosystem in Kerala and it is likely to continue as such. The climber *Centrosema molle*, native to Central and South America, has been introduced as a cover crop in plantations. It is now widespread in the State and has been observed to invade forest fringes. Growth and spread of this species need to be monitored and control measures adopted to avoid its spread into forests. *Alternanthera brasiliana*, an ornamental plant which currently falls under the low risk category is a fast spreading species through vegetative means. The survey revealed that naturalized species viz., *Mimosa pudica*, *Ageratum conyzoides*, *Amaranthus spinosus* and *Erigeron karvinskianus* had little impact on the native flora.

Over all, it can be inferred that there are two groups of plants under low risk species; those which have become naturalized and not posing a serious threat to the habitats invaded while species

such as like *A. brasiliana*, a recent invader; warrants monitoring because of its invasive traits.

Insignificant species

Insignificant species recorded during the survey were found restricted to forest fringes and their distribution was scanty (Table 2). Most of them are characterized by poor ability for vegetative propagation and their rate of spread was low. Except for *Jatropha gossypifolia*, all others species are also susceptible to drought. Owing to these characteristics, species rated as insignificant are of least concern at present.

The results of the survey indicate that all high and moderate risk species require immediate attention and those in the other categories need be monitored closely for spread into interior forests. The following steps are proposed to manage existing IAPs and prevent any new incursions.

I. Preventive measures

This study revealed the presence of invasion alien plants in all the forest areas surveyed. It also showed direct and indirect impacts due to these invasions. It is recommended that a more comprehensive forest surveillance covering all the forest divisions in the State needs to be carried out before evolving proper control strategies.

To prevent new incursions of IAPs into forests, the following steps are to be adopted:

- i. All plants, plant propagules and soil intended for transportation into forest areas (soil for civil works, seedlings of forest tree species) should be thoroughly monitored for the presence of seeds and other propagules of IAPs.
- ii. Import of seeds, seedlings and other propagules of all plant species should be done only after risk

assessment and observing proper quarantine procedures.

- iii. Forest areas, especially those which are tourist destinations, need to have water filled dips at the entry point so as to wash agricultural implements and tyres of vehicles free of IAP propagules before entering into forest areas.

2. Early detection and rapid control

The most economical way to contain IAPs is to establish an efficient surveillance system so as to detect IAPs soon after their arrival and eradicate them when their population is small and the spread is limited. To achieve this, sea ports, airports and tourist and pilgrimage routes into forest areas are to be monitored regularly for new invasive species using proper tools and methods. The staff of quarantine/customs and forest department need be trained to identify IAS which are potential threats so as to adopt measures to stop incursions and contain the population.

3. Prevention of spread

For IAPs which have already established in some areas and immediate eradication is difficult, efforts should be focused on preventing their spread by: 1) restricting the movement of soil and plant parts from infested areas to un-infested areas and 2) removing the weeds manually or mechanically (cutting or pulling) before flowering and fruiting and burning them at the site.

4. Habitat restoration

Manual/mechanical control may be difficult, costly and unsustainable for alien weeds which have established in large areas. In such cases, systematic restoration strategies should be taken up. To achieve this, remove the weeds manually or mechanically (pulling along with roots/tubers)

in small areas at a time and subsequently plant the area with fast growing native species. Assisted regeneration may also be attempted in such areas.

Conclusion and recommendations

IAPs are a serious threat to forests of Kerala since they impact heavily on native biodiversity, productivity and result in landscape level changes. The problem demands urgent attention. Prevention of new incursions can be achieved by adopting risk assessments before import of plants and planting material and adopting proper quarantine measures at sea and airports. Forest surveillance, early detection and rapid control, manual/mechanical removal of weeds followed by planting of native species and assisted regeneration are suggested as immediate steps to control invasion and reduce impacts. Herbicidal application in forest areas need to be avoided as far as possible.

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Invasive Alien Species: Threats and Challenges for Biodiversity Conservation- A Case Study of Annapurna Conservation Area, Nepal

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Abstract

Invasive Alien Species (IAS) are emerging as one of the major threats to biodiversity conservation. They are considered as the second largest threat to global biodiversity loss after habitat destruction. Climatic variability, physiographic range, increasing trade, travel and tourism have accelerated the spread of unwanted non-native species to conservation areas, making vulnerable to the establishment of IAS. The ecosystem in conservation areas of high hills region in Annapurna Conservation Area (ACA) are now under serious threat due to rapid establishment of IAS, causing decline or even extinction of native species.

The paper highlights the people's perception towards the rapid expansion of IAS and explores IAS found in study area with the potential of threatening sustainability of livelihood and forest ecosystem. The study was carried out in seven Village Development Committees (VDCs) namely *Dhampus*, *Lwangghalel*, *Rivan*, *Lahachowk*, *Ghachowk*, *Machapuchhre* and *Sardikhola* of ACA. Total of 140 individuals were surveyed to know the people's perception and historical understanding of IAS. 21 plots of 20 × 20 m² for trees, 5 × 5 m² for shrubs and 1 × 1 m² for herbs were laid randomly adjoining the forest at 10 to 100 m distance from the road and settlement area. Total 11 IAS were recorded among which *Ageratina adenophora* was found to be the most dominant species and is also reported as one of the top six Nepal's high risk invader species. With the increasing canopy of forest cover decreasing invasion of IAS was found. Climate change was found as an additional triggering factor after human interference for making an area suitable for easy establishment of IAS. Though the study area was found to be invaded by the IAS, no scientific methods (effective biodiversity conservation measures) have been applied for protecting native species and controlling the rapid expansion of IAS.

Avoiding over-exploitation of the biological resources in forests, plantation in shrub lands and degraded area, effective controlling mechanism to check spreading of IAS, community participation and awareness have been recommended as some strategies to cope with the problem of IAS infestation. It is crucial to assess the status and develop a database on IAS in ACA as the area is considered to be highly diverse in terms of flora and fauna.

Keywords: Invasive alien species, climate change, conservation.

Introduction

Biodiversity has become one of the most popular topic for discussion at local, national and global level. Biodiversity entails all forms of biological entities inhabiting the earth including prokaryotes—wild plants and animals, microorganisms, domesticated animals and cultivated plants and even genetic material like seeds and germplasm (Kothari, 1993). IAS are species, native to one area or region, that have been introduced into an area outside their normal distribution, either by accident or on purpose and which have colonized or invaded their new home, threatening biological diversity, ecosystems and habitats, and human well-being (CBD, 1992). Biological invasion worldwide threatens biodiversity, ecosystem dynamics, resource availability, national economy and human health (Ricciardi *et al.*, 2000). The spread of IAS is now recognized as one of the greatest threat to the ecosystem. High climatic and physiographic diversity make Nepal a suitable habitat for easy establishment IAS. Majority of alien plant species in Nepal are confined to the low lands below 2000m whereas the highest concentration of endemic species (upto 91 percent) occurs in sub-alpine zone (3,000–4,000 m), particularly in central Nepal (Tiwari *et al.*, 2005). Invasive plant species alter native community composition, deplete species diversity, affect ecosystem process and thus cause huge economic and ecological imbalance (Dogra *et al.*, 2009). Annapurna Conservation Area (ACA) is considered to be rich in biodiversity. ACA represents several ecosystems, including broad-leaf forests, pine conifer forests and alpine meadows. It is an abode to more than 102 mammalian species, 488 bird species, 88 herpetofauna and 1,238 plant species (Bajracharya *et al.*, 2007). ACA is the only protected area of Nepal where all 6 Himalayan Pheasants of Nepal are found. ACA is not untouched with the rapid establishment of IAS. Public recreational opportunities and experiences have been severely degraded by rapid infestations

of invasive species (Thomas, 2003). The existing biodiversity and peoples livelihood is in threat because of IAS. The paper highlights the people's perception towards the rapid expansion of IAS and explores IAS found in study area with the potential of threatening sustainability of livelihood and forest ecosystem.

Materials and Methodology

Study Area: ACA is the Nepal's first and largest conservation area. ACA is known for its high biodiversity and home to many endangered species. 7 VDCs namely Dhampus, Lwang ghalel, Rivan, Lahachowk, Ghachowk, Machapuchhre and Sardikhola of ACA were selected for the study. ACA is also becoming home to many unwanted non-native plants. Very limited research has been carried out IAS in ACA.

Data collection: Questionnaire survey was carried out from February to March 2012. 140 individuals who have long been inhabited in the study area and utilizing the local resources for their livelihood were interviewed to explore their perception regarding IAS. 21 sampling plots of various sized quadrates (Tiwari *et al.*, 2005) $20 \times 20 \text{ m}^2$ for trees, $5 \times 5 \text{ m}^2$ for shrubs and $1 \times 1 \text{ m}^2$ for herbs were laid at 10 to 100m distance in adjoining forest from road and human settlement area. Nested plots $5 \times 5 \text{ m}^2$ and $1 \times 1 \text{ m}^2$ quadrates were allocated randomly in two corners of $20 \times 20 \text{ m}^2$ plot. Community consultations, individual interviews, field observations, literature review were conducted to collect data.

Data analysis: Both quantitative and qualitative techniques were used for data analysis. Density and frequency were calculated. The analysis was interpreted in a simple and understandable chart form. Climatic characteristics of the study area were assessed in terms of average annual maximum and minimum temperatures and annual precipitation

by analyzing the data recorded by Lumle meteorological station, Kaski, Nepal.

Methods of calculation:

$$\text{Density (per square meters)} = \frac{H/I}{A}$$

Where: H = Total no. of individuals of a species in all the quadrats.

I = Total quadrats studied.

A = Area of the quadrat.

Frequency = $J/I \times 100$

Where: J = No. of quadrats in which the species occurred.

I = Total quadrats studied

(Mishra, 1968)

Results and discussion

IAS in study area: Altogether 11 IAS (Table I) were encountered in the sampled areas. Among the IAS observed, *Ageratina adenophora* was most common in the study area. It had the highest cover in the adjoining forest, near settlement where human disturbances were high. Based on household survey *Ageratina adenophora* was found to be the most problematic IAS.

Table I. IAS observed in study area:

Scientific name	Local Name	Habit
<i>Oxalis latifolia</i>	Chari amilo	Herb
<i>Mimosa pudica</i>	Lajjawati jhar	Herb
<i>Bidens pilosa</i>	Kalo kuro	Herb
<i>Ageratum houstonianum</i>	Nilo gandhey	Herb
<i>Amaranthus spinosus</i>	Kande ludo	Herb
<i>Lantana camara</i>	Banmara	Shrub
<i>Chromolaena odorata</i>	Seto Banmara	Shrub
<i>Ageratina adenophora</i>	Kalo banmara	Shrub
<i>Imperata cylindrical</i>	Siru	Herb
<i>Rubus ellipticus</i>	Aaiselu	Shrub
<i>Solanum xanthocarpum</i>	Kantakari	Shrub

Source: Field data 2013

Rapid establishment of *Ageratina adenophora* is homogenizing the natural area. An area where tree canopy is dense and where the undergrowth do not find sufficient sunlight, invasion of species is low compared to open and degraded land. Therefore, with increasing tree canopy there is decreasing invasion of unwanted species. After *Ageratina adenophora*, *Agertum houstonianum* and *Chromolaena odorata* were other to IAS found with high density in the study area. The spread of IAS especially *Ageratina adenophora* is complex and is threatening both the natural biological richness and livelihood of inhabitants. Many locals have stopped grazing their livestock in forest as the palatable grasses in the forest like *Imperata cylindrical*, *Artemisia vulgaris* etc. are rapidly being replaced by the IAS especially by *Ageratina adenophora*. *Ageratina adenophora* has reduced the regeneration of tree species eg. *Alnus nepalensis* regeneration is heavily reduced and replaced by *Ageratina adenophora*.

Perception towards IAS: There are, altogether, 166 alien plant species naturalized in Nepal as assessed by Tiwari et al., 2005. Impacts of *Ageratina adenophora* was well observed throughout the study area. Edges of forests, agricultural lands, wetlands and roads were invaded by the species. The abandoned agricultural lands and adjoining forests served as a good refuge for *Ageratina adenophora*. All the respondents believe the new unwanted species are spreading and replacing the native species. This was also confirmed by field observations too. Exotic invasion is often associated with declines in local plant diversity (Richardson et al., 1989). In recent years, the establishment and spread of IAS in areas where they do not occur naturally, are receiving increasing importance from scientists, policymakers and the public (Tiwari et al., 2005). 52.1% believed human interference like open grazing, trampling, excess throwing of wastes and use of chemical fertilizer and pesticides in agriculture land and IAS are responsible for rapid establishment where as 47.9% believed increasing temperature is another reason of easy establishment of IAS. The reason behind the invasion of new species is increasing human interference and changing climate. Climate change has become additional triggering factor for rapid and easy establishment of IAS. For this, meteorological data were interpreted. The analyzed data (Chart I) showed the mean maximum temperature is increasing per year which is favoring the easy establishment of IAS.

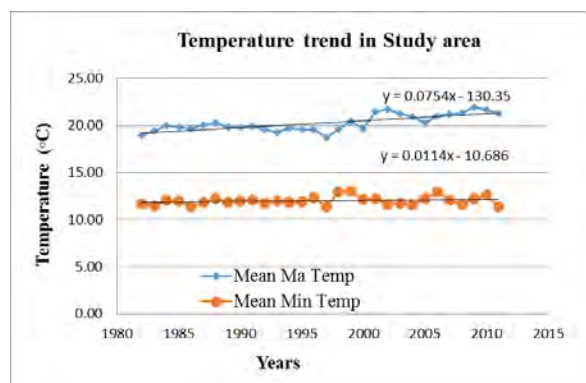


Chart I. Temperature trend in study area

Source: Meteorological station, Lumle 2011

Management practices:

The impact of IAS on biodiversity has been described as immense, insidious and usually irreversible (Mcneely, 2000). Majority of respondents (72.1%) were not using IAS in anyway, they are ignoring the impact caused by IAS and only 17.1% of respondents were found using *Ageratina adenophora* in composting. Many management practices (mechanical, chemical and biological) exist for controlling spread of IAS. However, in the study area people are found practicing rare hand pulling and composting not to spread of IAS in farmland. Once an invasive species becomes established, eradication may be impossible and ecological damage irreversible (Shrine et al., 2000).

Conclusion: IAS posses capability to alter the structure, function and dynamics of an area. IAS is responsible for the loss of diversity of species. The invasion of *Ageratina adenophora* is rapidly increasing in ACA. *Ageratina adenophora* has started replacing native grasses and affecting the growth of plant species. Though the effect of *Ageratina adenophora* has already been noticed, quick controlling methods are deemed necessary to control its rapid expansion. Preventing their introduction, early detection and reporting of infestation of new and naturalized IAS, awareness at the local level were recommended as strategies to deal with the existing problem of IAS in ACA. It is crucial to assess the status, impact on ecosystem and develop a database for IAS in ACA and elsewhere.

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The Biology and Management of Parthenium Weed: An Invasive Weed Now Affecting the Native and Agro-Ecosystems of Nepal

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Abstract

The information presented in this review demonstrates that parthenium weed is an extremely aggressive and prolific invasive weed of growing significance in Nepal. Several aspects of its reproductive biology and ecology contribute towards its invasiveness and reports of the weed's incursion into new localities are common place. In Australia, the integration of various management methods (legislative control, grazing management, sowing of healthy pasture seed, the application of herbicides and use of the biological control agents) have all been found to aid in the management of parthenium weed. Moreover, recent studies have concluded that parthenium weed can be effectively managed by complementing the presently existing biological control approach with suppressive plants, and this approach is likely to work in the future in Nepal and other locations around the globe where parthenium weed is becoming problem.

Keywords: Integrated weed management, invasive alien plants, control.

Nepal's next worst weed

Parthenium weed (*Parthenium hysterophorus* L.) is an annual herbaceous plant, that invades disturbed land, degrades natural communities, can cause serious allergic reactions in people, domesticated livestock and other wildlife, and is a significant problem in crop, grassland and forestry production (Adkins and Shabbir, 2014). It is a major invasive weed in many parts of the world, and is rapidly becoming a major threat to Nepal with a growing potential to cause immeasurable ecological and agricultural losses each year in this country.

The plant

Parthenium weed is native to the region around the Gulf of Mexico including the southern United States of America (Navie *et al.*, 1996) and possibly native to northern Argentina, southern Bolivia and south west Brazil. Parthenium weed is an annual with an erect and much branched plant reaching a height of 2.5 m at maturity, although most individuals do not exceed 1.5 m. The leaves are pubescent and strongly dissected into narrow lobes. The small white flowers usually have five distinct ray florets and grow on the ends of the branches. A typical flower produces four or five small, blackish achenes enclosed in a straw coloured fruit layer with two lateral attached sterile florets. The rapid germination rate and fast growth and the allelopathic nature of the weed help it suppress neighbouring vegetation and allow it to grow vigorously and as a result produce a large number of seed which add to the soil seed bank.

Spread

The weed can produce large quantities of viable seed (>20,000 per plant: Nguyen, 2011) and more than 340 million seed per ha can be present in the soil seed bank (Navie *et al.*, 1996). The seed is easily spread by vehicles, farm machinery, domestic and wild animals in contaminated pasture

and stock feed lots, and in river or flood water (Adkins and Shabbir, 2014). International spread between countries has occurred due to the movement of contaminated produce (grain for human or cattle feed, and planting seed lots) or is introduced on vehicles. International spread of parthenium weed in the past 3 to 4 decades has been rapid and by a variety of pathways (Table 1). Parthenium weed was first reported in Nepal in 1968 (a herbarium record) and was thought to have been introduced from India. Populations establishing in the 1980's are thought to be those that have given rise to the major outbreaks seen today. By 2013 it had invaded large portions of the Terai and regions of the mid hills (Shrestha *et al.*, 2014 in press).

Biology

Parthenium weed normally germinates in the spring, producing flowers and seed throughout its life cycle and dies in late autumn. It can start flowering when plants are only 1 month old and will continue to flower for a further 6 to 8 months. Parthenium weed is able to germinate, grow and flower over a wide range of temperature and photoperiod conditions; hence in Nepal it can be seen growing in the field at any time of the year. However, the principal season of growth is in the monsoon when it is warm and rainfall is plentiful. Its aerial parts do not tolerate frost well and most plants die during cold winters. With respect to soil type the weed grows and develops very well on black, alkaline, cracking-clay soils of high fertility but it is also present on a wide variety of other soils from sandy loams to clay loams. Parthenium weed is found mostly in naturally disturbed areas and in areas that have poor ground cover such as wastelands, cleared lands, and degraded pastures. Other common habitats for this weed include many types of crops, orchards, plant nurseries, public lawns and open spaces in towns, sides of roads, rivers, canals and railway tracks, on construction sites and in forests.

Table 1. Global distribution of parthenium weed within its native and introduced range (modified from Adkins and Shabbir, 2014).

Range	Country
Native range (20 countries)	South America: Argentina, Paraguay, Uruguay, Venezuela, Bolivia, Brazil, Guyana, Chile, Peru. North and Central America: USA, Mexico, Haiti, Cuba, Honduras, Guatemala, Puerto Rico, Trinidad, Nicaragua, Republic of Panama, Costa Rica.
Introduced range (35 countries)	South Asia: Pakistan, India, Bangladesh, Sri Lanka, Nepal, Bhutan. East and Southeast Asia: Malaysia, China, Vietnam, Japan, Republic of Korea, Taiwan. Middle East: Israel, Oman, Yemen. Australia and Oceania: Australia, Vanuatu, New Caledonia, Hawaii, Papua New Guinea, Christmas Island. East Africa: Ethiopia, Somalia, Uganda, Kenya, Eritrea, Djibouti, Southern Africa: South Africa, Mozambique, Zimbabwe, Swaziland, Tanzania, Seychelles, Mauritius, Madagascar, Northern Africa: Egypt.

Seed biology and seed banks

Navie *et al.* (1996) found that the best temperature for germination was between 22 and 25 °C, but the weed had a wide range of temperatures in which germination could take place (9 to 36 °C). The same authors also demonstrated under field conditions more than 70% of seed buried 5 cm below the soil surface would live for at least 2 years, with a half-life of 7 years. In Australia, Navie and co-workers (1998) determined the size of the viable soil seed bank at two infested beef pasture sites and found it to range from 3,200 to 5,100 seed m⁻² in a black, cracking clay soil with a low ground cover and up to 20,500 to 44,700 seed m⁻² in a sandy loam soil close to a creek. Nguyen (2011) has recently reported that a parthenium weed seed bank still exists at these two field sites, and now 15-years later, after some management had been applied, both sites still have moderate seed banks in the range of 5,000 to 6,000 seed m⁻². In other locations around the world, much

higher parthenium weed seed banks have been recorded. For example, Joshi (1990) estimated the parthenium weed soil seed bank to be ca. 200,000 m⁻² in a series of abandoned, but weed invaded fields in India.

Allelopathic interference and phytotoxicity

Parthenium weed has been reported to be a strongly allelopathic species (Kanchan and Jayachandra, 1980) and this trait has been suggested to be important in invasion and persistence in a wide range of native and non-native ecosystems. Parthenium weed contains potential allelochemicals within its aerial parts (e.g. leaves), pollen and in its roots. It is reported that these chemicals can inhibit the germination and growth of a wide range of plant species including native plants, as well as various crops and pasture species (Adkins *et al.*, 1997). Parthenium weed residues are reported to have a phytotoxic effect upon a number of important field, horticultural, vegetable and agroforestry crops.

Direct and indirect effects on crop and livestock production

Parthenium weed can invade a wide range of crops and of particular concern is the invasion of cereal crops such as wheat (*Triticum aestivum* L.), maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* Monech L.). In such crops, parthenium weed has been shown to reduce yields by as much as 40% in India or by as much as 28% in Ethiopia. Contamination of rice (*Oryza sativa* L.) and wheat seed lots with seed of this quarantinable species has severe consequences for the export of these crops. Parthenium weed is also a serious weed of pastures and rangelands in different parts of the world. It has been reported that parthenium weed can reduce the carrying capacity of pastures by as much as 40% in Australia (McFadyen, 1992) and up to 90% in India. Other indirect costs to livestock producers include the additional expense incurred for the purchase of herbicides and their application, and labour and machinery hire to help manage the weed. The indirect impacts of parthenium weed on agricultural production are also significant. On a local scale, contamination with parthenium weed seed can affect the marketing of pasture and crop seed lots. Parthenium weed can also cause indirect losses to crop production by acting as a secondary host to a number of important crop pests and diseases. These include economically important pests such as the common hairy caterpillar (*Diacrisia obliqua* Walk.), bean black rot (*Xanthomonas campestris* pv. *Phaseoli*) and tobacco streak virus, TSV.

Effects on native plant communities

Studies have shown parthenium weed disrupts the structure of natural ecosystems and displaces numerous native plant species from those ecosystems (Shabbir and Bajwa, 2006). The weed has become a major threat to many protected areas, forest reserves and national parks around the

world including the Kruger National Park, South Africa, as well as Chitwan National Park in Nepal (Shrestha et al. 2014 in press).

Effects on health

Parthenium weed is a notorious allogeneic plant, with health effects being reported from almost all the countries where this weed has invaded (e.g. Goldsworthy, 2005). People can become affected in two ways, either by direct contact, or by indirect contact through airborne particles. There is no treatment for sensitivity to the plant or its airborne parts, and no desensitising therapies are available. Dermatitis, hay fever, asthma and bronchitis can be managed with antihistamine medications but these are not always effective or obtainable in many locations where the weed is found. Non-contact, allergic respiratory disorders in susceptible people have been reported to have caused some deaths in India. The weed is poisonous to livestock and may cause death after 30 days if significant quantities are ingested. Chemicals within the plant are thought to alter the microbial composition of the rumen of dairy cattle, buffalo and sheep, and can impart a bitter taste to their milk and the meat of cattle and sheep can develop an undesirable flavour.

Management approaches

A number of different approaches have been used for managing parthenium weed, but to date no single method alone has been shown to be effective. Thus, an integrated weed management approach is more commonly used for parthenium weed and this involves a number of the management approaches described below.

Cultural management: In Australia, parthenium weed whenever found, needs to be reported to the concerned State authorities and management undertaken. Machinery and vehicles coming from infested areas must be cleaned thoroughly to

remove all parthenium weed seeds before they can continue their work. This can be done by washing with a high-pressure hose or by using road-side wash down facilities. Reductions in stocking rate and more appropriate rotational timings between each grazing event are the most useful methods to manage parthenium weed in pastures. So far very few control measures have been put into place for parthenium weed in other countries. In India, the State of Karnataka placed parthenium weed into the category of an agricultural pest in 1969, but this legislation could not be enforced and therefore was unable to prevent its spread to other States. In South Africa, in 1983, parthenium weed was declared a Category 1 weed, preventing people from transporting it to uninfested areas. Similarly in Sri Lanka, parthenium weed was also declared as a noxious weed and under this legislation, the movement of adult plants is strictly forbidden to areas which are not presently infested.

Physical management: In some countries, the manual removal of parthenium weed is not considered to be a cost effective approach due to the size of the weed infestations present and the cost of the labour in that country. In addition, this method of management may also affect the health of the workers who are employed to do this job. Furthermore, parthenium weed populations readily regenerate after manual removal and will regrow from cut or partly pulled plants that still have a root system. The hand pulling strategy is commonly used in Nepal where labour is cheap and people are not aware of the associated health risks of pulling up the plant.

Chemical management: Chemical control is only financially feasible within some high value crops and in other circumstances such as along roadsides, in public parks or on small areas. It is not cost effective to chemically control this weed over the vast areas where the weed is commonly found. Plants should be chemically treated when they are small and at

the pre-flowering stage. In pastures, maintaining plant competition is important for the effective management of parthenium weed with chemicals. Various selective herbicides (e.g. glyphosate, paraquat, metsulfuron) have been reported to be effective in the chemical management of parthenium weed in a number of different situations.

Biological management with suppressive plants:

Attempts to use beneficial plants that can suppress the growth of parthenium weed were initially undertaken in India. Among the plants screened, one leaf senna (*Cassia uniflora* Mill.) was found to be the most suitable with this plant suppressing the growth of parthenium weed seedlings. Recently, Khan and co-workers (2013) tested a number of native and introduced pasture species and identified several that could suppress parthenium weed in the field. More recently Shabbir and co-workers (2013) showed in a field study, biological control agents and the suppressive plants to act synergistically to significantly reduce the biomass and seed production of parthenium weed.

Biological management with insects and pathogens:

Classical biological control is one of the most important approaches used for the management of invasive weeds. In this approach, insect herbivores or plant pathogens from the native range of the weed are introduced, to suppress the growth of the weed, in the introduced range. Only five countries (Australia, South Africa, India, Ethiopia and Sri Lanka) so far have released biological control agents against parthenium weed. A further country (Vanuatu) is in the process of releasing biological control agents, and others (Kenya, Pakistan, Nepal, Ethiopia) have agents that have accidentally arrived there. Biological control is the most widely used management tool for parthenium weed in Australia where this strategy has been investigated for more than 20 years and was recently reviewed Dhileepan and McFadyen, 2012. The initial surveys for potential natural enemies of parthenium weed

started in 1975 in Central and South America, and to date, 11 biological control agents (nine insect species and two rust fungi) have been released into the field in Australia (Table 2). Three agents, *Epiblema strenuana* Walker (a stem galling moth), *Zygogramma bicolorata* Pallister (a leaf feeding beetle) and *Listronotus setosipennis* Hustache (a stem boring weevil) appear to be having a significant impact upon the weed in the field.

Integrated weed management: In many locations parthenium weed is able to survive the individually applied management measures. Integrated weed management, on the other hand, involves the combination of all available methods for the weeds management and is considered to be the most effective approach to the long-term control of parthenium weed. Such packages of integrated weed management need to be effective and economical against the weed, easy to implement and environmentally friendly. The

integration of suppressive pasture plants with the existing biological control agents is considered to be one part of an integrated parthenium weed management program. So far this approach has not been widely applied against parthenium weed. In several countries, the application of management methods falls up on the community and other land management teams to carry it out. To link different regional working groups and to facilitate the exchange of information on parthenium weed and its management, an international parthenium weed network has been established at the University of Queensland. Since its establishment in 2009, the network has expanded significantly with more than 300 members across 30 countries. This online network has contributed significantly in the dissemination of information, creating new research ideas and has provided access to its members to various on-line resources such as identification kits, best management practice guides and regular e-newsletters.

Table 2. The biological control agents that have been released to help manage parthenium weed, their movement to other countries and the status of their establishment in those locations.

Insect/pathogen species	Order	Origin	Released country or country where found	Establishment
<i>Epiblema strenuana</i> Walker	Lepidoptera	Mexico	Australia, China ^a	Yes
<i>Zygogramma bicolorata</i> Pallister	Coleoptera	Mexico	Australia, Ethiopia, India, South Africa, Pakistan ^b , Nepal ^b	Yes
<i>Listronotus setosipennis</i> Hustache	Coleoptera	Argentina	Australia	Yes
<i>Smicronyx lutulentus</i> Dietz	Coleoptera	Mexico	Australia	Yes
<i>Contrachelus albocinereus</i> Fiedler	Coleoptera	Argentina	Australia	Yes
<i>Carmenta nr ithacae</i>	Lepidoptera	Mexico	Australia	Yes
<i>Bucculatrix pathenica</i> Bradley	Lepidoptera	Mexico	Australia	Yes
<i>Platphalonidia mystica</i> Razowski & Becker	Lepidoptera	Argentina	Australia	No
<i>Stobaera concinna</i> Stal	Homoptera	Mexico	Australia	No
<i>Puccinia abrupta</i> var <i>parthenicola</i> (Jackson) Parmelee	Uredinales	Mexico	Australia, India ^c , South Africa ^c , Kenya ^c , Nepal ^c , Ethiopia ^c , China ^c	Yes
<i>Puccinia xanthii</i> f.sp. <i>parthenium hysterophorae</i>	Uredinales	Mexico	Australia, South Africa, Sri Lanka	Yes

^a First released as biocontrol agent against rag weed, *Ambrosia artemisiifolia*

^b Come through neighbouring country, India.

^c Source unknown

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Genetic Diversity Assessment of the Alien Invasive Weed *Parthenium hysterophorus* L. in Nepal

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Abstract

Parthenium weed (*Parthenium hysterophorus* L.) is one of the most serious and obnoxious weeds which has spread to significant parts of Nepal causing adverse effects on agriculture, forestry, the urban environment as well as human and livestock health. Invasion by this weed is an emerging problem for Nepal with its first suspected introduction dating back to the 1960's. *Parthenium* weed is among the top seven world's worst weeds with a pantropic distribution. It is now spreading widely in most urban and peri-urban areas, along highways, in pastures in the tropical and sub-tropical areas of Nepal and more recently into cropping lands. This weed does not only reduce land values and cause economic losses of agricultural products but is also the source of air-borne particles (pollen and fine hairs) that can cause various health problems in human as well as in domesticated and wild animals. Due to its rapid expansion in the past 20 years, its risk status in Nepal has dramatically increased. Thus, understanding the molecular genetic diversity of its populations will be an important step forward to help understand its polymorphic status and the potential impacts of potential control measures may have on it. Sequence based phylogenetic studies will help to determine the invasion pathways of this weed into Nepal. Since morphological and physiological traits are subjected to environmental influences, emphasis has shifted to nucleic acid based studies to generate information on intrinsic genetic variation within and among weed populations. Consequently, a Simple Sequence Repeats (SSR) study is being undertaken to assess the population genetic diversity and structure of Nepalese populations of *parthenium* weed. So far, 375 leaf samples from 375 plants, representing 25 populations, have been collected from across Nepal. After optimization, a modified DNA extraction technique yielded good quality DNA in a concentration range of 173 to 526 ng μL^{-1} . Optimization of the PCR reaction conditions is being carried out for each of 15 primer pairs by varying the MgCl_2 , template DNA, primer and *Taq* polymerase concentration. The primers that identify the best polymorphisms will be selected to profile the *parthenium* weed accessions from different Nepalese populations. In order to find out the origin of Nepalese populations, samples from India and its native countries i.e. Mexico and USA will also be incorporated into the study. The generated data will be used to assess whether the genetic diversity in *parthenium* weed populations has facilitated its rapid expansion in Nepal.

Keywords: Weed, weed invasions, population genetics, molecular markers, simple sequence repeats.

Introduction

Parthenium weed (*Parthenium hysterophorus* L.), regarded as one of the top seven world's worst weeds (Patel, 2011) and with a pantropic distribution, has become a significant problem in Asia including Nepal, India, Pakistan, Bangladesh, Bhutan, Sri Lanka, China, Vietnam and more recently Malaysia. For Nepal, it is an emerging problem with its suspected first introduction dating back to the 1960's. It was first collected in 1967 from the Trishuli Valley, north of Kathmandu. Since then it had spread into the Kathmandu Valley and in the last 10 years has become a dominant weed species in this region (B. B. Shrestha, pers. obs.). It is now spreading widely in most urban and peri-urban areas, in pastures and along highways in the tropical and sub-tropical areas of Nepal. In 2005 it was categorized as a medium risk alien invasive species for Nepal by the World Conservation Union (Tiwari *et al.*, 2005). However, due to its rapid expansion rate, its current risk status has grown to high risk. Parthenium weed does not only reduce land values and cause economic losses to agricultural and forest produce but is also the source of air-borne particles that can cause various health problems in human (e.g. asthma, allergic-rhinitis as well as skin problems e.g. dermatitis and other forms of skin allergies) (Goldsworthy, 2005) and in domesticated animals as well (B. B. Shrestha, pers. obs.).

The strong allelopathic activity (Kanchan and Jayachandra, 1981; Sharma, 1985; Singh *et al.*, 2002; Maharjan *et al.*, 2007), the prolific seed production (Pandey and Dubey, 1988) and the phenotypic plasticity in growth forms of parthenium weed (Annapurna and Singh, 2003; Pandey *et al.*, 2003) are thought to enable this species to invade into a wide range of habitats in areas where natural ecosystems have been disturbed to varying degrees by anthropogenic activities. Taking into consideration the potential impact that parthenium

weed can pose on agriculture, environment, animal and human health (McFadyen, 1995; Evans, 1997), an urgent need is now felt to initiate a national level effort for parthenium weed management.

The interactive effects of climate change and invasive alien species (IAS) is posing serious threats to native biodiversity, ecosystem functions and human well-being worldwide. Climate change is expected to have profound effects upon plant community biodiversity, inducing changes in the phenology of individual species, the genetic composition of populations, and the range a species may have (Parmesan and Yohe, 2003; Parmesan, 2006). On one hand, the survival of native, endemic, rare and threatened species, having limited distributional range is of major concern as their distribution will be more restricted in changing climate scenarios, while on the other hand, distribution of IAS will be more profound as more suitable locations for them are being created by climate change (Smith *et al.*, 2012). Rapidly evolving IAS are therefore the centre of attention to many plant biologists and environmentalists as they are one of the major threats to the reduction in species biodiversity under a changing climate. There can be different consequences of climate change on invasive species including altered impacts of existing invasive species, altered distribution of existing invasive species and altered effectiveness of control strategies for invasive species (Hellman *et al.*, 2008).

Many different molecular marker systems have been employed to study genetic diversity and their relationships when trying to understand the biology and integrated management of various weeds (Shrestha *et al.*, 2003; Ye *et al.*, 2004; Shrestha *et al.*, 2010; Burgos *et al.*, 2011; Yan *et al.*, 2011; Qian *et al.*, 2012). Genetic markers are able to provide clues in the patterns of weed invasion, the heritability of traits (e.g., herbicide resistance), taxonomic relationships, point of origin, and gene

flow. Population and species-level diversity is important in weed management to understand genetic bottlenecks, fitness, and numbers of introduction events that contribute to successful invasion (Goolsby *et al.*, 2006; Hufbauer, 2004; Sterling *et al.*, 2004).

Understanding the molecular genetic diversity of a weed in its native and introduced habitats is vital for devising effective weed control strategies using various biological, chemical and cultural means (Nissen *et al.*, 1995; Lopez-Martinez *et al.*, 1999; Amsellem *et al.*, 2000; Tang *et al.*, 2008). Furthermore, the knowledge of population genetic structure of invasive plants is essential for improving the efficacy of biological control programs (Burdon *et al.*, 1981; Chapman *et al.*, 2004; Gaskin *et al.*, 2005). Intra-specific genetic variation has been shown to play an important role in determining effectiveness of biocontrol agents as different weed populations may exhibit different defence mechanisms against various agents (Wang *et al.*, 2008). A mixture of both resistant and non resistant genotypes within an invasion may hinder biological control efforts because plants resistant to the biological control agent will become dominant (Burdon *et al.*, 1981). Moreover, analyses of

molecular genetic variation can characterize the roles that local and long-distance dispersal events have played in invasions (Walker *et al.*, 2003). So far, such studies haven't been carried out for Nepalese populations of parthenium weed and the proposed study will add new dimension in weed science research in Nepal.

Present study is aimed at determining if distinct populations of parthenium weed exist in Nepal based on collections made across Nepal. This study will also determine the within and between population genetic diversity and which will help devise effective weed management strategies for this weed in Nepal.

Materials and Methods

Plant Material

Leaf samples were collected from 25 locations representing different parts of Nepal (Table 1). At each location, 15 plants at flowering stage were selected within 15–20 m distance and 3–5 leaves were collected from each plant and stored in silica gel with proper labeling. Therefore, 375 leaf samples were collected for molecular analyses.

Table 1. Details of the parthenium weed leaf collections made.

SN	Code (GPS way point)	District	Locality	Latitude (°)	Longitude (°)	Elevation (masl)
1	62	Sarlahi	Kabilas	26.91473	85.55566	80
2	102	Udayapur	Triyuga	26.78617	86.69535	148
3	131	Dhankuta	Belhara	26.93148	87.32000	301
4	153	Sunsari	Duhabi	26.56148	87.27999	76
5	174	Jhapa	Dhulabari	26.66026	88.10273	127
6	208	Taplejung	Dokhu	27.31938	87.67814	1050
7	255	Sindhuli	Kamalamai	27.23004	85.91407	500
8	258	Bara	Simara	27.16353	84.97545	112
9	285	Kavre	Mangaltar	27.47058	85.74703	704
10	350	Ramechhap	Manthali	27.39692	86.06401	506
11	358	Kavre	Dolalghat	27.64517	85.70252	682
12	383	Nuwakot	Bidur	27.92971	85.15228	606

SN	Code (GPS way point)	District	Locality	Latitude (°)	Longitude (°)	Elevation (masl)
13	442	Baglung	Baglung	28.26464	83.60299	935
14	481	Gulmi	Hardineta	27.99511	83.35557	1478
14	511	Arghakhanchi	Sandhikharka	27.97240	83.12487	915
15	563	Dang	Tulsipur	28.20795	82.31837	1032
16	591	Surkhet	Gadi	28.63534	81.62145	1402
17	625	Kailali	Balia	28.61335	81.23035	189
18	674	Doti	Dipayal	29.26113	80.97183	1164
19	690	Baitadi	Dasarath	29.56235	80.39767	1306
20	706	Rupandehi	Budhachok	27.68450	83.47977	160
21	720	Chitwan	Das Dhunga	27.78805	84.43288	199
22	60	Tanahun	Bandipur	27.56181	84.2412.3	982
23	251	Kathmandu	Kirtipur	27.67333	85.28306	1342
24	252	Lalitpur	Satdobato	27.651536	85.32784	1312
25	253	Bhaktapur	Madhyapur	27.673056	85.42222	1337

DNA Extraction and Estimation

Two main DNA extraction techniques were assessed for their usefulness in generating SSR profiles of parthenium weed (modified Doyle and Doyle, 1987; Graham *et al.*, 1994). DNA quantification and quality assessment was carried out using an Eppendorf-AG22331 Biophotometer (Germany).

Gel Electrophoresis

The PCR amplified products were separated using 4.0% Agarose gel electrophoresis for 2 hours at 90 V in 1X TAE (tris-acetic acid and EDTA) buffer in a gel tank (Major Science, USA). Ethidium bromide (10 mg mL⁻¹ solution, PRO- MEGA Co.) was used to stain the gel, which was added in the concentration of 5 mL per 100 mL agarose gel (Sambrook and Russell, 2001). The gels were visualized and documented using gel documentation system (IN GENIUS, Syngene Bioimaging, UK).

SSR-PCR optimization

The Simple Sequence Repeat (SSR)-PCR reaction conditions were optimized for each primer pair

by varying key PCR reaction parameters (MgCl₂, template DNA and primer concentration). All PCR reactions were carried out in the final volume of 25 µL. Fifteen published primer pairs for parthenium weed (Qian *et al.*, 2012) are being used for the optimization process and will be selected for the genetic diversity analyses.

Results

Firstly, a comparison of the two DNA extraction protocols (Doyle and Doyle, 1987 and Graham *et al.*, 1994) was made using a random selection of the collected leaf samples for DNA extraction. Of the two techniques, the modified Doyle and Doyle (1987) technique was selected as it produced intense and crisper amplifications, although both techniques produced reasonably pure DNA (A260/280 ratio ranged from 1.68–2.03) samples.

So far, out of 15 SSR primers selected for study, PCR reaction parameters for only two primers (Phys 01 and Phys 09) have been optimized (Table 2).

Table 2. PCR parameters tested and optimized parameters for two SSR primers specific to parthenium weed.

PCR parameters	Tested range	Selected optimized conditions (Phys 01)	Selected optimized conditions (Phys 09)
NA concentration (ng)	50 to 150	100 ng	100 ng
MgCl ₂ concentration (mM)	2.0 to 4.0	2.0 mM	2.5 mM
Primer concentration (pM)	0.1 to 0.8	0.4–0.8 pM	0.4 pM

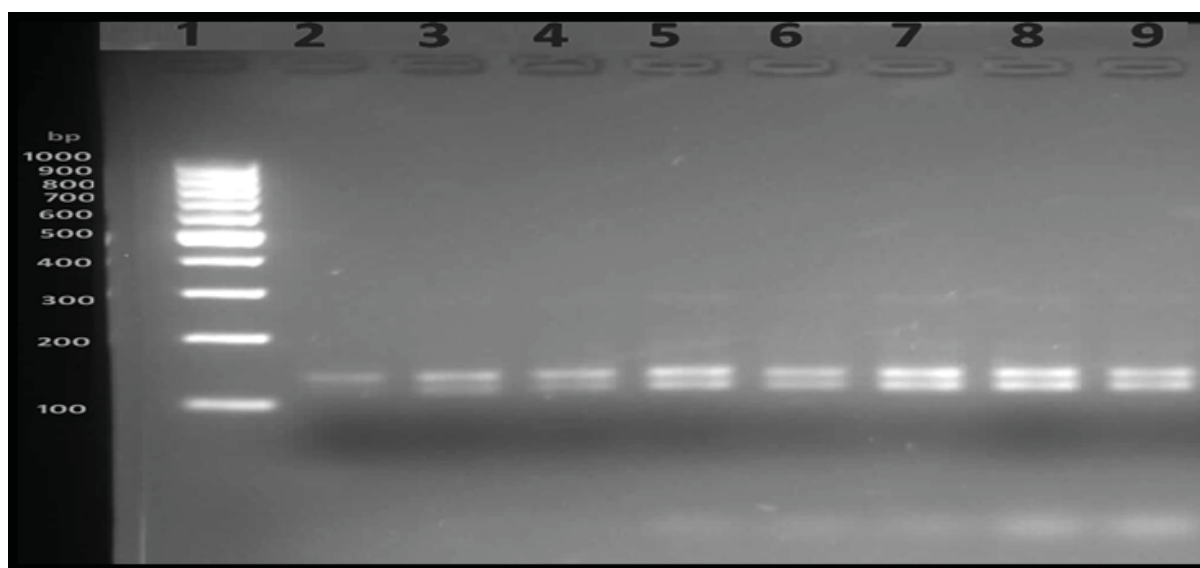


Plate 1. A gel picture of the optimization of primer concentration (Phys 01). Lanes 2 to 9 are primer concentration 0.1 pmol to 0.8 pmol, respectively and lane 1 is a 100 bp GeneRuler DNA ladder. The best concentrations were determined to be lanes 5 to 8 i.e 0.4 to 0.8 pmol.

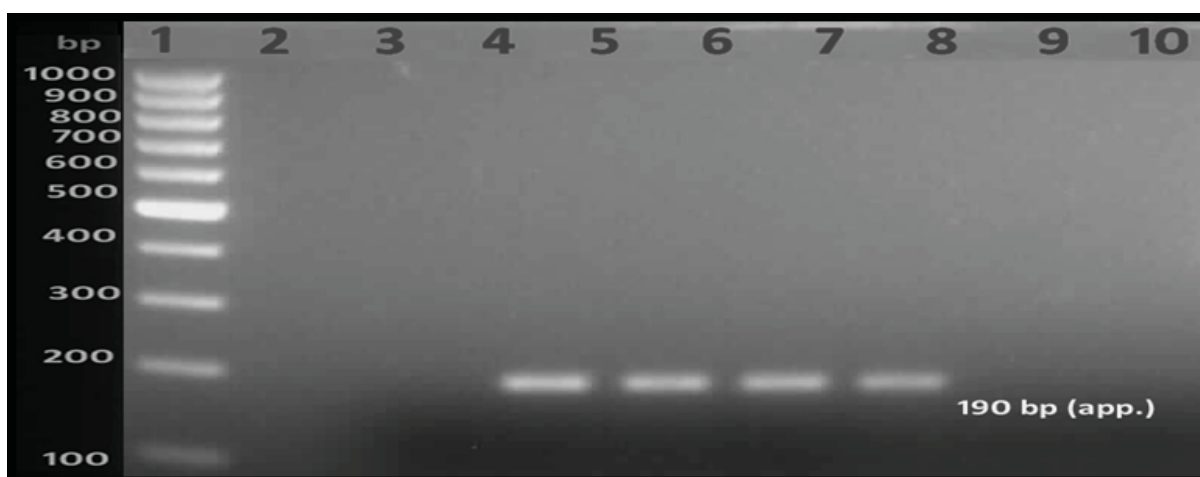


Plate 2. A gel picture of the optimization of MgCl₂ concentration for SSR primer Phys 09. Lanes 2–10 are MgCl₂ concentration: 2.0 to 4.0 mM respectively and lane 1 is a 100 bp GeneRuler DNA Ladder. The best concentration was determined to be lane 4, 2.5 mM

Discussion

Biological invasions have been recognized as a leading threat to biodiversity (Wang *et al.*, 2008). Some IAS species such as parthenium weed cause severe economic loss in agriculture, forestry and the natural environment. Knowledge derived from genetic markers provides fundamental information for advancing chemical and biological control in weed management (Nissen *et al.*, 1995; Lopez-Martinez *et al.*, 1999; Amsellem *et al.*, 2000; Tang *et al.*, 2008). Identifying closely related species through marker study may indicate the potential for hybridization, cross reactivity of chemical application and non-target biocontrol agents. Both population and species level genetic diversity studies are important in weed management as genetic bottle necks, fitness and number of introduction events contribute to successful invasion (Tracey and Slotta, 2008).

Further optimization of PCR reaction parameters with remaining 13 primers is still underway. Selection of best annealing temperature for each primer pair is also being carried out using gradient system of the thermal cycler. The optimized SSR PCR reaction and cycling parameters will be subsequently used to screen all populations using fifteen primers and profiles generated by selected polymorphic primers will be used for the estimation of genetic diversity and population genetic structure *P. hysterophorus* populations of Nepal. Following primary screening of alleles using agarose gel electrophoresis, capillary electrophoretic analysis using ABI 3500 XL genetic analyzer will be performed for more reliable and robust discrimination of alleles. Various genetic diversity and population genetic estimates will be computed using standard softwares such as NTSYS pc, POPGEN, STRUCTURE and Arlequin.

Climate change and IAS are widely recognized as serious environmental and socio-economic issues worldwide (Smith *et al.*, 2012). However, despite growing evidence that these major drivers of global change have strong and complex connections with each other, climate change and IAS are being typically treated as independent problems, and their interactions are ignored in policy and management initiatives. With the ever increasing anthropogenic activities as well as climate change effects, parthenium weed populations will substantially grow in different geographical gradients of Nepal in foreseeable future, which is already evident in different parts of the country.

Following completion of this molecular study, we would be able to say if there are multiple introductions of parthenium weed and this is responsible for rapid range expansion of this weed in Nepal. This information will be crucial for policy formulations for the long-term management of IAS such as parthenium in Nepal. Present study will also reveal within and among population genetic variability of Nepalese populations furnishing valuable information necessitating effective and integrated weed management strategy involving chemical, biological and other available control measures.

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Invasive Plants and Rural Livelihoods: An Assessment of the Effects of the Invasion of *Mikania micrantha* in Rural Livelihoods in Nepal

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Abstract

This study assesses the livelihood effects of the invasion of *Mikania micrantha* in the buffer zone of Chitwan National Park, Nepal. The results of a household survey show that the invasion of *Mikania* disproportionately affects the livelihoods of forest-dependent households. The results show that the effects of invasion of exotic plants on rural livelihoods particularly determined by the suitability of the invasive plant species to produce locally important forest products. Literatures assessing the effects of invasive plants on rural livelihoods were inconclusive whether they have beneficial or harmful effects. This study categorized the invasive plants based on their life-form whether woody and non-woody, and the mode of introduction whether accidental or deliberate. The study concludes that the invasion of accidentally transported non-woody exotic plants undermines the rural household.

Keywords: *Mikania micrantha*, rural livelihoods, invasive plant species, non-woody plants.

Introduction

Invasive species are exotic species, which have been relocated deliberately or accidentally, with the expansion of global trade and the increase in human mobility (Meyerson and Mooney, 2007; Holmes *et al.*, 2009). These species may be in the form of plants, animals and microbes. They are widely heralded as one of the greatest threats to native forest ecosystems and species richness (Wilcove *et al.*, 1998; Moore, 2000; D'Antonio and Kark, 2002). In general, when a new species enters into an ecosystem, it influences structures of the ecosystem and then their functions. Ultimately, it alters the supply of goods and services from the invaded ecosystem (Wilcove *et al.*, 1998).

The effects of invasive plants on rural livelihoods cannot be evaluated from the perspective of their effects on the native ecosystem. The studies assessing the impacts of invasive plants on rural livelihoods are inconclusive to answer whether they are friends or foe, pest or providence, and weed or wonder (Pasciecznik, 1999; Foster and Sandberg, 2004; Shackleton *et al.*, 2011). Empirical evidences have indicated that invasive plants contribute rural economy supplying a variety of forest products and services including fuelwood, animal feed, soil conservation, rehabilitation of degraded lands, and cultural values (Kaufmann, 2004; Siges *et al.*, 2005; Shackleton *et al.*, 2007; Mwangi and Swallow, 2008; Shackleton *et al.*, 2011).

In terms of the management, a majority of rural community usually prefer to eradicate invasive plants over the prevention (García-Llorente *et al.*, 2011), as the negative effects of invasive plants on ecosystem services far outweigh the positive effects (Charles and Dukes, 2007). However, the eradication of species may jeopardise the livelihoods of those households who derive benefits from those species and can increase their dissatisfaction (de Neergaard *et al.*, 2005). If they are not

eradicated, the households perceiving the negative effects of invasion may have to change their livelihood strategy to manage the crisis situation. In conclusion, an invaded area management program without acknowledging these complexities may create social conflicts.

The plant species studied to examine the livelihood effects of invasive species are disproportionately focused on intentionally transported species such as *Prosopis juliflora*, Prickly pear (*Opuntia ficus-indica*), and Black Wattle (*Acacia mearnsii*). These species are introduced in many countries aiming to fulfil the demands of rural populations for forest products, for production of biofuels and for rehabilitation of degraded lands (McNeely *et al.*, 2001; Witt, 2010). However, they have turned into an invasive but are still useful, at least for some sections of the community (Pasciecznik *et al.*, 2001; Shackleton *et al.*, 2007). Their additional common feature is they are woody plants.

In the assessment of the effects of invasive plants on rural livelihoods, the plant species which are transported accidentally and in particular, non-woody species are not well-considered. Most species recorded in this category are herbs such as Triffidweed (*Chromolaena odorata*), Mile-a-minute (*Mikania micrantha*), and Parthenium weed (*Parthenium hysterophorus*). These species are transported with cattle-trade, grain shipments for famine relief programs, and tea seedlings (McWilliam, 2000; McNeely *et al.*, 2001; Tiwari *et al.*, 2005). The negative effects of these species on biodiversity are widely reported (Zhang *et al.*, 2004; Sapkota, 2007; Siwakoti, 2007; Willis *et al.*, 2008; Timsina *et al.*, 2011). Their effects in rural livelihoods have not assessed well and, usually it is evaluated from the perspective of their ecological impacts.

In part, the interface between invasion of exotic plants and rural livelihoods is examined by assessing

the effects of the invasion of *Mikania micrantha*, on the livelihood of buffer zone households in Chitwan National Park (CNP), Nepal.

Study Site and Methods

2.1 *Mikania micrantha* invasion in the buffer zone of Chitwan National Park

The selection of buffer zone (BZ) of CNP was motivated by several factors. BZ is the peripheral area of protected areas (National Parks and Wildlife Reserve) including villages, settlements or hamlets declared by the Government of Nepal (GoN, 1996). These motivation factors includes; CNP is renowned as a biodiversity hotspot and has been enlisted in the World Heritage Site, the park is one of the popular tourist destinations in Nepal, and the invasion of exotic plants has seriously affected economic activities and native landscape in the area (Sapkota, 2007; Rai and Scarborough, Forthcoming).

Mikania micrantha (hereafter *Mikania*) is one of the important invasive plant species in tropical and sub-tropical Asian countries including Nepal (Kuo et al., 2002; Zhang et al., 2004; Tiwari et al., 2005). This species is listed as one of the worlds' thirty-two worst terrestrial invasive plants (Lowe et al., 2000), and recognized as the most problematic weed in the tropical parts of Nepal (Poudel et al., 2005). The species is assumed to be transported with tea seedlings from India, before its westward move in Nepal (Tiwari et al., 2005). Now, it is recorded in twenty out of seventy-five districts of Nepal (Rai et al., 2012a).

The species has two noticeable characteristics. First, it grows aggressively and proliferates rapidly from both seed and vegetative parts (Swamy and Ramakrishnan, 1987; Kuo et al., 2002). The vines have competency to create monocultures within

a short period of time. Second, *Mikania* does not only displace native plants but also kill them. The vines climb-up and create a dense cover on the top of canopy, and damage or kill the host plants by blocking the light and smothering them (Holm et al., 1977).

The effects of the colonization of *Mikania* on native plant species, in the BZ of CNP of Nepal, are well documented (Sapkota, 2007; Rai et al., 2012a). The BZ management program involves local people in the protected area management by delegating management authority of forest patches and distributing benefits to the local community from the national park. Forest patches in the BZ are managed by local households as members of buffer zone community forest user groups (BZCFUGs). Agriculture and tourism are the main sources of household income of BZ community.

As previously discussed there is a variation in peoples' perception of invasive plants and the perceived effects basically determined by how the particular plant species influence the livelihoods strategy of individual households (Binggeli, 2001). The previous study indicates that the BZ ecosystem, in terms of biodiversity and livelihoods households, is considered degraded because of the infestation of *Mikania* (Rai et al., 2012b). However, the study was limited to assessing the perception of the households.

This study examines the livelihood effects of *Mikania* following a conceptual framework prepared by Shackelton et al. (2007). Their study categorized the livelihood effects of invasive species in two-by-two matrix in terms of beneficial traits and competitiveness. This study follows an assumption that the beneficial traits of a species either high or low depends on whether the species is woody or non-woody.

Data collection

For this study, five BZCFUGs: Janakauli, Baghmara, Kumroj, Chitrasen and Ghailaghari, were selected for the household survey. The prerequisites to select from the pool of potential BZCFUGs were:

- i. The intensity of *Mikania* colonisation in the respective community forests; and
- ii. The location of the forest user groups—whether in villages or urban areas.

The BZCFUGs with different levels of *Mikania* infestation were considered and selected accordingly. Questionnaire test was carried out during five focus group discussions with members of BZCFUGs. The questionnaire mainly focuses on their knowledge of *Mikania*, perceived effects after the infestation, and change in their activities they are experiencing. The respondents were asked to evaluate the current situation compared with five years ago. The reason behind asking the situation five-years ago is that colonization of *Mikania* was noticed widely in year 2004/2005 in the study area (Poudel et al., 2005).

Household interviews were carried out between February and March 2011 by local enumerators, who were trained and supervised by the research team. Local cultural diversity and gender issues were considered while forming an interview team. The interviews were conducted in different languages including Nepali (official language) and

Tharu (a local dialect). The households were selected systematically i.e. the first household was selected randomly and then every following tenth household considering their locations on both sides of the street was interviewed along with scattered houses as well. Household heads of either gender were interviewed based on their availability during the visit.

Analytical Framework

A conceptual framework proposed by Shackleton et al. (2007) describes the livelihood effects of invasive species based on the characteristics of the IPS using a two-by-two matrix of species competitiveness and usefulness. The framework had two categories for each characteristic: weak and strong competitive ability, and highly and least useful. This study assumed that species' usefulness depends upon two factors: (i) life-form of the species—woody or non-woody, and (ii) their mode of introduction—accidental or deliberate (Table 1). In general, woody plants are more suitable for providing locally demanded forest products: small pole, fuelwood and fodder compared to non-woody plants. So, their status in the landscape, whether as an invasive or a non-invasive, does not limit their role to contribute rural livelihoods. On the contrary, the invasion of non-woody species is likely to undermine rural livelihoods as these species are mostly unsuitable to produce locally important forest products. Hence, woody plants are considered as highly useful and non-woody plants as least useful.

Table 1. A Two-by-Two Matrix of Species life-form and the mode of introduction

Mode of the introduction	Life-form	
	Woody	Non-woody
Deliberately	Negligible or low impact on rural livelihoods; as these species are already a part of the rural ecosystem	Moderate impact on rural livelihoods, already a part of the rural ecosystem, can provide benefits mostly indirect
Accidentally	Moderate impact on rural livelihoods, people can extract benefits from these species	The species has no or limited direct or indirect benefits to rural people. It may have the most severe effects on livelihoods

(Adapted from Shackleton et al., 2007)

Usually, accidentally transported species are widely regarded as unwanted (McWilliam, 2000; McNeely et al., 2001). On the contrary, deliberately introduced species generate benefits for at least some of the community, who welcome their introduction. For instance, *Lantana camara*; is considered as a notorious herb, yet is still appreciated as an ornamental plant (Ghisalberti, 2000). In addition, deliberately introduced exotic species usually stay longer than the accidentally transported species before they become invasive. A long stay of exotic species in a landscape may lead to innovation and the species becoming an economic good (Shackleton et al., 2007; Mwangi and Swallow, 2008). Hence, it can be presumed that deliberately transported invasive plants provide benefits to the local community regardless of their life-form.

In the proposed framework, *Mikania* falls under the category of accidentally introduced non-woody species. The framework demonstrates that the species under this category have the most severe effects on rural livelihoods as they have no or limited benefits to rural people and their abundance reduces the availability of locally important native species. Hence, rural households become active to continue farm-based livelihood activities employing several coping strategies, when they face risk to their livelihood security (Frankenberger, 1992). These households have developed a wide range of coping strategies as they have been confronted with adverse situations that undermine their livelihoods (Carver et al., 1989; Berzonsky, 1992).

In general, most of the households in society employ coping strategies; however, crisis-affected and poorer households adopt coping strategies more frequently relative to unaffected and wealthier households (World Bank, 2011). This study assumed that affected households mostly practised larger numbers of coping strategies to adapt to the

shortage to forest products. Therefore, 'coping strategy'—defined as the number of strategies (listed in Table 4) practised by households—was used as a proxy variable for measuring livelihood effects. Since, coping strategies vary across individuals, socioeconomic variables including age, proximity to forest, landholding size, family size, income source and gender, were used to explain the livelihood effects of *Mikania*. These variables were important determinants of forest product consumption patterns in Nepal (Adhikari et al., 2004a; Sapkota and Oden, 2008).

The following multiple regression model was proposed to identify the determinants of the livelihood effects of the *Mikania* infestation:

$$Y = \alpha + \beta_1 \text{Age} + \beta_2 \text{Gender} + \beta_3 \text{Income} + \beta_4 \text{LU} + \beta_5 \text{Land} + \beta_6 \text{Distance} \quad (i)$$

Where, Y is the number of coping strategy that a household is using, α is the constant term, β_1 to β_6 are vectors of coefficients of respected variables including age of respondents (year), gender of respondent (value as 1 if the respondent is 1 and otherwise 0), Income (households' income source value as 1 if agriculture only and otherwise 0), LU (household livestock unit), land (households' landholding size), and distance (the time required to travel between respondents' resident to their community forest by walking in minute).

The Livestock unit (LU) equivalence measure was used. Based on the LU equivalence scale the average herd size for household with male and female household head was calculated. Estimation of livestock unit is based on the livestock conversion scale: buffalo = 1, Cattle = 0.7 and Goats = 0.08 considering 500 kg per unit (Kosilla, 1988). The average household herd size was 2.18 LU.

Results

Sample characteristics

Of total 500 respondents, 60% (301) were female and 40% (199) were male. As Chitwan National Park is one of the popular tourism destinations in Nepal, more than two-third of the respondents have both agriculture and tourism as households' income source. Albeit the diversification of income sources due to tourism and education, still 29% (147) of the total households solely depend on agriculture, and households having off-farm activities as only source of income constitutes 3.4% (17) of the total sample households.

Table 2 reports the sample characteristics. The average parcel size per household is less than the average Terai and National statistics (CBS, 2001). This might be due to the population pressure in the area as more than half of the respondents (56%) were immigrants.

Mikania and Livelihood Activities of Buffer Zone Households

All respondents were aware of a *Mikania* infestation in the BZ. They recognised the species by sight. According to the respondents, *Mikania* was first noticed in the BZ after the flooding in the Rapti River in 2003. They believed that the Rapti River, which flows to the south-west, brought the species to the BZ of CNP. This corroborates existing studies

that *Mikania* moved westward in Nepal (Tiwari et al., 2005). Respondents almost unanimously (99%) consider that the infestation of *Mikania* has negative impacts on their livelihoods. According to them the abundance of *Mikania* vines was increasing rapidly in both BZ and the core area of CNP over the last five years, and displacing native regenerations. They noted that the abundance of *Mikania* is destroying wildlife habitats and jungle hiking trails. In search of suitable habitats, wild animals have moved towards the core area of the CNP. As a result BZCFUGs are receiving fewer visitors, even though visitor numbers have increased steadily over the last five years in CNP (DNPWC, 2010; DNPWC, 2011). Locally, they considered *Mikania* as an *environmental terrorist*.

Survey respondents answered questions related to the change in their household activities including a change in forest products collection time, the amount of forest products collected per trip and the size of livestock herd compared to five years ago (Table 3). We asked them to recall the situation five years ago and compare, if these changes occurred due to an alteration of forest products availability. Number of households entering the community forest regularly to collect forest products decreased from 98% to 46% after infestation; however, they were keeping livestock and using fuelwood for cooking. For those households, who were collecting forest products from their respective BZCF, time required to collect forest products for a day requirements increased by more than two

Table 2. Sample characteristics

Variables	Mean	Description
Age	43.2 (0.57)	Age of the respondent (year).
Education	3.2 (0.20)	Number of years attended school.
Land	11.94 (0.57)	Land owned by household in Katha ¹ .
Family size	6.22 (0.12)	Number of family members.
LU	2.18 (0.07)	Livestock unit per household denoted by LU.

Note: standard deviation in parentheses.

¹ Katha is a unit of area approximately equals to 720 sq. ft.

Table 3. Change in the livelihood activities of households in the buffer zone of CNP

Variables	Before infestation	Current situation
Households Enter the forest	491	231
Average FP collection time ³ (Hours/ trip)	1.49 (0.66)	3.64 (1.04)
Enter the forest to collect FP (day/week)	6.0 (1.94)	1.6 (2.12)
Fodder (Bhari /trip)	1.13 (0.56)	0.55 (0.52)
Fuelwood (Bhari/trip)	1.29 (1.02)	0.40 (0.54)
Livestock per household	9.63 (8.47)	4.93 (3.42)

Note: standard deviation in parentheses, FP is the abbreviation of forest products.

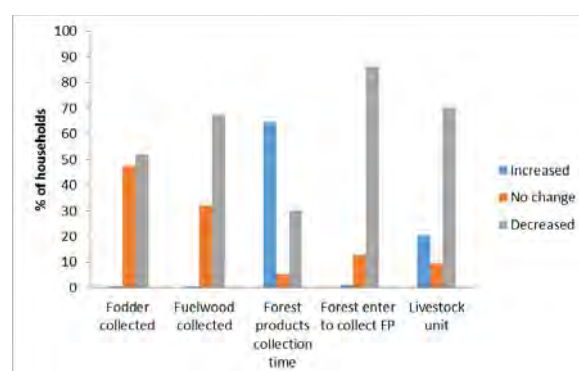
times, and their intensity of entering the forest to collect forest products decreased substantially from six days to 1.6 days per week. Fodder and fuelwood collected per trip decreased from 1.13 and 1.29 Bhari² to 0.55 and 0.40 Bhari respectively. Likewise, there was a substantial decrease (49%) in average livestock owned by the BZ households.

The number of households experiencing changes in household activities compared to five years ago indicates that the colonization of *Mikania* has led to a change in household activities (Figure 1). 86% and 70% of the total sample households reduced the frequency of entering BZCF to collect forest products and the number of livestock respectively. Likewise, 52% and 67% households were collecting less fodder and fuelwood per trip, and 65% households were spending more time for a single trip to collect forest products compared to the five years ago.

There was also a significant portion of populations who were not affected by the invasion of *Mikania*. For example; 48% of respondents were collecting fodder and 52% respondents collecting fuelwood per trip as much as they used to collect five years ago, and some respondents were collecting more now. According to respondents there were two reasons behind this scenario:

- the collection of forest products was not limited to community forest as they enter the national park illegal though; and
- a large portion of the population have decreased their dependency in community forests, which became an opportunity for those who were visiting forest regularly.

Figure 1. Households changing activities over the last five-year (in %)



Coping with the invasion of *Mikania*

Households were employing four main strategies to cope with a scarcity in forest products availability incurred due to the invasion of *Mikania* (Table 4). Only three households responded that they were not changing any activities due to the infestation of

² Bhari is the traditional unit of measurement for fuelwood and forage in rural areas and one bhari ~ 25 kg.

³ Forest products collection time is expressed as time spends per trip to collect either fodder or fuelwood for a day requirement. This does not include the travel time between forest and households.

Mikania. Out of four coping strategies, planting trees on private land was the most common strategy (85% respondents). The coping strategy category of using alternative energy includes bio-gas, liquefied petroleum gas, and Saw-dust stove. Only 9% of the total households were executing single coping strategy and remaining had more than one strategy. Government agencies and NGOs were supporting local farmers to install bio-gas plants as an alternative to fuelwood. More than one-fourth respondents (138) have installed bio-gas plants, which constitutes 49% of the households practicing alternative energy. In addition, 11% (56) of the total respondents were using *Mikania* as a fodder for goat mainly during the dry season (winter), when fodder becomes limited.

Table 4. Households practicing coping strategies

Strategy	Number of HH
Collect from CNP	149 (30%)
Planting on private land	425 (85%)
Buying forest products	361 (72%)
Using alternative energy	279 (56%)

The results of the multiple regression model (Table 5) indicate that variables such as age of respondents, family income source, the size of household livestock herd and proximity to community forest are the major determinants of using coping strategies. The number of coping strategies is positively correlated with the age of household heads. Likewise, households with agriculture as a main source of family income and keeping more number of livestock practice more coping strategies. On the other hand, distant households practice a less number of strategies.

Table 5. Factors influencing practicing a number of coping strategies

Variables	Coefficient (Standard Errors)
Constant	1.470 (0.246)***
Age	0.008 (0.003)***
Gender	0.111 (0.081)
Income source	0.504 (0.230)**
LU	0.126 (0.023)***
Land	-0.001 (0.003)
Distance	-0.004 (0.001)**
Adj R ²	0.46

Note: **, and *** denote significant at 5% and 1% respectively.

Discussion

BZ households believe that local river floods introduced *Mikania* to their landscape. This fact confirmed that the vines were accidentally transported to the BZ and for many households these vines are an unwanted guest (Rai et al., 2012b). The results of the household survey have illustrated that the invasion of *Mikania* has caused a substantial reduction in the dependence of local communities on their community forests, despite the efforts of BZCFUGs to regularise forest product collection and impose a ban on cattle grazing to improve the condition of the community forests. In Nepal, community forestry practices have been successful in improving forest product supply to local users but this is not the case in this study (Pandit and Bevilacqua, 2011). This situation may be due to the invasion of *Mikania* in the BZCFs.

The abundance of *Mikania* reduces the availability of native species particularly young plants (Sapkota, 2007). When the invasive plants themselves become unsuitable to produce locally demanded forest products then their infestation undermines rural livelihoods as the supply of forest products turn out to be limited. Ultimately, they challenge the ability of the ecosystem to farm and prosper

(McWilliam, 2000). The results show that rural people evaluate the effects of IPS on their livelihoods from the perspective of how the supply of forest products availability has changed after the invasion. Therefore, livelihood effects of IPS particularly depend on their suitability to produce locally important forest products. For example; the invasion of exotic species such as *Mikania*- which is unsuitable to offer locally important forest products- has the utmost effects on rural livelihoods.

In our study area, a small portion of farm households was using *Mikania* vines as goat fodder despite the fact that their use causes abdominal disorder to livestock (Siwakoti, 2007). This is not unexpected because the abundance of *Mikania* causes high opportunity cost of not using the vines (Shackleton et al., 2007). As poor have shorter time horizons and tend to adopt strategies with immediate returns, they make efforts to cope with the paucity of basic forest products whatever they can (Rai et al., 2012b).

If they don't use *Mikania*- as fodder- then they use one of two coping strategies for adapting to the reduced forest products availability. Either they reduce the demand of fodder by downsizing livestock or invest more to maintain a continuous supply of forest products. Households unable to afford these strategies, usually seek alternative source to collect forest products in free of cost. In this study area, they were harvesting forest products in the core area of the national park, illegal though. This may jeopardize the harmonious relationship between the BZ community and the park, which was improved after the implementation of BZ management program (Stræde and Treue, 2006).

The results of the multiple regression analysis indicate that the invasion of *Mikania* disproportionately affects forest-dependent households. Usually, a high proportion of farmers

in developing countries are older people, and farm households are the most vulnerable victims of invasive plants (McWilliam, 2000; Mwangi and Swallow, 2008; Rai et al., 2012b). It is also equally true that older people have comparatively lower-levels of education and for them the possibility of alternative employment opportunities may be limited. Hence, it is expected that older heads of household are likely to continue their existing livelihood strategy with employing a number of compensating options.

Distance decay effects for forest products collection pattern are observed frequently in community forestry practices. Households in the close proximity to community forests collect more forest products than the distant users (Sapkota and Oden, 2008). This means a change in household activities of distant villagers due to a change in forest product availability in community forests is less likely. Likewise, households with a high number of livestock are likely to have more coping strategies, as they have to feed their animals.

Mikania is notorious for its aggressive growth rate and is commonly named as mile-a-minute (Zhang et al., 2004; Willis et al., 2008). Respondents of this study have observed an increasing trend in the spread of *Mikania* in the buffer zone of CNP. They had practiced control measures but failed to control the species (Rai et al., 2012a). In this context, it can be postulated that effects on rural livelihoods are likely to be severe in the near future if the spread of *Mikania* is not controlled. The livelihood vulnerability and cost of management increase with the abundance of undesirable and highly competitive invasive plants such as *Mikania* (Shackleton et al., 2007).

Conclusion

The study sheds insight into the understanding of the livelihood effects of invasive plants by

categorizing IPS based on their life-form and the mode of introduction. The effects of the invasion of exotic plants on rural livelihoods depend on the suitability of the particular invasive plants to supply locally important forest products rather than the invasion process itself. Hence, the invasion of accidentally transported non-woody plants such as *Mikania* undermines the rural livelihoods. It negatively affects rural ecosystem degenerating ecosystem services and undermining rural livelihoods. Beyond these direct impacts the invasion may jeopardize the institutional relationship between the buffer zone community and the national park, as the infestation increases the reliance of local community in the core area of the national park.

As the spread of *Mikania* is increasing and the livelihood vulnerability increases with the abundance of invasive plants, the results of a household survey suggest an immediate need to intervene forest management activities aiming to control the spread of *Mikania*. In the absence of management activities, the study suggests two possible way outs to minimize the effects of the invasion of *Mikania*. First, the limitations of households to address the uncertainties should be considered while designing a coping strategy. If not, these strategies could be counterproductive. For instance, installation of bio-gas plants as an alternative to fuelwood increases demand for fodder as farmers have to keep cattle to operate the bio-gas plants. Second, a further investigation is sought to seek out the possibility of the commoditisation of *Mikania* into an economic good.

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Status of *Mikania micrantha* Invasion in the Rhino Habitat of Chitwan National Park, Nepal

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Abstract

Mikania micrantha (Mikania) is one of the world's 100 worst weeds and the primary invasive species in Chitwan National Park (CNP), Nepal. Following a Mikania survey in 2008, an additional survey was carried out in 2011 as part of greater one-horned rhinoceros (rhino) censuses to measure the extent of change of Mikania invasion in major rhino habitats in CNP. 2008 survey protocols were adopted: a plot including a half-circle of 50 m radius in front of a researcher was surveyed from elephant back for the ocular estimation of Mikania cover. Mikania coverage was quantified in the scales of 0, 1 and 2 where 0 - Mikania absent, 1 - Mikania present but less than 50 % coverage and 2 - Mikania covering more than 50% of the plot area. Mikania was found present (1 and 2 combined) in 43.3% (n=3073) of the plots in 2011 and this was approximately the same as of 2008. In 2011, as in 2008, the preferred rhino habitats - wetland, tall grassland, riverine forest - were found to have higher level of Mikania invasion than other habitats. In between the three years of the assessment percentage of the plots in category 2 (more than half of plots covered by Mikania) has increased by 3.45% from 14.50 % in 2008 to 17.95 % in 2011. Overall, Mikania has not spread out in new areas but intensified where it was already present. Thus there is still the threat of Mikania high infestation on the area where it is present.

Keywords: *Mikania micrantha*, extent of invasion, rhino habitat, Chitwan National Park.

Introduction

Naturally occurring usually in low abundance in its native range i.e. tropical and subtropical Central and South America, *Mikania micarantha* (hereafter 'Mikania') is a notorious weed in most of the South and South-East Asia (Murphy *et al.*, 2013; Barreto and Evans, 1995). It is one of the 100 worst invasive plants, also commonly known as mile-a-minute weed because of exceptionally faster growth rate (Holm *et al.*, 1977). It poses high risk of smothering and sometimes killing the native flora and affects both natural ecosystem as well as agricultural areas. Mikania is the most problematic invasive plants in tropical Nepal which already have spread in twenty Terai and Siwalik districts (Rai, 2013; Siwakoti, 2007) in the south of the country. It was first reported in Nepal from the eastern district of Ilam in 1963 (Tiwari *et al.*, 2005) and appears to be spreading aggressively westwards up to Dang along the terai (grassland-forest) habitats of Southern Nepal (Murphy *et al.*, 2013). Three protected areas i.e. Koshi Tappu Wildlife Reserve, Parsa Wildlife Reserve and Chitwan National Park (CNP) have been already affected by Mikania invasion (Murphy *et al.*, 2013).

Mikania is the primary invasive plant of CNP. It is believed that Mikania reached CNP in early 1990s as nature guides reported this weed in low densities from the Rapti floodplain of Bhimle-Tiger tops area of Chitwan. The plant was identified positively as Mikania in 1997 (Murphy *et al.*, 2013). Many local people believe the Mikania is distributed throughout the park after a large flood in 1994; it did become widespread and abundant after another large flood in 2003, although no scientific explanation could be found (NTNC, 2009). Mikania is now abundant especially on the floodplains of the three major river systems i.e. Rapti, Reu and Narayani along with their tributaries.

The Mikania is one of the major concerns as it has been invading the prime one-horned rhinoceros

(rhino) habitats i.e. the alluvial floodplain grasslands, wetlands and riverine forests. A recent study in Chitwan by Subedi (2013) has shown the significant reduction on biomass production of rhino food plants in Mikania invaded areas. The home range of the rhino has also increased significantly which indicates the deteriorating habitat quality due to Mikania and other factors such as drying of water holes. It has the potential to destroy prime habitats of threatened and important species in CNP, a UNESCO World Heritage Site. Although it was a concern for park managers, researchers and other stakeholders, no systematic assessment of Mikania was carried out till 2008. Along with a rhino census, an assessment in 2008 measured the actual extent of the invasion in all rhino habitats of CNP which showed 44% of the rhino habitat is already being invaded by Mikania (Murphy, 2013; DNPWC, 2009). This study is based on the other replication of such assessment which was conducted in 2011 in conjunction with another rhino census. Thus, the primary objective of the study was to measure the extent of Mikania, invasion in CNP and to assess how the extent of Mikania invasion has changed in three years from the previous 2008 survey. But the opportunity was also taken to measure the extent of two other important invasive plants in CNP: *Chromolaena odorata* (= Chromolaena) and *Lantana camara* (= Lantana).

Study Area

Chitwan National Park (27°16.56' - 27°42.14'N and 83°50.23' - 84°46.25'E), a World Heritage Site and the first National Park (1973 AD) of Nepal, is home for second largest population of greater one-horned rhinoceros (hereafter rhino) (CNP, 2012). Covering an area of 932 km² in core and 750 km² in buffer zone, the park is situated in south central lowlands of inner Terai (Figure 1). The majority of the park is dominated by forest (sal, riverine and mixed hardwood) 80 %, grassland 12%, exposed surface 5% and water bodies (3%)

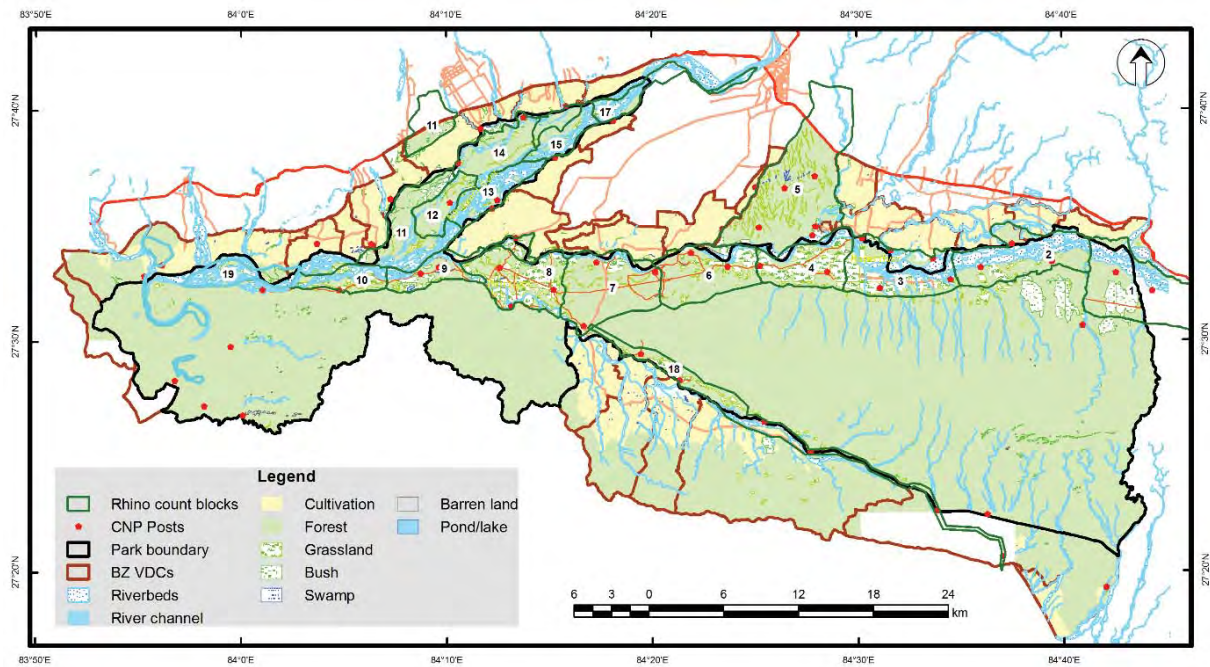


Figure 1. Map of CNP, Buffer zone and rhino count blocks (2011)

(Thapa, 2011) and is drained by three major river systems i.e. Narayani, Rapti and Reu. The Narayani River marks the western boundary, the Rapti River marks the northern boundary, the Parsa Wildlife Reserve is contiguous at the eastern boundary and the Reu River and the international border with India along the Valmiki Tiger Reserve marks the southern boundary of CNP. The park has monsoon dominated sub-tropical climate with average monthly maximum temperature 24 - 38 °C, monthly minimum temperature 11 - 26 °C, average rainfall 2,437 mm/year (2004-2007) and relative humidity 89-98% (Thapa, 2011). About 70 mammal species, over 600 bird species, 49 species of reptiles and amphibians, 156 species of butterfly, 120 species of fish have been reported from the park (CNP, 2012).

Methods

The assessment of the *Mikania* in the rhino habitats of CNP was carried out along with the rhino censuses in 2011 and followed the methods in Murphy *et al.* (2013) and DNPWC, 2009. The rhino censuses were carried out by a direct head

count method sweeping all the potential rhino habitat but not including the dry and hilly area of the park. The survey area was divided into 19 blocks (11–75 km²) respectively in 2011. Within each block 30–40 parallel strip transects were surveyed simultaneously from elephants. The distance between two transects was maintained at c. 100–200 m in open grasslands and 50 m in dense forests, to ensure areas were thoroughly covered. On each transect, an observer sits on the elephant back and looks for rhinos within his range.

The assessment of the *Mikania* infestation level was carried out through estimation of *Mikania* cover by each observer within an approximately semi-circular plot of 50 m in front, left and right of the elephant. The level of infestation was measured using a simple ranking of cover within the area through ocular estimation as: 0 - absence; 1 - *Mikania* present but coverage < 50%; 2 - High *Mikania* infestation covering > 50%. All the technicians and observers were trained on this measurement system to reduce the observer's biases. Assessments were made every c. 30 minutes during the census and thus sampling was approximately proportional

to the area covered by each habitat. In 2011, an assessment was also carried out for the other major invasive plants, *Chromolaena* and *Lantana* using the same scale of 0, 1 and 2 in each of the plots (DNPWC, 2011).

The survey block, type of habitat and GPS position of each plot were recorded as covariates along with the level of *Mikania* infestation. The major rhino habitats that the rhino uses in Chitwan were divided into six types: riverine forests, subtropical mixed hardwood forests, Sal forest, tall grassland, short grassland, and wetland (Murphy *et al.*, 2013; DNPWC, 2009). The information on the recorded sheets was checked and entered into a spreadsheet at the end of each survey day. The level of invasion of *Mikania* was summarized as frequencies of plots invaded in each habitat. Rhino count data was similarly summarized in relation to habitats assessed. The *Mikania* data was mapped using ArcGIS v. 10.0 (ESRI, Redlands, USA).

Rhino density based on sighting records was calculated in ArcGIS Kernel density estimation method (output grid size - 1 ha, buffer 2 km). This rhino density value was assigned to each *Mikania* assessment plots using 'Extract values to point' tool in ArcGIS. Average rhino density for the three categories of *Mikania* coverage was calculated. Comparative analysis of the overall and habitat wise *Mikania* coverage between the assessments of 2008

(Murphy *et al.*, 2013; DNPWC, 2009) and 2011 was done in MS-Excel 2007.

Results

1. Assessment of Mikania, Chromolaena and Lantana distribution and incidence

In the 2011 study, a total of 3073 locations were assessed to measure the distribution and level of invasion by *Mikania*, *Chromolaena* and *Lantana*. The area surveyed was 504 km² and took 3,194 elephant hours to complete. As the assessments were taken uniformly across the habitats, the total number of assessed plots in each habitat provides a relative measure of the geographical size of the habitats.

Overall, 43.29 % of plots contained *Mikania*. Of these, 17.95 % of plots had severe *Mikania* invasion (>50% coverage (Table 1). Wetlands were the most invaded habitats by *Mikania* with its presence on total 76 of the plots including 40 % of the plots highly invaded (covered < 50%). Habitat types in descending order of invasion level were wetland, riverine forest, tall grassland, sub-tropical mixed forest, short grassland and Sal forest (Table 1). The distribution of levels of invasion of *Mikania* across CNP is shown in Figure 2.

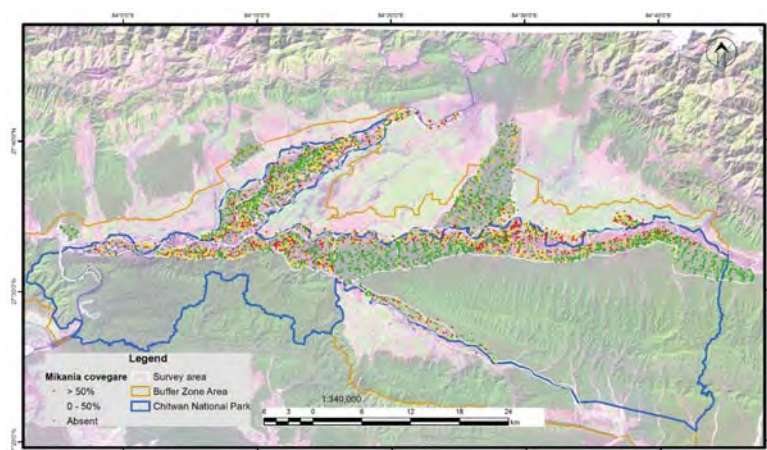


Figure 2. Distribution and level of *Mikania* invasion in CNP, Nepal (2011)

Table 1. Level of Mikania, Chromolaena and Lantana invasion in CNP, Nepal (2011).

Vegetation type	No of plots	<i>Mikania</i>			<i>Chromolaena</i>			<i>Lantana</i>		
		0	1	2	0	1	2	0	1	2
Riverine Forest	949	39.99	32.98	27.03	65.12	24.39	10.48	83.03	10.91	6.06
Sal Forest	602	85.88	9.88	4.24	73.42	19.77	6.81	97.51	1.74	0.75
Tall Grassland	828	49.64	30.19	20.17	79.47	14.61	5.92	92.51	4.35	3.14
Sub-tropical mixed forest	235	58.85	26.44	14.71	75.48	19.83	4.69	88.49	8.32	3.20
Short Grassland	251	61.75	25.9	12.35	70.12	22.31	7.57	91.63	8.37	0.00
Wetland	80	23.75	36.25	40.00	26.25	38.75	35.00	78.75	11.25	10.00
Not Specified	68	91.18	5.88	2.94	89.71	7.35	2.94	98.53	1.47	0.00
Other	60	65.00	23.33	11.67	68.33	28.33	3.33	86.67	11.67	1.67
Total	3073	56.71	25.34	17.95	70.63	21.08	8.3	89.4	7.02	3.58

Similarly, Chromolaena and Lantana were present in 29.37 and 10.6 % of the plots and a high level of invasion was observed from only 8.30 and 3.58 % of the plots respectively. Wetland was the most invaded habitat by Chromolaena and Lantana too. The descending order of Chromolaena invasion

on different habitat types were wetland, riverine forest, short grassland, sal forest, sub-tropical mixed forest and tall grassland. Likewise, Lantana invasion in different habitats in decreasing order were wetland, riverine forest, sub-tropical mixed forest, short grassland, tall grassland and sal forest.

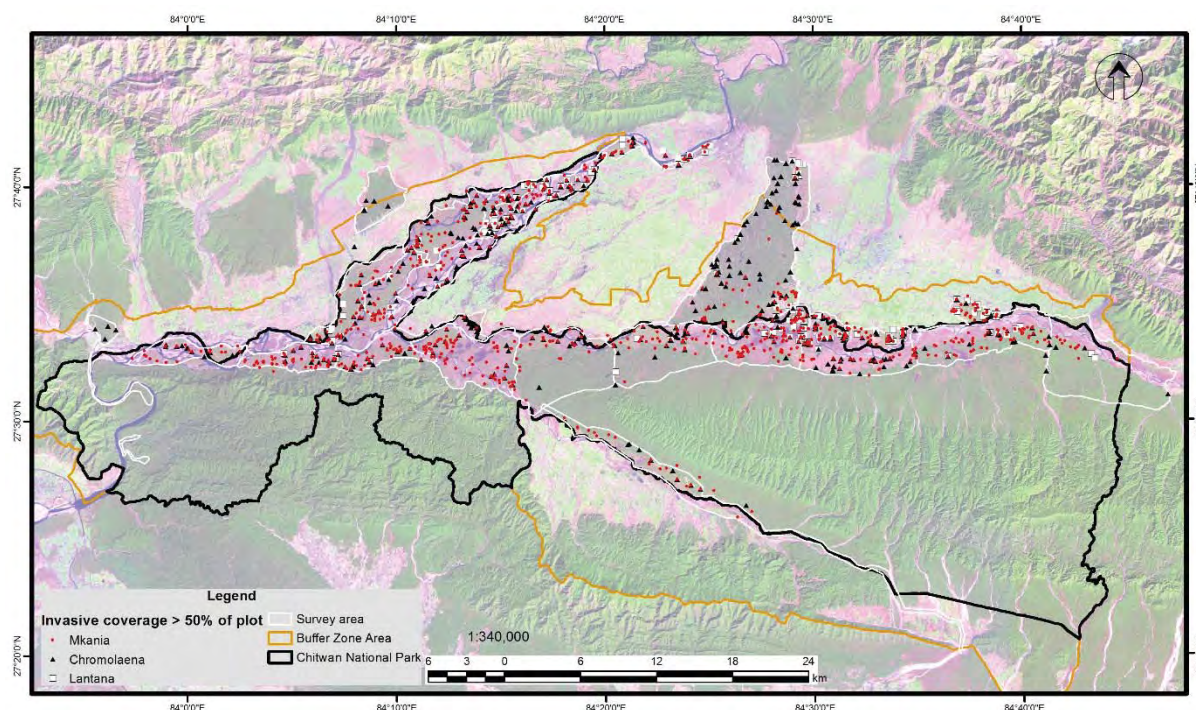
**Figure 3. Distribution of high invasion of Mikania, Chromolaena and Lantana in CNP, Nepal (2011).**

Table 2. Mikania and other invasives in CNP (2011)

		Mikania			Total
		0	1	2	
Chromolaena	0	45.94	15.21	9.47	70.63
	1	8.15	7.99	4.94	21.08
	2	2.61	2.14	3.54	8.30
Lantana	0	54.30	21.28	13.81	89.40
	1	1.83	2.94	2.24	7.02
	2	0.58	1.11	1.89	3.58
Total		56.71	25.34	17.95	100.00

The combined analysis of Mikania and Chromolaena showed that 55.06 % of the surveyed habitat have been invaded by either Mikania or Chromolaena or both (Table 2). A small portion of overlap is observed between Mikania and Chromolaena invasion (category 1 - 7.99% and category 2 - 3.54). Nearly a quarter (24.68%) of the total plots having Mikania were found free from Chromolaena 10.67% plots with Chromolaena were free from Mikania.

This further explains the ecology of these two species whose favorable habitat is different, Mikania is found more in moist areas whereas Chromolaena is found in drier areas. But interestingly Chromolaena has been recorded from many wetland areas (73.75% of total 80 plots) which is not usual. This could be due to oxbow lakes in

the river floodplains which acts as primary wetland sites in Chitwan. As these sites have high chance of getting flood which brings the Chromolaena seeds/ plant from the upstream and when flood dries up, these seed/plant finds a way to colonize.

2. Mikania and rhino

Mikania was distributed widely in all potential rhino habitat across CNP. The highest rhino density was recorded from tall grassland followed by wetland, short grassland, riverine forest, sub-tropical mixed forest and sal forest (Table 3). The average rhino density for all plots was found to be 1.18 rhinos/ km². Although there is no significant difference ($F_{df(3)}=0.28$, $p=0.83$) of the rhino density between the different Mikania invasion levels, the average rhino density on the plots with Mikania invasion was found to be higher.

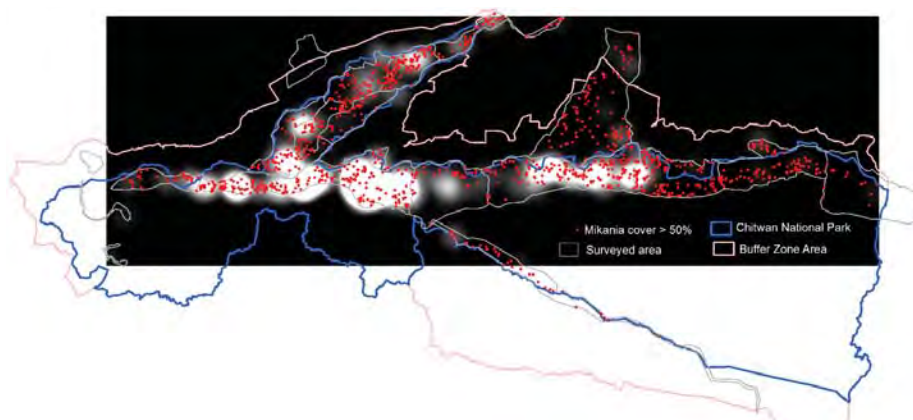


Figure 4. Mikania Invasion and rhino density in CNP (Increasing brightness shows the higher rhino density)

Table 3. Rhino density and Mikania invasion

Habitat type	Number (& %) of rhinos recorded	Average rhino density on different Mikania invasion level			Total
		0	1	2	
Tall Grassland	199 (39.56)	2.57	2.04	2.09	2.32
Wetland	32 (6.36)	1.28	1.45	1.80	1.55
Short Grassland	25 (4.97)	1.26	1.53	1.72	1.39
Riverine Forest	160 (31.81)	1.05	1.16	1.12	1.11
Mixed Tropical	4(0.80)				
Hardwood		0.91	1.08	1.51	1.05
Sal Forest	22(4.37)	0.44	0.56	0.79	0.47
Other	7 (1.39)	0.41	1.5	0.43	0.69
Not specified	54 (10.74)	0.62	0.56	0.00	0.60
Grand Total	503	1.06	1.31	1.36	1.18

Table 4. Mikania infestation change over time (2008–11).

Mikania infestation on assessment plots	% of assessed plots		Change (%)
	2008	2011	
0 - (No Mikania)	55.90	56.71	0.81
1 - Mikania < 50%	29.50	25.34	-4.16
2 - Mikania > 50%	14.50	17.95	3.45

3. Change on Mikania invasion in three years (2008 - 2011)

A total of 1,506 plots were assessed in 2008 using the same protocols of data collection and Mikania was found in 44.0 % of the plots (see Murphy et al., 2013) whereas in 2011 Mikania was found in 43.29% of the assessed plots (n=3,073). The plots with high Mikania infestation (> 50%) has increased by 3.45 % from 14.5% in 2008. This suggests, the rate of Mikania range expansion has stabilized in these three years but Mikania is intensifying on the areas where it is already present (Table 4).

If such intensification continues it may cover more than 40 % of the prime rhino habitats which could adversely affect on carrying capacity of the rhinos and other herbivores. Thus, Mikania poses an increasing threat in Chitwan.

In three years (2008–2011) Mikania infestation has increased in all the habitat types except subtropical mixed forest (Table 5). The maximum increase (intensification) was observed in wetland habitats (30.38%) which can be linked with the ecology of Mikania.

Table 5. Habitat wise Mikania infestation change from 2008 to 2011

Vegetation type	% of the plots having high <i>Mikania</i> infestation (> 50%)		% Increase from 2008 to 2011
	2008	2011	
Riverine Forest	26.02	27.03	1.01
Sal Forest	2.23	4.24	2.01
Short Grassland	1.02	12.35	11.33
Tall Grassland	19.86	20.17	0.31
Subtropical mixed Forest	51.33	14.71	-36.62
Wetland	9.62	40	30.38
Other	14.89	11.67	-3.23
Not specified	N/A	2.94	2.94
Grand Total	15.12	17.95	2.83

Discussion

CNP is one of the high priority national parks with high diversity. Spread of *Mikania*, *Chromolaena*, *Lantana* and other invasive plants pose a high threat to the park. Earlier studies have already proved that abundance and cover of the native food plants of herbivores decreases significantly in the *Mikania* invaded areas (Subedi, 2013; Sapkota, 2007). *Mikania* invasion was found to be higher in the more preferred rhino habitats such as tall grassland (39.56% rhino sightings), riverine forests (31.81 %) and wetland (6.36%) which is very consistent with the previous observations in 2008 (Murphy et al. 2013). The higher average rhino density on the plots with high *Mikania* invasion also indicates the strong incidence of *Mikania* in the rhino preferred habitats.

The 2011 assessment of the other two invasive plants i.e. *Chromolaena* and *Lantana* was also carried out in addition to the *Mikania*. These are also a threat to CNP. *Chromolaena* was found fairly widespread although higher level of invasion was occurred in pockets especially in drier sal forest and subtropical mixed forest habitats which is unsuitable for *Mikania*. *Lantana* was found only from few

pockets, thus still at the manageable level. Sporadic observation of the *Parthenium hysterophorus*, another notorious weed, is also recorded from CNP although actual extent and level of invasion is unknown.

From the comparative analysis of 2008 and 2011 data, the rate of *Mikania* expansion in new areas was found to have stabilized. This finding indicates that *Mikania* is widespread in the Park but there are ecological limitations to further spread. All of CNP cannot be suitable for the *Mikania*, thus it is now intensifying on the optimum habitats where it is already present. The overall impact of invasion has increased as *Mikania* has been colonizing in the areas where it is already present. A recent study of Subedi (2013), shows *Mikania* have devastating effects on rhinos when it covers more than 40% of the habitats. Rhinos during their foraging avoid the areas with such high invasion areas. Low to medium level invasion (<20%) is not a problem for rhinos (Subedi, 2013). The number of the plots with high *Mikania* invasion has increased by over three percent from 2008 to 2011. This three percent of the area which is converted from low *mikania* invasion to high is less suitable for rhinos.

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Vulnerability Assessment of Different Land Use Types to Invasion by *Parthenium hysterophorus* L. in Western Chitwan, Nepal

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Abstract

Distribution pattern of *Parthenium hysterophorus*, a noxious alien weed, across various land use types, its impact on species richness and forage production of grassland, and local people's perception of the weed were investigated in western Chitwan, Nepal, during monsoon of 2013. Distribution pattern was studied by examining the locations identified randomly using Arc GIS 9.3. Grassland ecosystem was sampled at 5 different sites with 10 pairs of 1 m × 1 m quadrats, i.e. 10 quadrats in high invasion sites (coverage *P. hysterophorus* >80%) and 10 in low invasion area (coverage *P. hysterophorus* <20%). People's perception on the arrival of *P. hysterophorus* in Chitwan, and its' negative impacts on crop production, and human and livestock health were assessed using group discussion with the locals at five locations. The spatial analysis of *P. hysterophorus* L. showed that the weed has had higher frequency of occurrence in urban area and hardwood forest, with presence rate of 100% and 52.47%, respectively, followed by non-irrigated cropland (26.6%), irrigated cropland (29.4%), sand and gravels (21.1%), and grazing land (17.4%). This study revealed that land use type has had significant effect on density and height of *P. hysterophorus* L. but not in the production of biomass (biomass for all grass species combined other than *P. hysterophorus* L. and total biomass). Species richness was significantly higher in sites with low cover of *P. hysterophorus* than in sites with high cover. Effect of land use type on species richness for same level of invasion was not significant. Similarly, there was high level of similarity of species composition between different level of invasion and different land use types. But majority of native species tends to be rarer in high invasion areas. According to people's perception, the weed first appeared in the study area about 10 years back (in early 2000s) and it has been rapidly spreading since then. The weed also caused harm to people and animals when exposed causing throat and mouth infection in cattle and skin allergies and eye infections in children. It has been perceived by the local people that transportation and monsoon floods were the primary reasons for the introduction of this weed to the locality.

Keywords: *Parthenium hysterophorus*, distribution pattern, land use types, effects on herbaceous biodiversity, community perception, Nepal.

Introduction

Among many invasive species globally, *Parthenium hysterophorus* L., a member of Asteraceae native to the subtropics of North and South America is an aggressive weed rated as one of three most important invasive weeds of Nepal. It has also been reported as one of the seven most dreaded weeds of the world within the last decade (Singla, 1992) that has now invaded Asia, Africa and Australia during the last 50 years. It can grow well where summer annual rainfall exceeds 500 mm (Kumar and Kumar, 2010). It is rapidly spreading in new areas of the world due to large-scale destruction of natural vegetation, overgrazing and frequent disturbances of high magnitude (Reddy, 1986).

Parthenium hysterophorus, with high yield of viable seeds, high regeneration capacity and disseminative potential, as well as its prolific growth nature on non-arable lands, is currently spreading at an alarmingly fast rate, colonizing large areas (Ayele, 2007) and also contributed by the absence of natural enemies (Riaz and Javaid, 2009). Even being a weak competitor and not being able to establish in any area where there was a dominant plant with close and compact canopy (Kumari et al., 2010), it can adjust to variety of habitat conditions and invades community forest, open spaces of urban areas, overgrazed pastures with low ground cover, cultivated lands, disturbed and bare areas such as roadsides and tracks, heavily stocked areas such as stockyards and watering points, market areas and waste lands (Kumar and Kumar, 2010; McFadyen, 1992; Singh et al., 2004). It had been threatening grassland ecosystem in many parts of the world (Dhole et al., 2011; Worku, 2010; Blackmore and Charlton, 2011) by negatively affecting the composition, diversity and biomass of natural plant species as well carrying capacity of grazing/range land (Ayele, 2007). It has also a huge potential for invasion in open spaces of agricultural land and other open area of rural and urban areas (Pandey

and Saini, 2010). Road sides are more commonly invaded and established than open spaces and farm land (Blackmore and Charlton, 2011). It is causing same problems regardless of crops grown and preventive/control measures (hand weeding and hoeing and chemical control) (Rezeneet al., 2005; Yenealem, 2008), but it couldn't establish as long cultivated crops didn't fail or pastures weren't severely overgrazed (Kumari et al., 2010). Once invaded in farm land it can be dominant after few years and continues to persist as a pure stand or weed monoculture until it is managed (Shabbir and Bajwa, 2007).

In Nepal, the invasion history of this weed is not well-known. The herbarium specimen of this weed was recorded from Trisuli (North central Nepal) in 1967 by Malla (Tiwari et al., 2005). Sharma and Pandey (1984) state that the weed was first introduced in Nepal from India in early 1980s. The present distribution of this weed in Nepal covers most urban areas in tropical to sub-tropical regions at altitudes ranging from 75 to 1350 m (Tiwari et al., 2005). Because of the invasive nature, it is spreading rapidly along roadsides, fallow lands, and rangelands in urban areas and it is gradually invading agricultural lands and forest in Nepal (Tiwari et al., 2005, Joshi, 2005).

Mostly confined to urban and peri-urban areas of Nepal until a few years ago, this weed is now expanding to natural habitats and rural areas (Shrestha, 2012) along the road network and transportation (Shrestha, 2011). In agricultural land it is found less frequently but if abandoned for 1-2 years the weed becomes dominant (Shrestha, 2011). *Parthenium hysterophorus* coverage increases towards the core of industrial and perennial barren and wasteland (Karki, 2009) and is mainly found in grassland, abandoned agricultural lands and fallow land of peri-urban and urban areas (Shrestha, 2011). Most of the study are focused in urban areas and did not assess the distribution from

urban to rural areas and preferences of *Parthenium hysterophorus* in different land use types.

This research has primarily focused to study the relationship between distribution pattern of *Parthenium hysterophorus* and land use types; effects in species composition of herbaceous community as well as assessing people's perception within the study area.

Methodology

Study area

The research was conducted in western part of Chitwan District, Central Nepal during monsoon season of year 2013. Barandabhar Corridor Forest was considered as the eastern border of the study area and Narayani River and Rapti River formed the remaining borders for the study. The study area borders with Chitwan National Park which is a World Natural Heritage site and habitat of

endangered mammals.

Data collection

The study consists of three stages, survey for spatial distribution of *Parthenium hysterophorus*, quadrat sampling, and perception survey of local people.

Survey of *Parthenium hysterophorus* was done to know the distribution pattern across the land use types by generating 500 random points using ArcGIS 9.3, of which 439 points were surveyed to collect the information regarding status of *Parthenium hysterophorus* and land use types.

Quadrat sampling was focused to assess the invasion effect of *Parthenium hysterophorus* on herbaceous plant community. Five sites meeting two criteria, i.e., area > 1 ha, and > 50% of the area covered by *Parthenium hysterophorus* were selected. Out of five sites, three sites were grouped as grassland and two sites as plantation tree land. Ten pairs of quadrats were randomly laid such that 10 quadrats lies on high coverage (high invasion area, coverage > 80%) and 10 quadrats in low coverage (low invasion, coverage < 20%) of *Parthenium hysterophorus*. Various information such as biomass of herbaceous species and total biomass, name and number of species present and individual height of *Parthenium hysterophorus* were collected from these quadrats.

For each unidentified plant species present at each quadrat, herbariums were prepared and were identified at Department of Plant Resources, National Herbarium and Plant Laboratory, Godavari, Lalitpur.

Social survey was focused to understand the people's perception and attitudes toward *Parthenium hysterophorus* weed in areas where quadrat sampling was carried out. Ten group discussions (5–10 people in each group) were

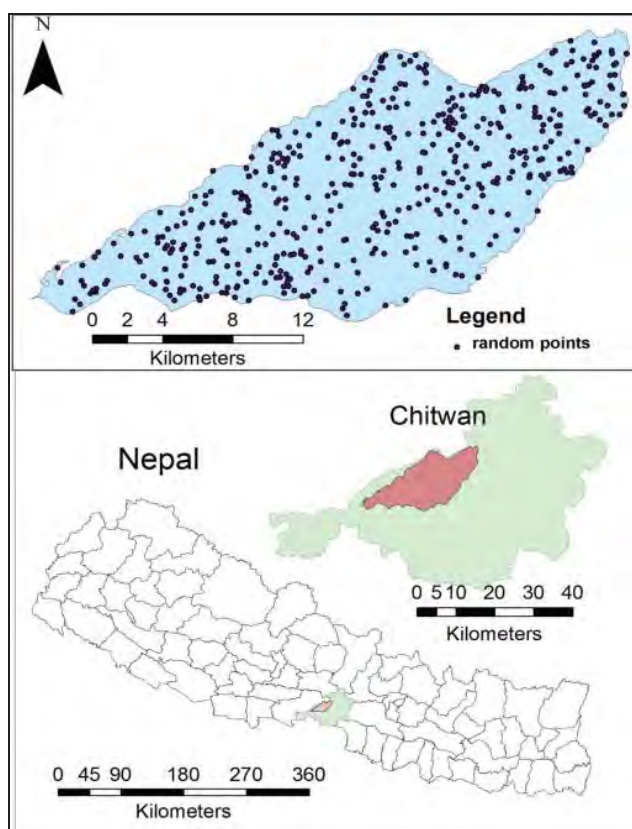


Figure 1. Map showing study area and random points

done to assess familiarity with the weed, its first appearance or notice, positive and negative impacts to people and cattle, uses of this weed and possible agents believed by local people that have brought the weed to their locality.

Data analysis

GPS data on the presence and absence of *Parthenium hysterophorus* was plotted on the land use type map. This gave an overview of the distribution pattern and land use preference of *Parthenium hysterophorus* in the area. The number of points at which it was present and absent at each land use types was calculated in percent for comparison with other land use types, and the number of points of presence and absence was also tested using Chi square test to examine the significance of land use types in its distribution.

To assess the effect of *Parthenium hysterophorus* on herbaceous community, species richness, similarity index, biomass of herbaceous species and total biomass, average height and density of *Parthenium hysterophorus* and frequency of herbaceous species were calculated for both high invasion and low invasion areas. Among five sites taken for quadrat

sampling, three sites were grouped as grassland and two sites were grouped as tree plantation for further analysis.

Results

Spatial distribution of *Parthenium hysterophorus*

The spatial distribution of *Parthenium hysterophorus* within the study area was found to be more concentrated towards the urban area (Figure 2). This study also found that there was gradual increase of *Parthenium hysterophorus* coverage towards the core of city or urban area, perennial barren/wasteland/unused land. The weed was found to be more confined along roadsides, industrial areas and non-cultivated agriculture/wasteland. Among 439 points examined, the weed was present at 131 points and absent from 308. The number of points studied from each land use types and number of points of presence of the weed at each land use types is presented in Table 1. The Chi-square test of spatial distribution of the weed showed the invasion by this weed is dependent on land use types and different land use types are invaded at different intensity and patterns.

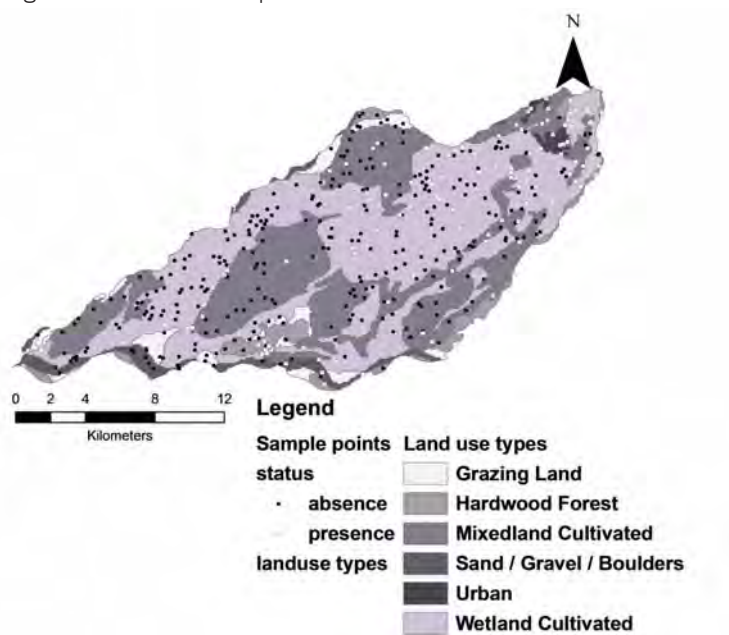


Figure 2: Spatial distribution of *Parthenium hysterophorus* within study area

Table 1. Number of study points and the occurrence of *Parthenium hysterophorus*

S.N.	Land use types	No. of study points	Points of		Percent of	
			presence	absence	presence	absence
1	Urban area	7	7	0	100.0	0.0
2	Wetland cultivation	245	72	173	29.4	70.6
3	Mixed land Cultivation	124	33	91	26.6	73.4
4	Hard wood forest	21	11	10	52.4	47.6
5	Grazing lands	23	4	19	17.4	82.6
6	Sand and gravels	19	4	15	21.1	78.9
	Total	439	131	308		

Effects of *Parthenium hysterophorus* on community structures

I) Density of *P. hysterophorus* and land use types

The average density of *Parthenium hysterophorus* was 45 stem/m² at high invasion areas. The maximum density of the weed was 126 stem/m² at high invasion area of grassland and 81 stem/m² at high invasion of tree plantation. The average *P. hysterophorus* for high invasion area of

grassland is 53 stem/m² and for tree plantation is 34 stem/m². The effect of land use types on the density of *Parthenium hysterophorus* was significant (P -value=0.05).

II) Species richness and similarity

The number of species found was higher in areas with low *Parthenium hysterophorus* invasion (Figure 4).

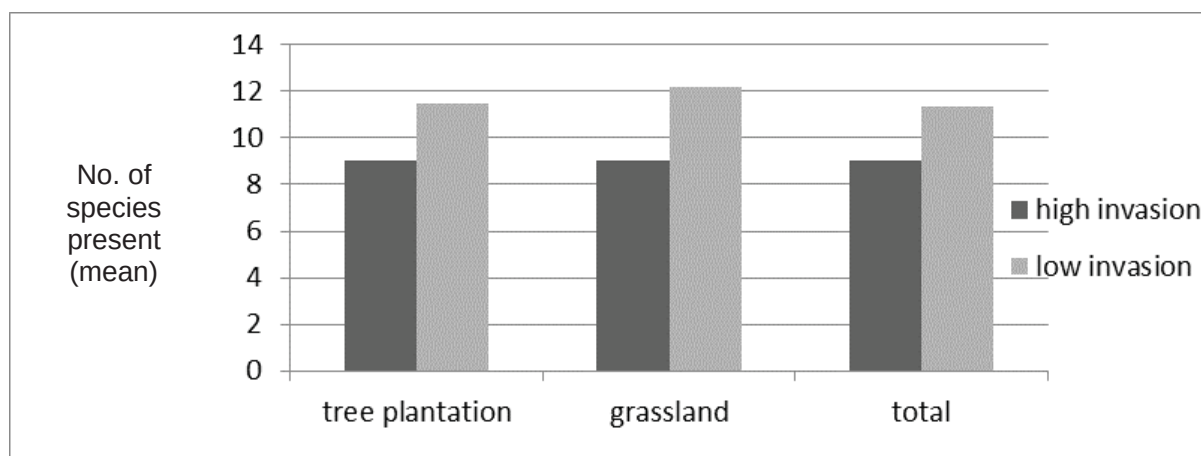


Figure 4. Herbaceous plant species richness at high and low invasion of *Parthenium hysterophorus* on different land use types.

Altogether 46 species were found collectively from both areas with high invasion and low invasion and 43 species common in both. Among those species, *Scoparia dulcis* was found only in areas with high *Parthenium hysterophorus* invasion while species *Sida rhombifolia* and *Linderina* sp. were found only in areas with low *Parthenium hysterophorus* coverage.

On each land use types, the effect of invasion on the species richness was significant, i.e., the number of species varies significantly between areas of high and low invasion of *Parthenium hysterophorus* (for both category, $P < 0.0001$). But the effect of land use types on species richness was not significant for same level of invasion (for both level of invasion, $P > 0.5$).

The index of similarity of species composition between areas of low and high invasion within same land use types and between high and low invasion for both land use types combined was very high ($> 90\%$). Since there exists a high levels of similarity index ($IS_j = 93\%$ and $IS_s = 96\%$), species within same land use type but different level of invasion by *Parthenium hysterophorus*, it can be concluded as invasion did not have any significant effect on species composition in the present study sites.

III) Effect of invasions on frequency of species

Majority of the species were frequently found in areas with low *Parthenium hysterophorus* invasion or

conversely species tends to be rarer in *Parthenium hysterophorus* invaded areas, this was also evidenced by the higher frequency for majority of species in low *Parthenium hysterophorus* invaded areas. Only 8 species out of 46 species had higher frequencies in high invaded areas. Most common species included *Clerodendron viscosum*, *Fimbristylis trichotum*, *Paspalidium flavidium*, *Oplimanus compositus*, *Panium paludosum*, *Kylinga nemesralis*, *Cyperus* sp., *Ageratum conyzoids* and *Cyanodon dactylon*.

IV) Effects of invasion on biomass production

The average of biomass combined for all herbaceous grass species other than *Parthenium hysterophorus* and total biomass combined for all herbaceous species and *Parthenium hysterophorus* for different land use types and different level of invasion is tabulated in table 2.

The analysis for biomass other than *Parthenium hysterophorus* from each site showed there were no significant differences in the biomass production from herbaceous species among same types of land use types between low and high invasion areas for tree plantation, $P > 0.6$ and for grassland, $P > 0.1$).

Similarly, *Parthenium hysterophorus* invasion has also not produced significant differences in the total biomass in the area (biomass combined for *Parthenium hysterophorus* and other herbaceous species) between different land use types in both

Table 2. Average biomass for different land use types

S.N.	Land use types	Level of invasion	Biomass other than <i>P. hysterophorus</i> (in g/m ²)	Total biomass (in gm.)
1	Tree Plantation	High	152	408
		Low	171	442
2	Grassland	High	1223	416
		Low	143	241

areas with high invasion and low invasion (for high invasion area, $P = 0.871253$ and for low invasion area, $P = 0.056222$)

V) Average height of *Parthenium hysterophorus*

The average height of *Parthenium hysterophorus* for areas of high invasion at tree plantation and grassland was 97.19 and 95.49 cm, respectively. Similarly, individual height of *Parthenium hysterophorus* from areas with high invaded areas of both tree plantation and grassland areas showed there were no significant differences in the height of *Parthenium hysterophorus* between these two different land use types ($P = 0.779877$).

Local people perception

Local people have noticed that the weed had first appeared approximately ten years before but dominated the areas in last 5 years and is still spreading in new areas.

They initially thought that this plant was some kind of problematic weed without having any use. They said this had been affecting biodiversity as the weed replaces other palatable grass leading to decrease in the availability of fodder grass and grazing land. Species like *Cassia tora*, *Ageratum conyzoides*, *Chyrosopogon aciculatus*, *Borreria articularis*, *B. alata*, *Scopari adalcis*, *Linderina Sp.*, and many herbaceous species were found less after invasion by *P. hysterophorus*

Some people complained that their cattle encountered throat or mouth infection and also avoids fodder when the weed was found mixed in the fodder. But some goats were found to graze only young plants of the weed. Even though cattle graze in *Parthenium* invaded areas they used to avoid it and only forage other grass species. Similarly, it has been reported that health related

problems to people are not common, while some children encountered skin allergies and few had eye infections. They also confirmed that it is mostly the pollen responsible for causing the problems.

Majority of local people had common perception regarding the weed and believe that transportation or road access as major causes for the introduction of the weed in their localities while few assumed that flooding during the monsoon may have brought the weed to their localities.

Conclusion

The spatial analysis concluded that *Parthenium hysterophorus* was more concentrated towards core of city/urban followed by hardwood forest. Likewise, agricultural land had high potential for further invasion from this weed if not managed timely.

The density of *Parthenium hysterophorus* was dependent on land use types and land use types significantly affect density of this weed. The effect of invasion was not significant on the production of biomass of both herbaceous species and *Parthenium hysterophorus*. Invasion had significant effect on species richness but land use types didn't have significant effect on species richness. Similarly, high level of similarity indices for different level of invasion showed effects of invasion in species composition was not significant but species tends to be rarer.

Local people believed that the weed was introduced not later than 10 years ago in the study area and is rapidly spreading and affecting fodder/ grazing species and also causing harm to people and animals, when exposed. The weed is totally useless for any purpose. Transportation and monsoon flood were primary reason for the introduction of this weed to their locality.

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Changes in Cropping Patterns, Resilience and Invasive Plant Species in Social-Ecological Systems: A Study of the Home Gardens of Kerala, India

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Abstract

Changes in the environment that affect ecosystems and impact on the ability of people to achieve livelihood security can result in increased vulnerability. In Kerala, South India, home gardens are the traditional form of agriculture and represent examples of small social-ecological systems (SES). This research outlines the characteristics of home gardens; their diversity and changes over time considering factors influencing farmers' cropping decisions and vulnerability to invasive alien plants. Semi-structured interviews were conducted with 30 households, including two participatory components – a photo activity and farm walk. An ecological site assessment was undertaken and in-depth interviews were conducted with two women's self-help groups. Data collection and analysis used both qualitative and quantitative methods. The findings suggest that, with increasing global connectivity, the economy is becoming cash crop orientated in accordance with reports of a similar worldwide trend from diverse agroforestry systems to cash crop production. An extremely high abundance of invasive plants was found in the study area with the most prevalent being *Mikania micrantha*, *Mimosa diplotricha* (*invisa*) and *Chromolaena odorata*. In conclusion, changes in farming practices alongside invasive alien species domination of the landscape result in a general homogenisation of the environment, which in turn increases the vulnerability and reduces the resilience of the SES. With ever increasing growth and use of trade routes in addition to factors such as climate change, system resilience must be enhanced through extension, policy and institution support to maintain both biodiversity and essential ecosystem services.

Keywords: Socio-ecological systems, invasive alien plants, agroforestry systems, ecosystem services.

Introduction

It is widely recognised that humans are a significant cause of changing environmental conditions, from local to global scales (Folke, 2006). Changes in the environment that affect ecosystems impact the ability of people to achieve livelihood security which can result in increased vulnerability due to reduced availability of basic resources (Carpenter *et al.*, 2009; Perrings, 2005). This is especially true for those who depend on the environment directly for their everyday needs such as poor rural communities. They are affected first by changes in the environment, often live in the most vulnerable places and have the least access to resources to protect themselves in times of environmental change.

Invasive alien species¹ (IAS) are second only to habitat loss in terms of biodiversity decline and are a direct driver of biodiversity and ecosystem service loss, and a contributor to global environmental change (MA, 2005; GISP, 2007; Pejchar and Mooney, 2009). A consequence of human activities, they affect almost every ecosystem on the earth. They impact on native species directly by competing or preying on them and indirectly by altering ecosystem services (e.g. water availability, nutrient cycling and fire regimes) (GISP, 2007). These ecosystem services include the provisioning, regulating, cultural and overarching supporting services the environment provides that are essential in maintaining a functioning ecosystem (MA, 2005).

In order for people to meet basic needs not only is their accessibility to resources dependent on socio-political status, but the availability of resources is dependent on biodiversity and functioning ecosystems (MA, 2005). Marginal and poor communities are often the most vulnerable to

surrounding environmental and social conditions so it is not surprising that they are also the most vulnerable to the impact of invasive species. Biodiversity loss has important implications for poverty alleviation and achievement of the Millennium Development Goals (MDGs, 2010). Invasive species impact at multiple scales with varied and significant consequences and can result in land degradation and reduced yields. Weeds create the highest potential for crop losses, followed by pests and pathogens (Oerke, 2006). "Invasive species therefore contribute to social instability and economic hardship, placing constraints on sustainable development, economic growth, poverty alleviation and food security." (GISP, 2007).

There are a number of invasive plants present in India, with the following present in the study area of Kerala: *Mikania micrantha* ('mile-a-minute weed'), *Chromolaena odorata* (Siam weed), and *Lantana camara*, all of which are included in the world's 100 worst alien invasive species (Lowe *et al.*, 2000). Their impacts vary but include drastically suppressing growth of native plant species to secreting allelochemicals that adversely affect biodiversity (Parthasarathy, 2012). *Mikania micrantha* increases weeding costs for farmers and adversely affects communities - 45% of respondents attributing yield losses in excess of 30% (Sankaran *et al.*, 2001; Day *et al.*, 2011). *Chromolaena odorata* is very aggressive with its spread favoured by the practise of shifting cultivation, after *jhumed* fields abandoned this species is a primary coloniser, it produces enormous numbers of seeds, is noxious and a serious threat to native species (Rao and Sagar, 2012). *Lantana camara* forms dense impenetrable thickets completely replacing native vegetation and altering forest structure of understory species; it is also allelopathic and produces huge numbers

¹ "the term 'invasive species' refers to anthropogenically introduced (accidental and purposeful) biota that rapidly become naturalized, widespread and dominant in new habitats, harming ecosystems, economies or human health" (National Invasive Species Council, 2006; Pfeiffer and Voeks, 2008).

of seeds spread long distances by birds (Rao and Sagar, 2012). It is reported in many forest areas worldwide as the highest-impacting invasive species (Parthasarathy *et al.*, 2012). Other invasive plants present in the study area include *Mimosa diplotricha* (*invisa*), *Mimosa pudica*, *Ageratum conyzoides*, and the aquatic plant *Pistia stratiotes*.

Despite the long existence and the resurgence of interest across the globe in agroforestry practises there is concern over the future of the diverse home gardens present in Kerala. Socioeconomic changes and modernisation is resulting in a conversion to monoculture cash crop cultivation (Peyre *et al.*, 2006). This transition assumes market demand and global drivers are in place; those who follow such a route may have their livelihood undermined if they are completely dependent on a single cash crop, as has occurred in the past when the price of rubber crashed (Jose and Shanmugaratnam, 1993; Balachandran, 1998). Policies have also been brought in to help increase the incomes of farmers providing subsidies and loans for cash crop cultivation. However no policies or incentives exist for promoting agroforestry

despite its many wider benefits (Guillerme *et al.*, 2011).

The sustainable livelihood-based approach (DFID, 1999) provides a framework to consider the factors confining people in poverty as well as those that may help them to rise out of the poverty cycle (Figure 1). The theory examines the way key capitals; natural, human, social, physical and financial, interact and crucially impact on the ability of people to turn these assets into actualised livelihoods strategies. The environment is embedded in the approach which recognises that although the poor may be lacking in financial capital they often have an array of other capitals that can be utilised to make a living. Strengthening the sustainability of people's livelihoods is critical to the sustainable livelihood-based approach and therefore protection of their natural resource base is crucial:

"A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base." (Carney, 1998).

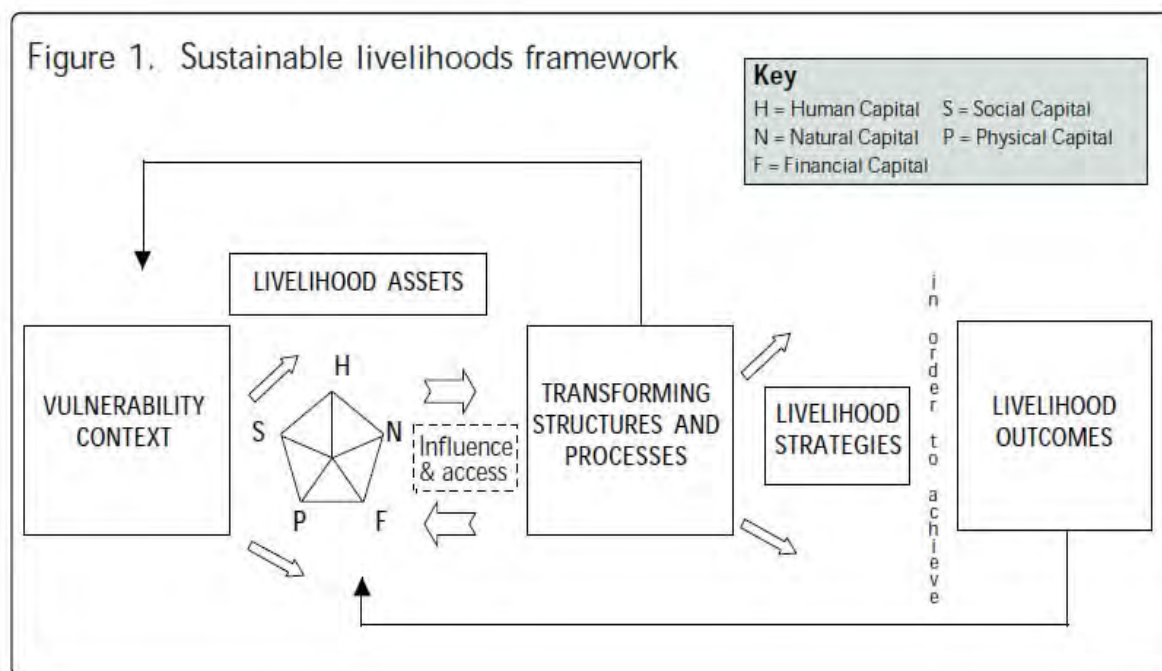


Figure 1. The sustainable rural livelihoods framework (DFID, 1999)

In addition, a systems perspective is useful in understanding linked, dynamic social-ecological systems (SEEs) containing people, agriculture and invasive species. Ecosystems, similarly to social systems, are intricately linked with feedbacks, time lags, nested phenomena and other complex dynamics (Turner and Daily, 2008). Understanding the relationship between ecosystems and their structures and functions, and the prevailing social organisation of the community and institutions within them is essential (Folke, 2006). Central to the sustainability of social-ecological systems is ecosystem resilience, which is defined as the ability of a system to return to its original state after disturbance (Hollings, 1973), with a focus on the 'whole' rather than the parts of the system (Walker and Salt, 2006).

This study investigates the characteristics and diversity of home gardens as systems of sustainable agriculture and the factors influencing farmers' cropping patterns and decisions within the aforementioned frameworks. It seeks to determine whether changes in farming patterns are placing farmers in a vulnerable position as they transition from a diverse and resilient system that has provided security for generations, to potentially, a more vulnerable position where they are driven by market forces susceptible to price volatilities and consumer demand at a global scale. The study investigates the extent invasive plants affect home gardens, followed by an assessment of how vulnerable the farmers are to invasive plants, and the factors determining the future resilience of this small social-ecological system.

The study area

This study takes place in Kerala, south India. Kerala, located on the south western coast within the area known as the Western Ghats, is a critically important forest region recognised as a 'biodiversity hotspot' (Pai, 2005) (Plate 1).

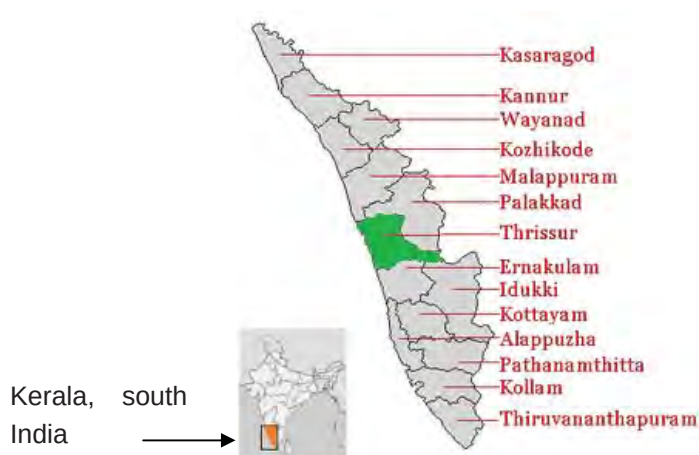


Plate 1. The study site (Puthur) was in Thrissur district in Kerala
(Image courtesy of KFRI)

The landscape in Kerala includes high, middle and lowland. The altitude varies from 20 to 215 m and the soil is acidic. The general cropping pattern is coconut, plantain, arecanut and rubber in the highland areas. The rain patterns vary according to the monsoon timings of which there are two (Viripu - April/May to Sept/Oct and Mundakan–Sept/Oct to Dec/Jan), with a short dry period between (Pai, 2005). "The dominant agroforestry practice of Kerala, is the tropical home garden, which represents an intimate, multi-storey combination of various trees and crops, sometimes in association with domestic animals, around the homestead" (Kumar and Nair, 2006). It is estimated that in Kerala an area of 1.2 million hectares of land is predominantly smallholdings with 80% of these being home gardens (Kumar, 2005).

The area has a high extent of invasion by alien plants such as *Lantana camera*, *Chromolaena odorata*, *Mimosa diplotricha (invisa)* and *Mikania micrantha*, with additional threats from newly arriving species (Parthasarathy, 2012).

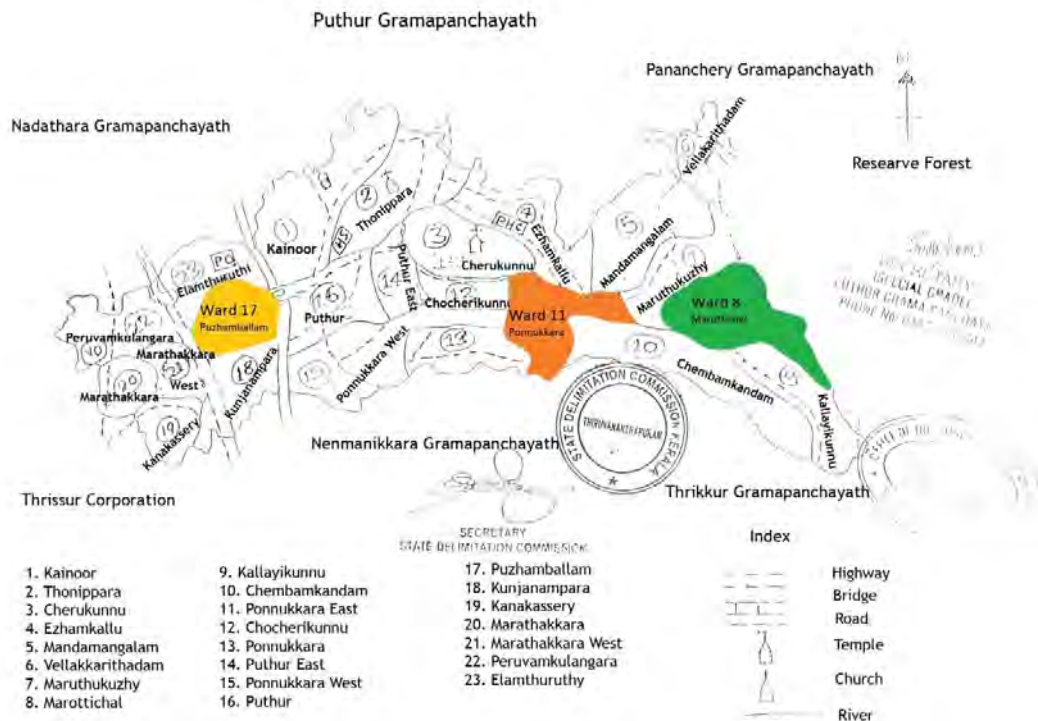


Plate 2. Map of Puthur Gramapanchayath in Thrissur. The wards where interviews took place during the study are highlighted (8 Marottichal, 11 Ponnukkara and 17 Puzhamballam) moving away from the Reserve Forest (map translated from Malayalam to English by Ambaly) (Primary Estimates, 2007).

There are fourteen districts in Kerala with Puthur Gramapanchayat selected for the study, located in the central district (Taluk) of Thrissur (Plate 1). Puthur Gramapanchayath (Office location: $+10^{\circ} 29' 25.08''$, $+76^{\circ} 16' 39.00''$) has an overall population size of 46,110 (according to 2001 census of India) with 22,873 male and 23,237 female. The total area is 79.08 km² which includes four villages and is divided into 23 wards (Plate 2). The water sources include the Puthur river and irrigation canal from Peechi dam. To the north are Nadathara and Pananchery Gramapanchayath's, to the east is reserve forest and Peechi Wildlife Sanctuary, to the south are Nenmanikkara and Thrikkur Gramapanchayaths and to the west Thrissur Corporation. 60% of the population depends on agriculture and associated sectors, with other livelihood options of the region including gold ornament making, construction stone mining, tile and brick making, packing case making and poultry farming.

Methods

The sample was stratified into three distinct groups of respondents from wards at increasing distances from the forest since this is a variable that could affect the distribution of invasive plants (Plate 2). Ten households were interviewed from each ward. In total 30 semi-structured interviews were conducted (with participatory activities) including with two in-depth interviews with women's self-help groups. All interviews were conducted with the assistance and translation by a member of KFRI staff. In addition two macro-level interviews took place.

Gaining access to participants occurred by visiting the panchayat office and obtaining a list of all farming households in the three wards to be sampled. From here farming households were selected randomly by inputting the total number of farming

households into a random number generator which selected 10 random numbers.

During each interview, the farmer was asked whether they had any weed problems and this was followed by asking about awareness of invasive plants and a photo identification exercise. Farmers were shown a selection of photographs of invasive plants present in Kerala and asked if they recognised any of them. The farm walk aimed to engage the farmers and encourage detailed discussion. This enabled matching up the plants identified in the photo activity with what was present on their land. If invasive plants were present specific questions were pursued.

A Mann Whitney-U statistical test was used to determine if there was a statistical difference in the level of infestation of the three most frequently recorded invasive plant species (*M. micrantha*, *M. diplotricha* (*invisa*) and *C. odorata*) across the wards.

Results and Discussion

In terms of crops grown, diversity in the study home gardens was found to be relatively low when compared to home gardens in the past that were reported to grow at least 37 fruit tree species in addition to crops grown at other structural layers (Godbole, 1998).

The interconnections between farmers and land are being gradually eroded due to the changing driving forces of production. For example, in the past the drive may have been for subsistence and diversity in order to ensure year round produce which would feed the family as well as earn some income (Feintrenie et al., 2010). Nowadays there is a heavy push towards profitability with cropping decisions driven by market prices. There are some subsidies encouraging certain crops (such as banana), and specific commodity boards provide technical and financial assistance (such as the Kerala State

Rubber Board). There is a lack of comprehensive public policies, financial or extension support for sustainable practices such as home gardens (agroforestry) (Guillerme et al., 2011). Reliance on external subsidies and support driven by outside forces may reduce social and cultural capitals which have a role in protecting and ensuring ecosystem security for future generations.

This is in accordance with a worldwide trend from agroforestry to intensification of cash crop production. The reasons cited are the integration of national economies into international markets, alongside decentralisation of governance where the benefits from agriculture accrue directly to regional governments who strive to further develop their local economy serving to increase the drive for agricultural profits and intensification (Feintrenie et al., 2010).

As a livelihood strategy, it is expected that the majority of farmers cite subsistence and profitability as the main crop choice reasons. Short-term crops, such as bananas, are valued since a yield is obtained within a year and subsidised seeds are provided as an incentive. Incentives play a huge role in farmers' decisions. In Kerala, acts such as the Coffee Act 1942, the Rubber Act 1974 and the Tea Act 1953, have assisted in clearing forest lands for plantations (Guillerme et al., 2011). Over time, with the addition of further state level schemes (including subsidies) promoting the uptake of cash crops (including coconut and pepper), small holder farmers have been transitioning to these cash crops with the promise of high profits. At the time of the study a high price was obtained for rubber latex (Rs. 195.50 per dry sheet). Five out of thirty farmers had invested in rubber and four of these were new investments in saplings.

The availability of financial capital is another precursor of crop choice since a certain level of finance is required before crop investments can

be made but also certain crops have a significant time lapse between planting and yield necessitating another income stream to be available in the meantime. If intercropping, the cost can be absorbed by income from other crops but if planting a single cash crop such as rubber, there will be a 5–7 year wait before tapping can begin (FAO, 2000). Farmers prefer however to invest in additional monocultures of cash crops that are more productive than intercropping and risk loss of income (Feintrenie *et al.*, 2010).

In accordance with findings in Indonesia, farmers seek 'a profitable crop with high productivity, low labour needs, and a short immature period. What they favour the most is a fast and high return to labour' (Feintrenie *et al.*, 2010). Farmers' decisions are driven by economic opportunities and the profitability of growing a monoculture cash crop is often reported as greater than that of an agroforest. In Sumatra agroforests have been replacing traditional swidden cultivation, but this is rapidly shifting to monospecific plantations due to 'an undoubtedly higher profitability than agroforests' (Feintrenie and Levang, 2009). In contrast, a study on the adoption of intercropping in rubber smallholdings in Kerala reports better rubber growth in intercropped fields, and suggests extension to promote intercropping would result in increased agronomic returns (Rajasekharan and Veeraputhran, 2002). Of concern is that although the monocropped rubber system is viable, smallholders are more vulnerable to price volatilities and market uncertainties (Viswanathan, 2008).

The annual harvest festival of Onum² takes place at the end of the banana growing season and farmers reported growing banana and certain traditional local plantain varieties in time for the festival indicating cultural aspects are still an influence on cropping decisions. However, 'sentimental attachment to traditional systems is a luxury for

rich people', demonstrated by the intercropping of coffee in the Western Ghats reserved as a privilege for the wealthy (Feintrenie *et al.*, 2010).

All the farmers in the study gain an income from their farm (one farmer by means of rent income). The average income per farm increases, as expected, from marginal to large farms. When net income is calculated (income–costs) all farmers still make a profit, but if the additional unclaimed family labour costs are included then a third of the farmers make a loss, outlining the high amount of unclaimed labour that managing these farms requires. In addition, the profits from some farms are also divided between shared owners.

The major constraint identified by farmers was the high wage rate followed closely by a severe labour shortage. The wage rate for agricultural work has steadily decreased over time (Jha, 2006; Sankaran *et al.*, 2001). Further constraints to production include pest and diseases, indeed 'pests, pathogens and weeds are the most visible of threats to sustainable food production' (Conway, 1997). Natural events such as floods and storms were of concern to farmers with the monsoon described by some as the most difficult time due to flooding. As a consequence of deforestation and changing landuse, there has been an increased occurrence of flash floods and landslides accompanied by soil erosion and the silting of reservoirs (Sajinkumar *et al.*, 2011). This has caused serious problems and feedback into agricultural production systems. Climate change is also reported to be impacting weather patterns (Kumar, 2005). One farmer mentioned climate change as a potential cause of changing weather patterns that he had noticed. The current high price for nutmeg was caused by a shortage of supply which was influenced by adverse weather (Nair, 2011). Additional concerns included the low price of crops (all reported coconut receiving a bad price), wildlife attack (especially the

2 Onum is the Hindu and harvest state festival of Kerala lasting for 10 days in August–September.

ward close to the forest), fertiliser costs, fluctuations in market price, forest fire and low yields. Weeds were mentioned as a problem by almost all respondents (26 out of 30 farmers).

The support and social structures available to farmers influences cropping decisions. The level of extension support was not found to be very prevalent in the study area with just under half the respondents reporting no contact. The majority of remaining farmers either had monthly or yearly contact, the latter simply to collect subsidies. A lack of extension has been previously reported in Kerala (Glendenning *et al.*, 2010).

The lack of extension and support means information concerning farming methods and practices does not easily make its way to farmers. In two instances women's self-help groups (SHG's) provided insight into their wider social networks. The concept of the SHG was introduced in Kerala in the 1980s and ensures extension is demand-driven since farmers can join together and learn from each other but also request extension as required. Kerala has the highest number of SHGs across the southern states (Glendenning *et al.*, 2010). The SHG model focus is on social and economic empowerment of poor vulnerable people, particularly women by "Community Driven Development" with inputs ranging from agricultural technology to education, health care, microfinance and insurance (Deininger and Liu, 2009).

The two women's groups were both Kudumbashree³ members. It became apparent that the Kudumbashree was highly regarded and instrumental in securing financial assistance for both groups from a co-operative bank enabling them to rent land to grow produce for market. Kudumbashree has received many positive reviews and is reported to demonstrate:

"...evidence of an economically and statistically significant impact on female social capital, economic empowerment, and political participation." (Deininger and Liu, 2009).

The women SHG's also took part in training courses allowing them to build their skills and knowledge resulting in both groups attempting to practice organic farming methods. SHGs provide a positive example of the benefits of working collectively to address poverty whilst also educating on environmentally sustainable agricultural practices that offer positive environmental benefits. They demonstrate that, provided with training, support and start-up capital, these women are empowered to lift themselves out of poverty and away from vulnerability.

Across the home gardens there was a high abundance of general weeds and invasive plants. The three most frequent invasive plants were *Mikania micrantha*, *Mimosa diplotricha (invisa)* and *Chromolaena odorata*. In addition, *Lantana camara* was seen along roadsides and *Mimosa pudica* was present in a number of home gardens. *Ageratum conyzoides* and *Pistia stratiotes* were also present but not seen as frequently in the study sites. The three worst weeds found across the study area were all intentionally introduced into India and have been present for a long time. Social and ecological drivers have facilitated their spread (Sankaran *et al.*, 2001, Dr Abraham, Weed Scientist, Kerala Agricultural University, *personal communication*).

Observation on the farm visits suggest that, where weeds were managed, they were kept under control by intensive manual efforts on the part of the farmer (or by hired labour). However, on land either left fallow as part of a rotation or uncultivated adjacent to a well maintained plot, the vegetation was generally almost completely covered with

³ The Kudumbashree concept is a community network working at the same time as local self-governments for poverty alleviation (Kudumbashree, 2012).

the invasive weed *M. micrantha*. This weed was frequently found infringing on farm borders, and will be resulting in higher weeding effort. Along many roadsides or abandoned land invasive plants were present often exhibiting high levels of infestation. The majority of farmers (80%) stated that weeds were a problem and most recognised *M. micrantha* in the photo exercise as present in the study area and/or on their farms. The recognition *M. diplotricha (invisa)* and *C. odorata* was less frequent with approximately half of the respondents recognising each of them present in the study area (but not necessarily on their farms). Four farmers reported weeds as a *significant problem*; they all had *M. micrantha* present on their farms and stated:

“We can’t keep on top of this weed and do not know how to control it”

“...it’s a big problem, I keep pulling but it keeps growing”

“Weeds are a problem this year – more so due to the summer rain - it [*M. micrantha*] is a problem due to its fast growth and spread, I’ve really noticed it in the last six years”

The effort required to clear *M. micrantha* is very high, especially when there are nearby

watercourses with dense cover, as it can spread rapidly (hence its common name ‘mile-a-minute weed’).

The ecological assessment was used to triangulate the farmers’ perceptions of weeds. The assessment indicated the presence of native (general) weeds was high across all three wards. *M. micrantha* exhibited the highest infestation level out of the three most frequent invasive weeds with infestation levels highest in ward 8 decreasing through ward 11 to ward 17. Higher levels of *M. diplotricha (invisa)* and *C. odorata* were identified in ward 17 (Figure 2).

Awareness levels differed depending on level of engagement in farming activities. Farmers who actively work the land demonstrate closer links with the environment, awareness of weeds and change in cropping patterns. In terms of sustainable livelihoods, these farmers hold traditional knowledge and represent a key entry point for any future invasive species management programmes. However, farmers could also have become desensitised to invasive plants as they have been present in the area for such a long time they have become naturalised (Dr Anitha, KFRI, 2012, *personal communication*).

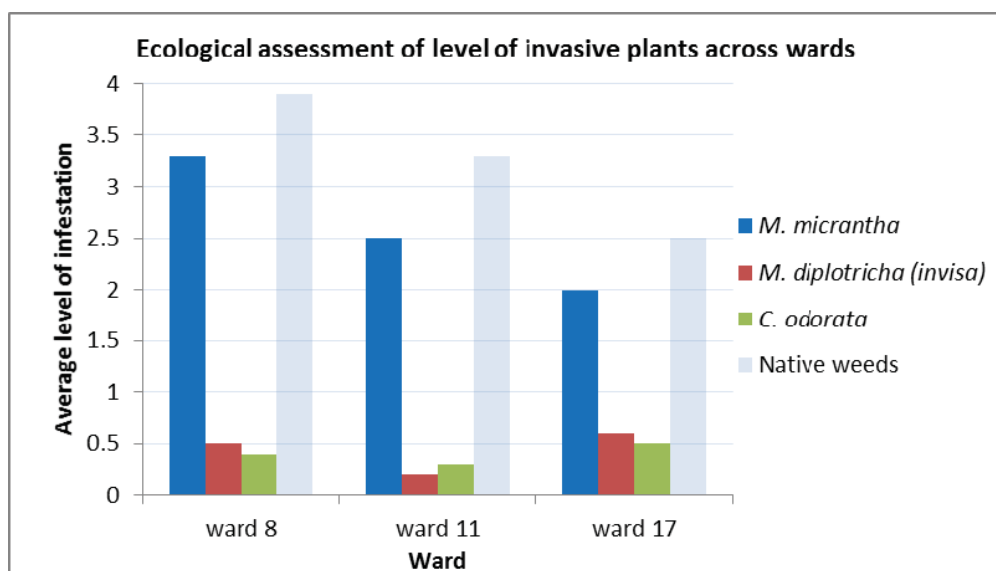


Figure 2. Ecological assessment of level of invasive plants across wards (note: general assessment)

The highest level of infestation of *M. micrantha* was in ward 8. No statistical difference was found in the level of (general) infestation of the invasive plants between the wards. At the transect level a statistical significance (at a 10% level) was found in the level of *M. micrantha* between wards 8 and 17, confirming visual observation that *M. micrantha* infestation was highest in Ward 8 (Mann-Whitney test result: $p(0.0758) < 0.10$).

Overall there is a blanket distribution of invasive plants across the wards in accordance with farmers' perceptions of a high amount of problematic weeds. The farmers deal with these weeds as one problem and do not distinguish between them. There was a low level of awareness of invasive plant species, but high interest when discussed, with enquiries into appropriate management techniques. Where external support is lacking it is suggested farmers 'make the best out of the worst situation' when confronted with invasive plants (Rai et al., 2012).

Mikania micrantha has a history of causing problems in agricultural systems. It has been reported to cause yield losses in excess of 30% in Papua New Guinea and, in poorly managed plantations, young plant death after six months (Day et al., 2011). In addition, when crops are stressed by factors that include the presence of weeds they are more susceptible to other pests (Leakey, 2012). A previous study in Kerala reported farmers ranking *M. micrantha* as the most significant constraint to production and gives an average cost of weeding in agricultural systems of 35% of the total cost of cultivation and a cost of weeding *M. micrantha* 6.2% for marginal and small farms (holdings below 1 hectare) and 7% for medium and large farms (above 1 up to 2.02 hectares) of that weeding cost (Sankaran et al., 2001). These figures were used to determine the average amount likely to be attributed to weeding in each farm to give an estimation of the extent farmers are unknowingly

impacted *M. micrantha*. In this study the estimated cost of general weeding at 35% of the total cost of cultivation was between 7,375 and 37,769 Rs. for marginal and small farms and from 37,769 to 99,275 Rs. for medium to large farms. The estimated annual cost of weeding mikania was 431 –2,205 Rs. for marginal to small farms, 6,495 Rs. for medium farms and 6,335 Rs. for large farms.

Weed disposal route is important because if invasive weeds are transported or burnt it could contribute to their spread. The accidental transport of species such as *Mikania*, *Chromolaena*, and *Lantana* has been reported to 'challenge the ability of the invaded landscape to farm and prosper' (McWilliams, 2000). No farmers in the study said they transported weeds with most leaving them somewhere on their farm to decompose. However, the practice of collecting and transport of fodder does occur which will contribute to spreading invasive plants, especially *M. micrantha* that can re-grow from small fragments. Some respondents placed weeds as mulch around the base of plants, whilst others soaked and applied as a fertiliser, in one case weeds were burnt twice a year. In these instances this will not sufficiently deal with the invasive plants but allow and even promote their continued spread, increasing repetitive and labour intensive weeding. Some farmers used weeds as fodder for animals but one stated "this plant gives the cow loose motions". Although *M. micrantha* is grazed by cattle, it is a less valuable fodder crop (Day et al., 2011). One farmer reported using *C. odorata* as a fertiliser.

Some farmers reported using invasive plants for fodder and fertiliser, therefore consideration is now given to potential IAS uses. The aggressive invader *L. camara* is regarded as one of the world's ten worst invasive plant species but is utilised in India as a hedge plant, a source of paper pulp, fuelwood and as a traditional medicine, even a craft material for weaving baskets and making furniture

(GISP, 2007). No one in the study site reported using *L. camara* for beneficial purposes although within the farm study sites it was not particularly prevalent. Some reported using *C. odorata* in the past (about 15 years ago) during an outbreak of a virus where it was used to sooth itching and at this time was sold for a high price. *C. odorata* is used in traditional medicine in Indonesia to treat skin wounds and chemical analysis suggests it may be a useful antimicrobial drug (Nwinuka et al., 2009). In addition *M. micrantha* was utilised as a fodder despite being an inferior source. It was reported that one Kadar tribal community member had mentioned using *M. micrantha* for medicinal purposes (J. Krishnakumar, 2012, (PhD student), *personal communication*). Literature suggests the root may have anti-inflammatory properties (Khare, 2007), and it was used to treat cuts as a medicine for stomach aches in Papua New Guinea (Day et al., 2011). This could be a potential new avenue for invasive species control - exploitation to benefit human welfare whilst also controlling its spread (Tripathi et al., 2012). However, such utilisation approaches are not generally recommended, for example, a heated debate recently surfaced over the use and adaptive management of *L. camara*. Here it was highlighted that utilisation is restricted to a small proportion of people, it is an inferior plant thus not a preferred choice and, since it grows rigorously from rootstocks when it is cut, utilisation in this way will only promote its further spread (Witt et al., 2012).

In the context of resilience SES's are constantly changing, non-static entities that remain in equilibrium within their thresholds. However, if exceeded, these thresholds can cause the system to move beyond its current state resulting in feedback loops and potentially a permanent shift into a new equilibrium with alternative structures and functions (Walker and Salt, 2006). In terms of invasive species, an environmental threshold may be reached where ecosystem functions are

impacted resulting in a shift and a new emergent system with reduced diversity, resilience and lower thresholds (Scheffer and Carpenter, 2003; Decker et al., 2012). In such instances the system may experience increased vulnerability to external shocks that the previously diverse system would have been capable of absorbing, with the native ecosystem experiencing a functional collapse (Reaser et al., 2007). A system's resilience has three properties which can be measured and include: 1. the amount of change a system can absorb, 2. the degree it is capable of reorganisation, and 3. the degree it can build capacity, learn and subsequently adapt (Carpenter et al., 2001).

In this context globalisation 'a defining feature of our times' must be mentioned since the resilience, vulnerability and adaptability of SESs are undoubtedly shaped by it (Young et al., 2006). This SES has experienced many disturbances over time from rapid population increase resulting in high levels of forest clearance, to land reforms and fragmentation, whilst also being affected by the spread of invasive plant species replacing native vegetation. The present day situation favours economic gains over environmental sustainability. The increasing connectedness resulting from the forces of globalisation have further facilitated the economic transition to cash crops and, at the same time, the spread of IAS. It is therefore possible that a threshold has been reached with a shift in vegetation towards "weedy" species potentially representing an irreversible change in plant species composition (Walker and Meyers, 2004). The Diversity Resistance Hypothesis (Decker et al., 2012) states that a more diverse system will be better able to resist invasion. The continued pressures contributing to the reduction of diversity in both ecological and social aspects is placing this SES in an increasingly vulnerable position.

The study area as a whole is suggested to be highly vulnerable and exhibits low resilience due to being

highly degraded, fragmented and simplified. The increasing connections resulting from international trade, transport and travel further threaten the area with new invasions. There are differences in the level of incomes across the farming community but the capacity to cope with the existing invasive plants, aside from any significant new invasive species, is low due a lack of awareness and means. Management strategies in such instances could involve improving overall system resilience by adopting policies that promote forest recovery, enhance soil fertility and reduce the clearing costs so that management becomes a viable option in which the involvement of all stakeholders is essential (Perrings, 2005).

The macro-level interviews provided insights into two organisations' opinions of IAS. The local Banana Research Institute was aware of weeds but did not include training or response to them on training courses but as they are a local point of contact for farmers it would be an obvious in-road. The Dean of Weed Science at Kerala Agricultural University reported many IAS in India, with many new arrivals. A policy approach was recommended alongside increased extension and assistance for on-the ground networks already present – this would be an entry point for well needed IAS management programmes such as Integrative Pest Management (IPM) using biological control methods, for example, a biological control programme found a rust pathogen (*Puccinia spegazzinii*) from the native range of *M. micrantha* that has been released at trial sites in India and elsewhere where *M. micrantha* is problematic (Ellison, 2010).

Conclusion

Overall there have been many changes in Kerala over the last few decades. The trend away from home gardens has been occurring for some time and is being adopted by increasing numbers of farmers who can afford to invest in monoculture

growing of cash crops. Other farmers are diversifying their livelihoods. As the land change has occurred, trade policies have been liberalised and globalisation has increased connections in the world market.

A suite of invasive plants has been present in Kerala for a long time during which they have become naturalised and accepted alongside other weeds as a normal constraint to farming. Although no farmer was able to state exactly how much time they spent weeding it is suspected to be high, particularly due to the rapid growth of *M. micrantha* which was highly abundant across the study area. The major constraint to production was highlighted as the high wage rate, which means that, with increased weeding effort in addition to a lack of labour, farm duties such as intensive weeding will fall on family members, a cost which is often not accounted for and consumes a considerable amount of time. This may have disproportionate effects on family members (such as women and children) and impact on achievement of the MDG's.

There are vast challenges ahead for biodiversity management when forming resilient and sustainable agricultural systems. The small SES of Puthur, Kerala demonstrates the strong forces underlying farmers' decisions at the grassroots level—forces stemming along a hierarchy of ever increasing SESs from local, regional to global scales.

The area is considered highly vulnerable to invasive plants and demonstrates low resilience in the face of future challenges, whether in market fluctuations or ecological disturbance. Additional new IAS arrivals are being observed—with the increasing homogenisation of the environment reflected in farming practices. In an area so close to the Western Ghats Biodiversity Hotspot the future resilience of this SES needs to be addressed through various pathways.

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An Investigation into the Compliance of Selected Nurseries and Garden Centres within Kwazulu-Natal Wthekwini and Umsunduzi Geographical Regions, South Africa

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Abstract

This paper examines compliance of nursery/garden centres with Invasive Alien Plant (IAPs) legislation in Wthekwini and uMsunduzi, South Africa. The South African government has identified removal of Invasive Alien Plants (IAPs) as priority and has enacted eleven national laws and various provincial laws which contain mechanisms for regulating the different threats posed by IAPs. Despite these regulatory laws, eradication and control methods, IAPs continue to invade valuable land at an alarming rate. The cost to clear IAPs in South Africa is estimated to be 12 billion Rand over 20 years. The horticulture industry has been identified as a major pathway for introductions of IAPs into the natural environment. However, Government regulation/instruction of nurseries/garden centres seems inadequate.

This study examined nurseries compliance with the Conservation of Agricultural Resources Act (CARA) 1983 (Act No. 43 of 1983) and the National Environmental Management: Biodiversity Act (NEMBA) 2004 (No. 10 of 2004). Data was collected via questionnaires, interviews and structured on-site observations. This study followed a mixed methods approach as the study required both the quantitative analysis of questionnaires and the interpretation of interviews. The survey was a means to gather statistically valid quantitative data and the interviews were aimed to collect in-depth qualitative data in terms of perception, idea or explanation through participant's expressions.

A careful analysis of the data indicates serious shortcoming with regard to communication between nurseries/garden centres and Government, IAPs training within Industry and awareness of the "Codes of Conduct for Nursery Professionals." However, based on the findings of this research, these shortcomings appear not to pose an obstacle in the compliance of legislation. The Industry, as a whole (within the area of study), is compliant with CARA legislation, although it appears, from the evidence presented in this research, that there is currently no pressure from Government to comply and, subsequently, no enforcement of the law. NEMBA regulations, on the other hand, are still pending (at the time the investigation was conducted) and selling plants that are listed is not an offence. Industry were also anxious to be kept informed about changes and developments in legislation, but had a negative attitude to what they perceived as a deterioration in the interactions between themselves and Government.

Keywords: Alien invasive plants, Conservation and Agricultural Resources Act, (CARA), Invasive Plant Legislation, National Environmental Management: Biodiversity Act, (NEMBA).

Introduction

South Africa has a major problem with invasive alien plants (IAPs) (Richardson and Van Wilgen, 2004). Studies have shown that IAPs impact negatively on biodiversity, natural resources and agricultural systems (www.gisp.org, 2003). Despite governmental legislation and programmes, there still seems to be a lack of public awareness regarding the extent of the problem (Wildy, 2002). This poses an obstacle to the effective implementation and management of control systems (Richardson, Henderson and Ivey, 2006).

Many of the IAPs within South Africa were intentionally introduced through the horticulture industry, as ornamental plants (Wildy, 2005) and are still available for sale in garden centres and other retail outlets (Groves *et al.*, 2005; Bell *et al.*, 2007). In this light, the nursery industry is often accused of being a source of “garden escapees” (Chin, 2006). This poses a significant issue to all stakeholders in the Industry as gardeners and landscapers do not intentionally plant IAPs (DiTomaso, 2005).

However, the Industry benefits financially from exotic plants as they add new and different species to landscapes and gardens.

Furthermore, most exotic plant species introduced through horticulture often grow readily with little maintenance in climates where they are introduced (Burt *et al.*, 2006). Therefore, nurseries/garden centres have an important role to play in promoting

responsible plant choices, garden management practices and to increase public awareness regarding IAPs to their customers, the general public (Richardson *et al.*, 2006). To achieve these roles, nurseries/garden centres need to be working with the appropriate authorities and have to be compliant with the relevant legislation (Richardson *et al.*, 2006).

Impacts of Invasive Alien Plants

Studies have documented that not all exotic plant species introduced for horticulture are invasive (Burt *et al.*, 2006). However, a small percentage has escaped from cultivation and has been identified as one of the main causes of biodiversity loss and direct habitat destruction worldwide (Bradshaw and Jones, 2005; Burt *et al.*, 2006; Culley and Hardiman, 2008).

IAPs do not only have an ecological impact on the environment, but also a significant impact on the country's economy (Pimentel, Zuniga and Morrison, 2000 and 2005; Richardson *et al.*, 2005). In South Africa, the cost to clear alien plant invasions is estimated to be around R12 billion or roughly R6000 million per year for the estimated 20 years that it would take to deal with the problem (McDonald, van Wilgen, and Mgidi, 2004; Wildy, 2005). Therefore, the public needs to know that IAPs are not only an environmental issue, but have a negative economic impact on every South African. (Table 1).

Table 1. Effects of Invasive Alien plants on the Environment and their Economic Consequences

INVASIVE ALIEN PLANTS EFFECTS	ECONOMIC CONSEQUENCES
Reduction of available water resources	Rates increase due to cost of construction of dams. Reduction in agricultural yield that leads to increase in food prices.
Loss of biodiversity and ecosystems	We are dependent on biodiversity for food, water, clean air, soil retention, and pollination, decomposition of waste, recreation, ecotourism and medicine. Therefore, biodiversity is a resource that should be conserved and sustainably used.
Loss of potentially productive agricultural land	Loss / reduction in land value.
Poisoning of livestock and humans	Cost of medical care.
Loss of grazing for livestock	Cost of supplementary feed that leads to increase in meat prices.
Greater incidence of bush and veld fires	Increase cost of fire control and insurance premiums.
Soil erosion	Cost of rehabilitation work.
Coagulation of dams and estuaries	Rates increases and redirection of tax income. Reduce fish yields resulting in job losses and loss of income.

Source: Adapted from Wildy (2005).

Invasive Alien Plant Legislation in South Africa

The South African Government has identified the removal of IAPs as a priority and has enacted eleven national and various provincial laws which contain mechanisms for regulating the different threats posed by IAPs (Paterson, 2006). Principle among these laws is the Conservation of Agricultural Resources Act 1983 (Act No. 43 of 1983), (CARA) (South Africa Government Gazette No. R.280:20, March, 2001) and the National Environmental Management: Biodiversity Act 2004 (Act No. 10 of 2004), (NEMBA) (South Africa Government Gazette No. 32090, April 3, 2009).

Conservation of Agricultural Resources Act 1983 (Act No. 43 of 1983)

CARA was originally enacted to regulate IAPs that may have an impact on agricultural resources, but in the absence of alternate relevant legislation, CARA

regulations have also been applied to regulate IAPs that impacted on biodiversity, water resource management and fire management (Paterson, 2006).

Regulations in terms of CARA were passed in 1984 and 50 plant species were declared as “weeds” or “invader plants” (Hanks, *circa*, 2004; Department of Water Affairs and Forestry, 2001). In March 2001, the Minister of Agriculture promulgated an amendment to CARA and increased the list of legally declared invasive alien species to 198 (Hanks, *circa*, 2004; Wildy, 2005) which are divided into the following:

- Category 1: Plant species that may not be grown anywhere in South Africa and must be eradicated;
- Category 2: Plant species with commercial or utility value, which may only be grown with a permit under controlled circumstances; and

- Category 3: Plant species which have amenity value and which need not be eradicated, but which may not be planted, propagated, imported or traded.

(Department of Water Affairs and Forestry, 2001; Hanks, *circa*, 2004; Wildy, 2005; Paterson, 2006)

Landowners are under legal obligation to control IAPs occurring on their properties and, if found to contravene any section of the Act, a criminal case may be brought against them (Department of Water Affairs and Forestry, 2001; Wildy, 2005). Penalties range from fines to imprisonment. Further, the Department may issue a directive setting a date by when the property must be cleared. The directive is binding on a successor-in-title (Department of Water Affairs and Forestry, 2001; Wildy, 2005). If the directive is ignored, the Department can clear the land or engage someone to do so. The cost of this clearing can then be recovered from the landowner and can also be registered against the title deeds of the property in terms of the Agricultural Credit Control Act. This will result in the property not being able to be sold until monies spent, to clear the property of IAPs, have been repaid (Department of Water Affairs and Forestry, 2001; Wildy, 2005).

The enforcement of CARA legislation is the responsibility of the Executive Officer appointed by the Minister of Agriculture (Department of Water Affairs and Forestry, 2001; Paterson, 2006).

Although, CARA was promulgated over twenty years ago, IAPs continue to invade valuable South African land at an alarming rate (Wildy, 2005; Burt *et al.*, 2006; Paterson, 2006) and, to date, there has not been a single successful conviction under this legislation (Paterson, 2006).

In light of the above Paterson's (2006) critique on CARA implementation includes the following;

- The lack of public awareness regarding the nature and extent of the IAPs problem, despite the various nationwide information campaigns implemented by organisations, such as Ukuvuka, Working for Water (WfW) and South African National Biodiversity Institute (SANBI).
- CARA is administrated by the Department of Agriculture whose core function is to protect agricultural production and not issues of biodiversity conservation and water resource management.
- CARA also fails to provide any clarity on the roles to be played by the various spheres of government in invasive alien plant control.
- Budgetary constraints compel officials to limit their focus to the agricultural sector.
- CARA Regulations do not provide adequate guidance regarding what control measures would be appropriate within a given context. This causes problems with regard to the implementation and enforcement of the CARA Regulations, given the scale of the problem, the range of the species involved and the need to tailor area-specific control measures.
- CARA Regulations provide no monitoring requirements and the sanctions imposed by the Act are so minimal that they do not constitute a deterrent.

[In terms of section 29(3): *Sanctions for non-compliance with CARA Regulations are limited to R500 and/or three months imprisonment* (South African Government Gazette No. 22929, December, 14, 2001)]

A holistic approach should be adopted to manage IAPs by forming a co-operative partnership with all relevant stakeholders in local and national level.

Government as well as non-governmental role players (Environmental Management Department, 2010) and developed an overall AIP strategy and management plan, which aligned local Government to national legislation (Haskins, 2009).

National Environmental Management: Biodiversity Act 2004 (No. 10 of 2004)

South Africa is rated the third-most biologically diverse country in the world (Department of Environmental Affairs and Tourism, 1997). However, this rich biodiversity is one of the most threatened worldwide and rapid spread of IAPs poses one of the greatest threats to it (Preston and Siegfried, 1995; Richardson and Van Wilgen, 2004).

NEMBA, was promulgated in 2004 and deals directly with the prevention of unauthorised introduction, spread and eradication of IAPs (Gubb, *circa*, 2005; Paterson, 2006). NEMBA is administrated by the Department of Environmental Affairs and Tourism (DEAT) and they have tasked SANBI, to assist the Minister in executing the various facets of the Act (Gubb, *circa*, 2005; Paterson, 2006).

NEMBA radically reformed South Africa's biodiversity conservation legislation and contains provisions with specific relevance to the control of IAPs (Paterson, 2006) including emerging species.

The Act specifies that:

- No person may import, export, grow, propagate or have alien species in their possession without a permit;
- Permits may be issued only after the prescribed assessment of risk to and potential impacts on biodiversity has been carried out; and
- An individual can be held liable should an alien species establish itself in nature as an

invasive species as a result of the actions of that individual. (Gubb, *circa*, 2005; Paterson, 2006).

NEMBA, together with the revised CARA legislation, lists six categories that reflect the importance of preventing new invasions (Southern African Plant Invaders Atlas, 2006). Categories 1, 2 and 3 (CARA) remain basically the same, except that 1a (NEMBA) are high priority emerging species that must be eradicated or strictly controlled. Category 1b (NEMBA) are wide- spread species that require a management plan. Further, Category 4 (NEMBA) lists indigenous species outside of their natural ranges that are a threat to biodiversity (Southern African Plant Invaders Atlas, 2006). Category 5 (NEMBA) known as Table X, includes all species under surveillance. These include many ornamentals commonly found in gardens that may be listed after due investigation. Category 6 (NEMBA) are species known to be invasive and are prohibited entry into this country (Southern African Plant Invaders Atlas, 2006).

NEMBA empowers the Minister and provincial MECs to publish national and provincial lists of invasive species, respectively (Paterson, 2006). Paterson (2006) further states, that the Act, to date, is still pending and does not make provision for an interim list of invasive species to be published. Therefore, any provisions regulating these invasive species will be inoperative until such time as it has been published (Paterson, 2006).

Henderson (2001) and the South Africa Government Gazettes (No. 22929, December, 14, 2001 and No. 32090, April 3, 2009) explain that the revised CARA and NEMBA regulations list 198 different exotic plant species, 122 of which are CARA Category 1 plants, known as declared weeds, 37 species in CARA Category 2, which have commercial value and 39 species in CARA Category 3 that have ornamental value. The

species in CARA Categories 2 and 3 are known as plant invaders (Henderson, 2001; South Africa. Government Gazette, No. 22929, December, 14, 2001 and No. 32090, April 3, 2009). CARA Category 4 includes bush encroachments and indigenous species outside of their natural ranges that are a threat to biodiversity, and Category 6 species that are prohibited entry into this country (Southern African Plant Invaders Atlas, 2006) [CARA list available online at: www.sana.co.za/Alien-Invasive-Plants/invasive-alien-plants-cara-list].

NEMBA Category 5 lists a further 36 species identified as potentially invasive (Southern African Plant Invaders Atlas, 2006). This list is known as Table X: Category 5, as per NEMBA 2001 (Southern African Plant Invaders Atlas, 2006). [NEMBA list available online at: www.sana.co.za/NEMBA-Proposed-IAP-List-May-2009.pdf].

Management Challenges in the control of IAPs

The Minister published the second draft of IAPs regulations under section 70 of NEMBA in April 2009 (Department of Environmental Affairs and Tourism, 2009). However, any provisions regarding invasive species under the Act will be inoperative until such time as the regulations have been finalised by Government.

Most control measures have been focused on eradication and crisis management of IAPs which are already established or are aimed at preventing introductions of high-risk species (Burt *et al.*, 2006; Mgid, Le Maitre, Schonegevel, Nel, Rouget and Richardson, 2007). Government recognises that, due to the magnitude of the problem, prevention is more cost effective than control and eradication (McDonald *et al.*, 2004; Burt *et al.*, 2006; Mgid *et al.*, 2007; Cully and Hardiman, 2008).

SANBI launched the “Early Detection and Rapid Response (EDRR) programme,” funded by WfW

(Southern African Plant Invaders Atlas, 2010). The EDRR plans to reduce the impact and cost of management of invasive plants by early intervention and management of emerging invasions.

(Southern African National Biodiversity Institute, *circa.* 2010). The key aspects of implementation are early detection, risk assessment and response planning and rapid response (Southern African National Biodiversity Institute, *circa.* 2010).

Recognition of the horticulture industry, as a major pathway for introductions of IAPs, has increased steadily (DiTomaso, 2005; Groves *et al.*, 2005; Vartanian, 2005; Burt, *et al.*, 2006; Bell, *et al.*, 2007). However, laws addressing the introduction of potentially invasive plants via the horticulture industry remain inadequate (Reichard and White, 2001; Pimentel *et al.*, 2005; Paterson, 2006). Therefore, Government and industry are looking at self-regulation by the horticulture industry to reduce possible introductions of invasive plants (Bradshaw and Jones, 2005; Vartanian, 2005; Burt, *et al.*, 2006). Participation of nurseries and garden centres with self-regulatory initiatives might ensure compliance with regulations regarding IAPs, as these initiatives are in conjunction with regulatory laws (Bradshaw and Jones, 2005; Burt, *et al.*, 2006).

The St Louis Declaration and Voluntary Codes of Conduct is the most widely-recognised initiative, to prevent horticultural introductions of IAPs (Burt *et al.*, 2006) and is endorsed by many nursery trade organisations, including South African Nursery Association (SANA), a key member of the Working for Water Nurseries Partnership Programme (WfW NPP).

The KwaZulu-Natal horticulture industry is relatively decentralised, as most nurseries and garden centres are not members of trade associations. Involvement in trade associations may be an important predictor of how familiar nurseries

and garden centres are with perceptions of the problem of IAPs, recommended actions with regard to the IAPs problem, their acknowledgement of the Industry's role in this problem, as well as their knowledge of IAPs regulations and the implications these regulations may have on the Industry (Burt *et al.*, 2006).

The Aim of this Study

The aim of this study was to assess the compliance of selected nurseries/garden centres, within KwaZulu-Natal Wthekwini and uMsunduzi geographical regions, CARA under section 29 (15) and NEMBA under section 70 (1b) and (3) and to investigate the associated communication between Government and the horticulture industry in this region in terms of the following research questions:

Research Questions

1. To what extent do Nurseries/Garden Centres stock/sell a selection of IAPs as defined in CARA and NEMBA?
2. Are Nurseries/Garden Centres staff able to identify a selection of IAPs on the CARA and NEMBA list and thereby contribute to advising customers on plant choices responsibly?
3. To what extent do Nurseries/Garden Centres stock/sell and are able to identify a selection of indigenous non-invasive plant alternatives on the CARA and NEMBA list and thereby respond to customer buying trends and demands and be able to advise customers on responsible plant choices?
4. To what extent is there communication between Nurseries/Garden Centres and Governmental programmes and/or initiatives directed at managing IAPs and emerging invasive plants?

Data Collection

Data was collected via questionnaires, interviews and structured on-site observations.

This study followed a mixed methods approach as the study required both the quantitative analysis of questionnaires and the interpretation of interviews. The survey was a means to gather statistically valid quantitative data and the interviews were aimed to collect in-depth qualitative data in terms of perception, idea or explanation through participant's expressions (Creswell, 2009).

Data Analysis

Descriptive and inferential statistical analyses were used to generate the quantitative results for this study and thematic statistical analysis for the qualitative results.

The quantitative results and analysis of the questionnaire were analysed using graftsand thematic analysis were undertaken for the interview and codified.

A total of 60 nurseries and garden centres were surveyed in terms of the following:

Awareness of CARA

Figure 1. awareness of CARA legislation.



Figure 1. % of respondents aware of the CARA legislation.

In terms of CARA legislation:

- 52% respondents were aware of CARA; and
- 48% were not aware of the CARA regulations

Awareness of NEMBA

Figure 2. awareness of NEMBA legislation.

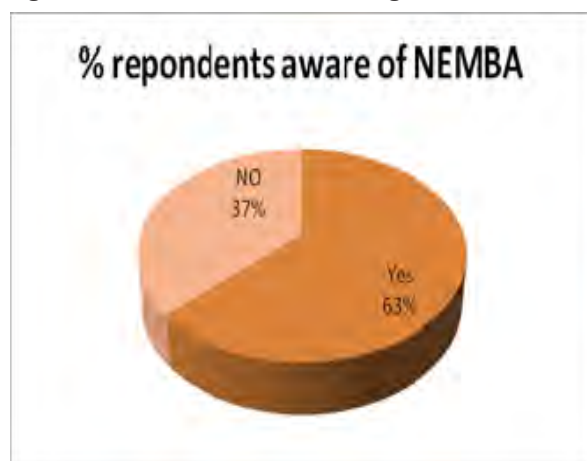


Figure 2. % of respondents aware of the NEMBA legislation.

In terms of NEMBA legislation:

- 63% respondents were aware of NEMBA; and
- 37% were not aware of the NEMBA regulations.

Awareness of key Governmental role-players concerning, the control and management of IAPs.

Figure 3. awareness of key role-players concerning the control and management of IAPs.

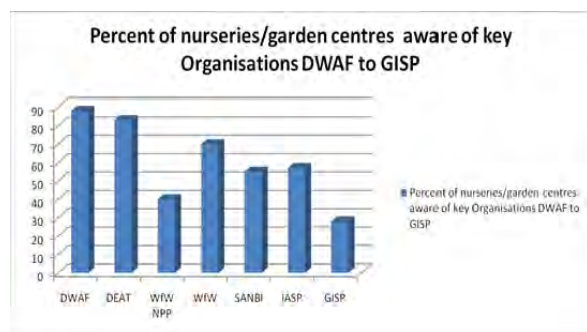


Figure 3. % of nurseries/garden centres aware of key organisations: DWAF to GISP.

The highest percentages of respondents' awareness of key governmental role-players, in the control and management of IAPs were:

- DWAF at 88.3%;
- DEAT 83.3%; and
- WfW 70%.

DWAF-Department of Water Affairs and Forestry

DEAT-Department of Environmental Affairs and Tourism

WfW-Working for Water

WfW NNP-Working for Water Nursery Partnership Programme

SANBI-South African Biodiversity Institute

IASP-Invasive Alien Species Programme

Affiliation to a Trade Association

Figure 4. nurseries/garden centres affiliated to a Trade Associations

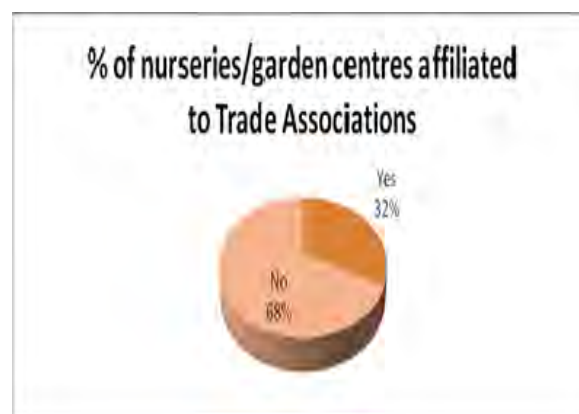


Figure 4. % of nurseries/garden centres affiliated to trade associations

In terms of nurseries/garden centres affiliation to a Trade Association:

- 32% (19) nurseries/garden centres are affiliated to a Trade Association; and
- 68% (41) are not affiliated to a Trade Association.

Risk of Non-compliance

The risk of non-compliance with CARA and NEMBA were tested by testing each Independent Variable $X_1 - X_{10}$, listed in Table 2, against each Dependent Variable $Y_1 - Y_{17}$, listed in Table 3

Table 2. Independent Variables

Variable X_i	Name of variable	Corresponding Survey Questionnaire Item	Range of possible values
X_1	Experience	1	1–5
X_2	Qualification	2	1–4
X_3	Type of Business	3	1–2
X_4	Degree of customer attraction	4a	0–5
X_5	Awareness of Voluntary Codes of Conduct for Nurseries	5	1–2
X_6	Awareness of CARA	7	1–2
X_7	Awareness of NEMBA	7	1–2
X_8	Awareness of Organisations	8	0–7
X_9	Affiliation to Trade Associations	10	0
X_{10}	Exposure to Training	11a	1–2

Table 3. Dependent Variables

Variable Y_j	Name of variable	Corresponding Survey Questionnaire Item	Range of possible values
Y_1	Stock CARA plants	15: $\sum$ CARA	0–10
Y_2	Stock NEMBA plants	15: $\sum$ NEMBA	0–11
Y_3	Stock Indigenous Alternative plants	15: $\sum$ Indigenous plants	0–4
Y_4	Identify/know CARA plants	15: $\sum$ CARA	0–10
Y_5	Identify/know NEMBA plants	15: $\sum$ NEMBA	0–11
Y_6	Identify/know Indigenous Alternative plants	15: $\sum$ Indigenous plants	0–4
Y_7	Receive Government info/feedback	12.4 & 12.5	2–10
Y_8	CARA category knowledge	12.6	1–5
Y_9	NEMBA category knowledge	12.7	1–5
Y_{10}	Customer Q 1	13.1	1–5
Y_{11}	Customer Q 2	13.2	1–5
Y_{12}	Customer Q 3	13.3	1–5
Y_{13}	Customer Q 4	13.4	1–5
Y_{14}	Posters	14.1	1–5
Y_{15}	Pamphlets	14.2	1–5
Y_{16}	Opinion: invasive plants	14.3	1–5
Y_{17}	Opinion: potential invasive plants	14.4	1–5

A “GENLOG Poisson” model programme was carried out on all the data. Many statistically significant results were obtained on each Y for each X. However, those tests that were significant only indicated that there were some significant differences between sub-groups of data, but they did not indicate what the nature of the differences was.

A feature of the “GENLOG” analyses is that significant differences can occur, for example, due to differing “skewness” around the median. However, the use of medians allowed the researcher to pinpoint where the central tendencies were in the data, and whether subsets of data were significantly different from each other in regard to their medians.

In terms this mixed methods enquiry; it was important to know if the central tendencies (i.e. the medians) of the Y’s associated with each subgroup X (independent variable) were significantly different. Therefore, a median test was carried out on all the Y data to calculate the medians with their 95% CI’s.

Summary of medians and related statistics with regard to nurseries/garden centres stocking and selling CARA and NEMBA listed plants

Although there were statistically significant differences in the distribution patterns between sub-groups according to GENLOG analysis, there were no differences in their central tendencies (medians) for stocking CARA listed plants. Nurseries/garden centres in this study stocked very few CARA plants, despite the fact that 68% of the respondents are not affiliated to a Trade Association (refer to Figure 4). A total of 95% of all businesses (57 out of 60) stocked zero of the CARA plants shown.

There were statistically significant differences in the distribution patterns between sub-groups

according to GENLOG analysis, but no differences in their central tendencies (medians) stocking and selling NEMBA listed plants. The median number of types of NEMBA plants out of 10 different varieties stocked by nurseries and garden centres, irrespective of the sub-groups were 4.

Observations conducted during the administration of the questionnaire confirmed the findings that nurseries/garden centres in general do not stock or sell CARA listed plants. Therefore it can be concluded that nurseries/garden centres in this study are compliant with CARA legislation.

However, nurseries/garden centres do stock and sell NEMBA listed plants, despite the fact that 63% of the respondents were aware of NEMBA regulations (refer to Figure 2). NEMBA listed plants are not legislated against and selling these plants is not against the law.

Results

In terms of the research questions it was found that the factors (independent variables) listed in Table 2 were not associated with significant differences in the responses of the two sub-groups; Nurseries and Garden Centres. But the medians for the whole sample (Nurseries together with Garden Centres), showed that in terms of:

Research Question 1

- No CARA plants were stocked or sold and a median of 4 out of 10 selected NEMBA plants were stock and sold.
- Therefore Nurseries and Garden Centres are currently compliant with CARA but not compliant with NEMBA;

Research Question 2

- The median number of CARA plants (out of 10) identified was 6 and the median

number of NEMBA plants (out of 10) was 8.

- Being able to identify CARA listed plants do contribute in Nurseries and Garden Centres advising customers on responsible plant choices.
- However, being able to identify 8 out of 10 selected NEMBA plants, made no difference in Nurseries and Garden Centres advising their customers on responsible plant choices. This may be because NEMBA regulations, at the time the research were conducted, were still pending and selling listed plants was not an offence;

Research Question 3

- It was found that the median number of indigenous non-invasive plants (out of 4), was 3.

Public awareness programmes, such as the Working for Water “Water-Wise-Plant” and the Working for Water Nursery Partnership Program “Plant Me Instead” campaigns may have had an influence on customer buying trends, and that Nurseries and Garden Centres are responding to customer demands;

Research Question 4

- It was found that there was no or little communication between relevant Governmental Departments and Nurseries /Garden Centres with regard to issues pertaining to IAPs.

Both the Quantitative and Qualitative results showed consistency with the above findings.

Conclusion and Recommendations

A careful analysis of the respondents' answers to the questionnaire and interview questions

indicates serious shortcoming with regard to communication between nurseries/garden centres and Government. However, based on the findings of this research, these shortcomings appear not to pose an obstacle in the compliance of legislation.

The Industry, as a whole (within the area of study), is compliant with CARA legislation. Although it appears, from the evidence presented in this research, that there is currently no pressure from Government to comply and, subsequently, no enforcement of the law. NEMBA regulations, on the other hand, are still pending and selling plants that are listed is not an offence.

According to nurseries/garden centres (within the area of study), no official notification nor IAP lists were received from Government between 2004, when NEMBA was promulgated, and 2011, when this study was conducted. At the same time, evident in this study, nurseries/garden centres had done little on their part to initiate contact with Government. Nevertheless, findings of this research confirm that high levels of awareness of the NEMBA regulations exist within Industry.

Respondents were able to identify listed NEMBA plants shown to them. This researcher, however, is of the impression that this was because the plants shown were routinely sold as a matter of course and not because of any special information received via the NEMBA Act. Many respondents feel that not all NEMBA listed species should be on the list, and that the horticultural industry should be able to challenge the Government designation of specific plants. Several respondents are also of the opinion that they should be allowed to stock and sell species that are, for example, invasive in the Western Cape and not in Kwazulu – Natal. This perception of these individuals elicits the need for training around IAPs, as the spread of IAPs are not always restricted by geographical regions.

In general, respondents would like more information about IAPs lists and want to be kept updated about emerging IAPs. They feel that more education and awareness, especially aimed at junior sales staff, is needed and that nurseries and garden centres should be included in Governmental and other initiatives against IAPs.

Government organizations, viz., DEAT and DWAF have their own initiatives and management programmes to manage and control IAPs. It appears that each of these organisations is caught-up with their own mandates and challenges in their fight against IAPs. Subsequently, little interaction exists between them and nurseries/garden centres. Liaising with nurseries and garden centres might be the last item on their agendas.

The WfW NPP plays a significant role in the fight against IAPs and embarked on nationwide awareness campaigns and industry training workshops concerning IAPs, in November, 2004 and February, 2006 and conducted two KZN Nursery surveys against IAPs in 2002 and 2010.

It appears, however, that these initiatives had little impact on the local Industry (within the area of study), as it is evident from the findings of this study that the majority of nurseries and garden centres were not aware of the WfW NPP existence nor participated in any of their programmes.

The EDRR programme, funded by WfW and under the directorship of SANBI, aims to control the spread of IAPs by “early intervention and managing of emerging invasions”. The EDRR, however, have limited staff members in KZN and they appear to be focusing on managing only a few invasive species at a time. Their main aim is to raise awareness among private home – owners and the public in general.

SANA is a major role-player in creating awareness around IAPs, especially in keeping their members

informed about legislative developments. However, evidence presented in this research, elicits the fact that the majority of local nurseries/garden centres are not members of SANA, nor do they have any intention of becoming members.

On the basis of the data analyses and the discussion of the findings, the following recommendations are made with regard to the compliance of nurseries and garden centres with invasive alien plant legislation:

IAPs Advisory Committee should be instituted under the directorship of the Department of Environmental Affairs. This pro-active Committee can be independent or it can be incorporated into the WfW NPP programme as this organisation already have managing systems and structures in place. This proposed committee should form a co-operative partnership with all relevant stakeholders, but dedicated to keeping nurseries/garden centres informed and updated concerning IAPs.

Objectives of the (proposed) IAPs Advisory Committee:

- To liaise between interests groups, instrumental in the management and control of IAPs, and nurseries/garden centres;
- To compile an “IAPs Information Guide” for Nurseries, featuring:
 - Invasive alien plant lists;
 - Names and contact details of relevant organisations dealing with IAPs; and
 - List of internet sources offering information containing IAPs.
- To play the role of a IAPs information centre where nurseries/garden centres can direct their questions and queries too.

The main aim of the (proposed) IAPs Advisory Committee should be to train Horticulture

graduates as IAPs Consultants, adding a new and interesting career to Industry as well as creating more jobs within Industry.

The functions of these Consultants should be as follows:

- To offer training concerning IAPs to Industry as a whole [Government could use this training as a tax incentive which would allow nurseries/garden centres to claim against the Skills Levy];
- To present awareness programmes and talks around IAPs to nursery/garden centre customers [A spin – off from these programmes is that it have the potential to increase sales of indigenous and non – invasive exotic plant alternatives to IAPs]; and
- To pay nurseries/garden centres a courtesy visit at least twice a year, not to police them, but to act in an advisory capacity.

The government published a new set of NEMBA regulations on 19 July 2013 and contain list of species which requires a range of control measures including removal, permits and management plants if found on your property. Among the 93 newly listed invaders a number of plants are commonly found in gardens. Further, the latest NEMBA draft alien and invasive species list was published for public comment on 12 February 2014. In light of these developments further investigation are required.

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An Overview of Legal Instruments to Manage Invasive Alien Species in Nepal

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Abstract

Biological invasion is a global problem with adverse impacts on all types of ecosystems and human welfare. The invasive alien species (IAS) is considered as the second greatest threat to native biodiversity after habitat loss in global context. The rapidly accelerating international trade and tourism have dramatically enhanced the spread of IAS and caused adverse impacts on agriculture, forestry, fisheries, and other human enterprises including health. Recognizing as one of the greatest threats to natural environment and human health some useful initiatives is being taken all over the world for their effective management and is now becoming a major focus of international conservation concern and the subject of cooperative efforts. The knowledge base on IAS is rather meager and limited in Nepal. There are about 218 species of naturalized alien plants and about two dozen highly invasive species in our ecosystems. The number of invasive alien animal species is not known but 27 alien animal species have been reported. Empirical data on the ecological impact of IAS is meager while the economic cost related to IAS has not been estimated. However, the country has recognized the threats posed by IAS, and incorporated the issues of IAS in different national strategy (e.g. Nepal Biodiversity Strategy 2002), reports (Fifth National Report to the Convention on Biological Diversity 2014) and legal instruments (e.g. National Wetland Policy 2003, revised 2012). Besides, the country has also formulated several sectoral laws and established quarantine offices to control and eradicate the germs, pests and weeds of agricultural crops. But, these efforts are not directly related to prevent the introduction and spread of IAS. Hence, revision of the sectoral laws is needed to address the IAS problems. Further, the specific strategy and laws are expecting to regulate and control the introduction IAS. Being a signatory to many global environmental treaties and conventions pertaining to IAS, it is mandatory for Nepal to fulfill obligations under these treaties and conventions. Paradoxically, the management of IAS is still not a national priority; the existing legal instruments are not effectively implemented; the commitments made have not been fulfilled.

Keywords: Naturalized species, national strategy, sectoral and cross-sectoral laws, international collaboration.

Introduction

Biological species which occur outside their natural distribution range are called alien species in their new habitats. Because they cannot reach this location by their own means, human is usually involved in moving or introducing the species. The alien species may be introduced intentionally for agriculture, forestry, fisheries, aquaculture, landscaping or ornamental purposes, or unintentionally as contaminant when materials are transported between regions and hitchhiked by human and transport systems. Increasing travel, trade, and tourism associated with globalization and expansion of the human population have facilitated intentional and unintentional movement of species beyond natural bio-geographical barriers, and many of these alien species have become invasive. In many countries, agricultural, commercial forestry, aquaculture/sport fishing and some other biological production systems depend on alien species. However some alien species escape from human control and go beyond the intended physical boundaries; they proliferate and spread rapidly with significant negative impact on resident community and ecosystem, and considered as invasive alien species (IAS). The IAS are considered to be one of the main direct drivers of biodiversity loss at the global level (Vitousek *et al.*, 1997). They can produce substantial environmental and economic damage, and their negative effects are exacerbated by climate change, pollution, habitat loss and human-induced disturbance. Increasing domination by a few invasive species increases global homogenization of biodiversity, reducing local diversity and distinctiveness (<http://www.cbd.int/invasive/>). The Convention on Biological Diversity (CBD) defines IAS as an alien species which threatens ecosystems, habitats or species (Article 2). According to Clare *et al.* (2000), "invasive species

means an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change and threatens native biological diversity". The invasive species also include subspecies and lower taxa, as well as any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce (IUCN, 2000). Living modified organisms (LMO), including genetically modified organisms (GMO) are also considered as a subset of alien species, because the genetic material of such organism has been altered in a way that does not occur naturally by mating or recombination (Clare *et al.*, 2000).

Several alien plant species have become aggressive and have rapidly colonized in different ecosystems of Nepal and is considered as one of the major threats to native biodiversity and natural ecosystems of the country (MFSC, 2014). Pathways for introducing the alien species in Nepal, particularly *via* India, are land connected borders, roads and international trade networks and air corridor. The common vectors include people, soil, packaging, animals, machines such as trucks, buses and cars, including natural forces like wind and floods. Biological invasion usually follows a common sequence beginning with introduction, and progressing to colonization and naturalization (Radosevich *et al.*, 2003). Not all introduced species are invasive, there is a commonly used "rule of tens" which suggests that about 10% of introduced species will escape and survive in the wild, 10% of these will become established or naturalized and 10% of naturalized species will spread and become invasive (Keam *et al.*, 2009).

Common characteristics of IAS include rapid reproduction and growth, high dispersal ability, phenotypic plasticity, and ability to survive on various food types and in a wide range of environmental conditions (Davis, 2009).

Ecosystems that have been invaded by alien species may not have the natural predators and competitors present in its native environment that would normally control their populations. Native ecosystems that have undergone human-induced disturbance are often more prone to alien invasions because there is less competition from native species and high resources availability. The disturbed areas such as roadsides and agricultural fields are more prone to invasion than the intact closed forests.

Status of Naturalized Alien Species in Nepal

Nepal has about 218 species of naturalized alien plants belonging to 53 families (Tiwari *et al.*, 2005; Siwakoti, 2011) which share about 4% of the total angiosperm flora of Nepal. These are invasive or potential invasive species to Nepal. Most of the naturalized species belong to Asteraceae, followed by Solanaceae, Fabaceae, etc. (Figure 1). Majority of these naturalized species are herbs (Figure 2).

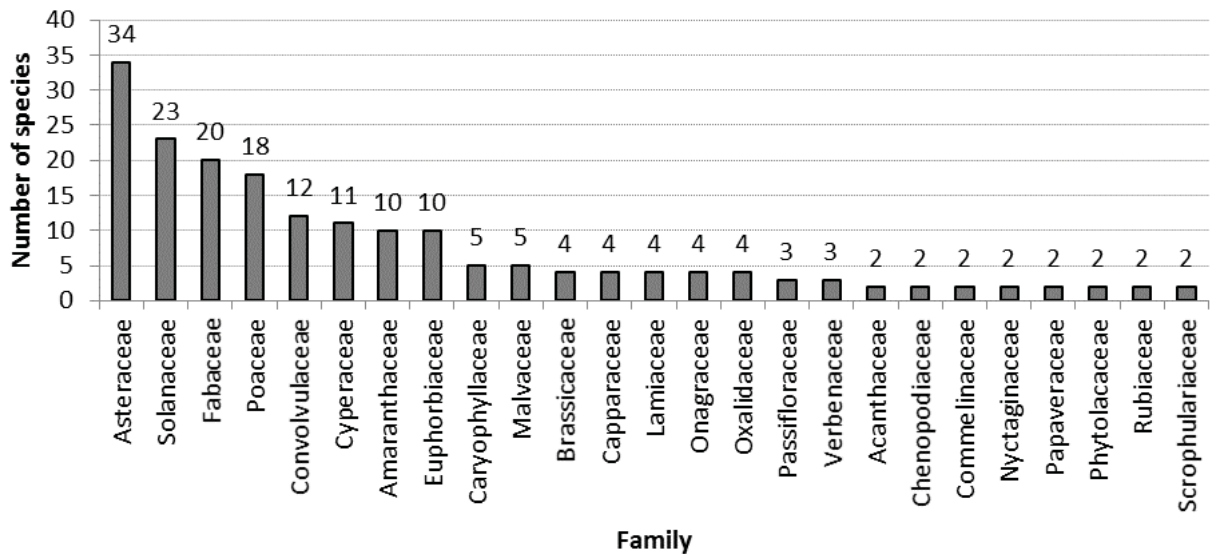


Figure 1. Number of naturalized plant species belonging to different families. Only the families having > 1 species are presented. There are 28 families with single naturalized species in Nepal.

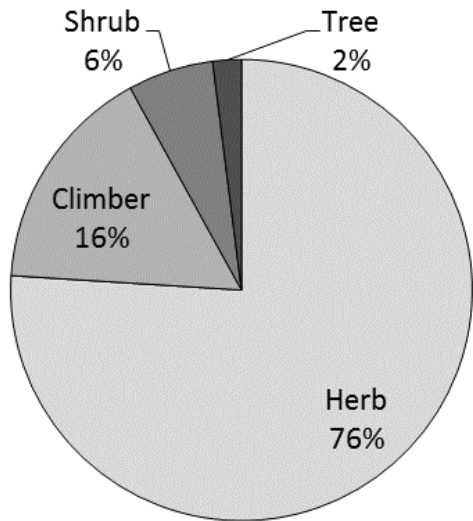


Figure 2. Contribution of different growth forms to the naturalized plant species of Nepal.

Over two dozen plant species including *Ageratina adenophora* (L.) King and Robinson, *Ageratum houstonianum* Mill., *Alternanthera philoxeroides* (Mart.) Griseb., *Chromolaena odorata* (Spreng.) King and Robinson, *Eichhornia crassipes* (Mart.) Solms., *Hyptis suaveolens* (L.) Poit., *Ipomoea carnea* Jacq.ssp. *fistulosa* (Mart. ex. Choisy) D.F. Austin, *Lantana camara* L., *Mikania micrantha* Kunth, *Parthenium hysterophorus* L., *Pistia stratiotes* L., etc., are aggressively invading different ecosystems in Nepal. Some of the invasive weeds of Nepal such as *Eichhornia crassipes*, *Lantana camara*, *Mikania micrantha* and *Chromolaena odorata* are among the world's 100 worst IAS (Lowe et al., 2000).

Invasion of water hyacinth (*Eichhornia crassipes*) is a major threat to tropical and sub-tropical wetlands of Nepal. Important wetlands, including the Beeshazari Lake in Chitwan, and Phewa Lake in Pokhara, are severely invaded by water hyacinth. Invasive species such as *Pistia stratiotes*, *Ipomoea carnea* ssp. *fistulosa*, *Mikania micrantha*, etc., are also becoming abundant in wetlands, thereby affecting habitats of water birds and other wetland dependent fauna and flora. Whereas, the forest biodiversity has been seriously threatened by *Ageratina adenophora*, *Chromolaena odorata*, *Mikania micrantha*, *Lantana camara*, etc., and has emerged as a major threat to protected areas and other forests located in the Terai, Siwalik and Mid-hills in recent years. Among the protected areas, Chitwan National Park has the highest number of naturalized species (112 species) followed by KoshiTappu and Parsa Wildlife Reserves (108 species each) (M Siwakoti and BB Shrestha, unpublished data). Similarly, the biodiversity in degraded forests and grasslands are also invaded by *Ageratina adenophora*, *Chromolaena odorata*, *Lantana camara*, *Mikania micrantha*, *Parthenium hysterophorus*, *Xanthium strumarium* L., etc., and its severity and extent is consistently increasing (Tiwari et al., 2005; Shrestha, 2014). The agricultural lands also invaded by *Ageratum conyzoides* L., *A. houstonianum*, *Bidens pilosa* L., *Oxalis latifolia*

Humb., *Parthenium hysterophorus*, etc., reducing the crop production and fertility of soil.

It is found that over 70% of naturalized plant species in Nepal are Neo-tropical i.e. tropical American origin. The Terai, Siwalik and Midhill regions have been seriously invaded by IAS, however, the problem of IAS has been not seriously realized in high mountains. Although IAS has potentially high threat to biodiversity in different ecosystems of Nepal, the loss in term of economy has not been valued. Once IAS is established, it is almost impossible to completely eradicate it. Therefore, the best option is to utilize the species, but a risk assessment is needed before promoting the utilization of IAS. People usually do not assess the impact of IAS, if it provides some benefit, so the scientific community does not encourage for using the IAS for commercial utility. Local community has been utilizing some of the IAS in limited amount, for example, *Eichhornia crassipes* has been used for preparing manure, production of biogas, for making handicrafts and also mixed in animal feed. Similarly, *Ipomoea carnea* spp. and *Fistulosa* are used as fencing material, fire wood, construction materials (i.e. to prepare hut by poor people), and also planted in landslide area to stabilize soil; *Chromolaena odorata* as animal bed and for preparation of bio-briquette; *Lantana camara* as fire wood; and *Mikania micrantha*, *Alternanthera philoxeroides*, *Pistia stratiotes* as fodder/animal feed.

Information on the naturalized animal species in Nepal is relatively less. However, several alien animal species have invaded different ecosystems and threatened native animal species. Twenty seven animal species have been identified as alien in Nepal (Budha, 2013). There has been introduction of Mozambique Tilapia (African origin, *Oreochromis mosambicus* WKH Peters) via India and *Oreochromis niloticus* Linnaeus via Thailand due to their high economic value and fast breeding habit. Cat fish (African origin, *Clarias gariepinus* Burchell) was

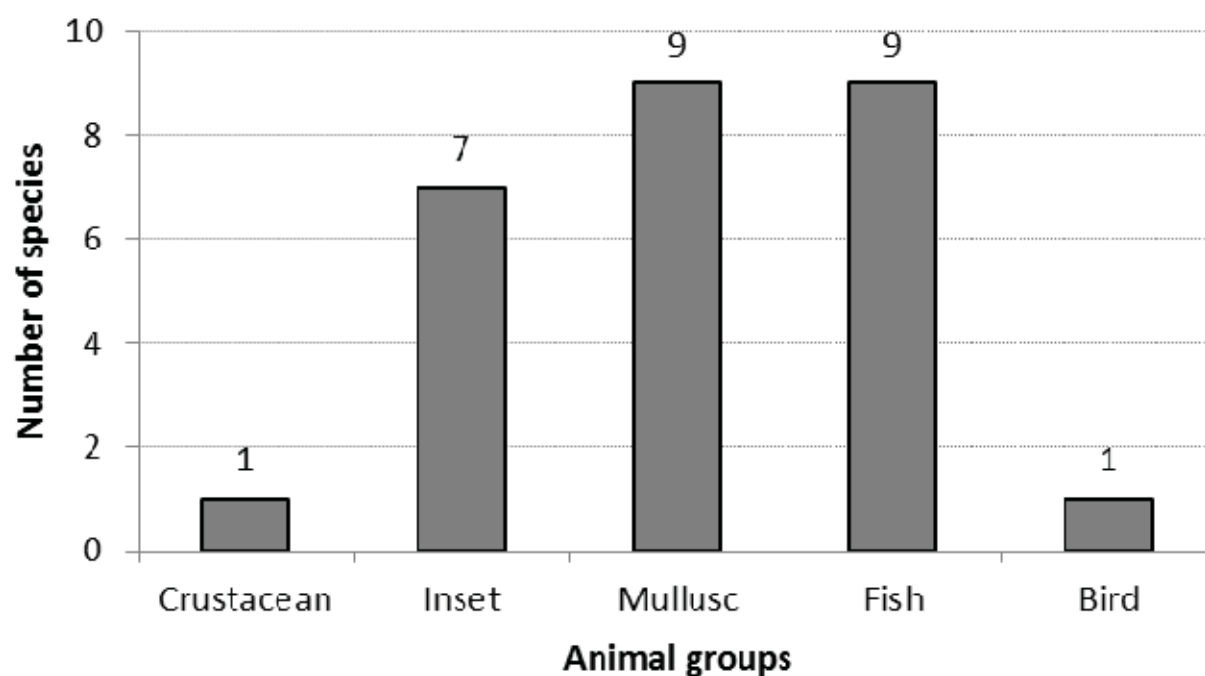


Figure 3. Number of alien species belonging to different groups of animals (Data from Budha, 2013)

introduced illegally in fishery ponds by farmers, and it is now can be found in natural ponds and rivers of Terai. The promotion of alien Chinese carp fishes (*Aristichthys nobilis* Richardson, *Hypophthalmichthys molitrix* Valenciennes, *Ctenopharyngodon idella* Cuvier and Valenciennes) reduced about 42% of native fish from Begnas lake of Pokhara (Swar and Gurung, 1988). There is a report of eleven alien fish and one freshwater prawn species introduced in Nepalese wetlands for aquaculture development (MFSC, 2014). Research at the national level, regarding the extent of exotic species introduction, has not yet been conducted. However, limited studies conducted at specific locations show the rapid expansion of exotic species' habitat, and its significant potential to pose negative effects on local biodiversity in the future (CSUWN, 2011). The invasion of African giantland snail (*Achatina fulica* Ferussac) in eastern Terai, possibly via cargo, has been displacing the native molluscs (*Khasiella pansa* Benson and *Cyclophorous fulguratus* Pfeiffer) (BR. Subba, per.com, Sept. 2011). Some of the alien animals such as African giant land snail, Western Mosquito fish (*Gambusia affinis* Baird

and Girard), Mozambique Tilapia, Rainbow trout (*Onchorhynchus mykiss* Walbaum), Brown trout (*Salmo trutta* Linnaeus), Terrestrial flatworm (*Platydemus manokwari* DeBeauchamp), etc are among the world's 100 worst invasive species (Lowe et al., 2000). Unfortunately, fishes like tilapia and trout have been introduced intentionally for commercial purposes and they have already escaped to natural habitats.

Overview of Legal Instruments related to IAS

Empirical data on the ecological impact of IAS in Nepal is meager. Impacts of IAS have been recognized but the economic loss in term of monetary value has not been estimated. However, IAS are a global issue that requires international cooperation and actions. There are many international and regional binding agreements and voluntary guidelines focusing on invasive species. The earlier agreements before 1960s were focused to prevent the introduction and spread of pests and diseases for the safety of human, animal and

plant health. During 1960s, agreements reflect growing scientific concern about the impacts of alien invasive species on global biodiversity. Since 1990s, several agreements and technical guidelines were developed to minimize the risk of IAS. Nepal is also a signatory to the major international agreements related to IAS. An overview of some important international agreements to which Nepal is a contracting party and national legal instruments to address the problem of IAS are presented below.

International Legal Instruments

The Convention on Biological Diversity (CBD):

Article 8(h) of the CBD states that “Each contracting Party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species”. The Conference of the Parties (COP) acknowledged the urgent need to address the threat due to IAS at its fourth meeting (decision IV/1) in 1998. The Convention further states that IAS occur in and affect all major taxonomic groups and ecosystems, and are considered a cross-cutting issue applicable to all work of the Convention (<http://www.cbd.int/invasive/>).

Cartagana Protocol on Biosafety to CBD: The Protocol ensures an adequate level of protection to safe transfer, handling and use of LMO/GMO. The main focus of the Protocol is on transboundary movements of LMOs. It urges the transboundary movements for international introduction into the environment are subject to advanced information agreement of the importing State.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES):

The CITES aimed to ensure that international trade of wild animals and plants does not threaten their survival. A provision in article XIV states that the Convention does not affect the right of Parties to adopt domestic measures restricting or

prohibiting trade. The provision has been used in Europe to address specific alien species.

Convention on Migratory Species of Wild

Animals (CMS or Bonn Convention):

The Convention on the Conservation of Migratory Species of Wild Animals aims to conserve terrestrial, marine and avian migratory species. The IAS are considered a threat to migratory species and are addressed in article III, 4c and V, 5.

Convention on Wetlands (Ramsar Convention):

The aim of the Ramsar Convention is the conservation and wise use of wetlands and resources. The COP 7 resolution VII/I 4 of the Convention addresses threats of invasive species to wetland ecosystems.

The International Plant Protection Convention

(IPPC): The IPPC is a treaty that aims to prevent introduction of pests of plants and plant products in international trade. IPPC defines pests broadly as any species, strain or biotype, animal life or any pathogenic agent injurious or potentially injurious to plants or plant products. Parties to the IPPC are required to adopt legislative, technical and administrative procedures and standards to identify pests that threaten plant health, assess their risks and prevent their introduction and spread.

Sanitary and Phytosanitary Measures

(Quarantine): The World Trade Organisation (WTO) has implemented Sanitary and Phytosanitary Measures for the convenience of all the member countries to strengthen their capacity building for safely handling, transporting and storing the food products that do not cause any deleterious effect to the consumers. The main objective of Sanitary and Phytosanitary Measures is to protect humans, animals and plants, wild and cultivated from damage due to pests and diseases, many of which are alien species. The agreement on the application of Sanitary and Phytosanitary Measures has no

specific alien species content in the agreement but it provides an international legal basis for all sanitary and phytosanitary measures that affect international trade.

International Health Regulations: The aim of the International Health Regulations is to prevent the international spread of diseases. Parties are requested to detect, reduce or eliminate the sources of infection, improve sanitation in and around ports and airports, to prevent the dissemination of vectors and to encourage epidemiological activities.

In addition, IUCN designed guidelines for the prevention of biodiversity loss caused by IAS (IUCN, 2000). The guidelines help to implement article 8h of the Convention on Biological Diversity and raise awareness and understanding of impacts of IAS to reduce the negative effects of alien invasive species. The guidelines also provide direction for the prevention on introduction, control and eradication of IAS.

National Legal Instruments

Nepal has also incorporated the issues of IAS in national legal documents in addition to the international agreements. Followings are the major national legal instruments related to IAS.

Nepal Biodiversity Strategy 2002 (NBS), which is in the process of revision, has indicated that the introduction of alien species tends to be one of the major root causes for the loss of species and genetic resources (MFSC, 2002). The NBS pointed out that some native species have disappeared from Nepal over the past years. However, the total number of species has increased due to the deliberate or accidental introduction of exotic species. Immigration of species is also rising with increased human movement. The introduction of three fish species (*Salmo gairdneri*, *S. trutta* and

Oncorhynchus rhodurus) from India, England and Japan between 1971 and 1975 (Shrestha, 1994) is an example of a deliberate introduction. Similarly, new fruit species (e.g. strawberries and grapes) have been introduced in Nepal in the last three decades. There are over one hundred non-native plant species that are so well established that they have become weeds in Nepal. According to NBS, *Ageratina adenophora*, *Lantana camara*, *Mikania micrantha*, *Bidens pilosa*, *Amaranthus viridis* L., *A. spinosus* L., *Cassia tora* L., and *C. sophora* L. are so common that they have changed the species composition of fallow and cultivated lands; similarly, the introduction of *Eucalyptus*, *Pinus*, *Cryptomeria* and *Populus* species has also affected the composition of Nepal's biodiversity.

National Wetland Policy 2003 (revised 2012) identifies IAS as one of the major causes for the loss of native species and habitat degradations. The Policy has recommended to take concrete steps to stop the infiltration of invasive plants and animals, creatures, and genetically altered or other living organisms into the country that are likely to invade, displace and destroy endemic species as well as other wetlands biodiversity, and take necessary actions to control and manage the invaders that have already found their way into the country (MFSC, 2012).

The **Fourth National Report to CBD** (2009) also identified IAS as a serious threats to biodiversity and made one of the targets to control pathways of IAS, and to prepare and implement management plan for three invasive weeds (*Mikania micrantha*, *Parthenium hysterophorus*, *Eichhornia crassipes*) by 2010. However, the target has not been met probably due to lack of empirical data and national priority.

According to **Nepal's Fifth National Report to CBD** (2014), the Nepal Biodiversity Strategy and Action Plan (2014) to be published soon, has formulated a number of strategies to meet the

Aichi Biodiversity Targets of ensuring environmental sustainability by 2020 and the Millennium Development Goals (MDGs) by 2015. NBSAP also sets the national targets corresponding to the Aichi Targets. According to the Report, by 2020, IAS and pathways will be identified and prioritized, priority species will be controlled or eradicated, and measures will be in place to manage pathways to prevent their introduction and establishment. Some of the priority actions provisioned by the NBSAP to control IAS by 2020 include: (a) carrying out a detailed survey of the coverage and research on modes and pathways of propagation, ecological and economic damage and loss, control measures, and possible uses of at least five most problematic IAS that have posed high threat to native species and habitats, (b) developing and implementing program to raise awareness of local people on identification of IAS, their impacts and control techniques, (c) identification and use of biological control agents, and (iv) providing technical assistance to local people in the control and management of IAS. Strengthening the knowledge and understanding for controlling IAS by enhancing national capacity for their identification, prevention, early detection, and management is a part of knowledge generation and management strategy included in the NBSAP. National stakeholders such as the Department of Plant Resources, Department of Forest Research and Survey, National Agriculture Research Council (NARC) and the Central Department of Botany, Tribhuvan University are to work closely and in cooperation with international organizations such as the CBD, Global Invasive Species Information Network, Asia Pacific Forest Invasive Species Network and/or Global Invasive Species Program to develop Invasive Plant Atlas for identification, early detection, prevention and management of invasive alien plants (MFSC, 2014).

Agrobiodiversity Policy (2008) of Nepal calls on to regulate and monitor LMO/GMO and was silent for alien species, whereas, the revised draft

of Agro-biodiversity Policy (2013) recommends controlling the introduction of alien species which impact to native agro-biodiversity, and also calls to develop national policy, legislation and regulations on biosafety to regulate GMOs, LMOs etc. with particular emphasis on the conservation and promotion of agro-biodiversity.

A Wetlands Invasive Alien Species Management

Guidelines (2011) is developed by the wetland project of the Ministry of Forest and Soil Conservation (CSUWN/MFSC, 2011). The guidelines indicate that Nepal lacks act and institution for regulating and taking overall responsibilities related to IAS, as a result, several native species and their habitats have been threatened by the introduction of IAS. It has also proposed 10 strategic management guidelines to minimize the problem of IAS such as raise public awareness and increase support, promote scientific research, build capacity (institutions and human resources), formulate legislation and institution, promote alternate uses for IAS, prevent further entry of IAS, develop an early warning and rapid response system, control/eradicate and manage problematic species, increase international collaboration, support and networking and allocate fund for IAS related programmes.

Alien species and their invasions intersect multiple sectors. Attempt has been made to review some of important biodiversity sectoral acts and regulations pertaining to IAS. The **Plant Protection Act** 1972 (PPA) a pioneer Act for plant protection in Nepal and **Plant Protection Rules** (1974) have been enacted to control and eradicate the accession and extension of destructive germs and diseases in agricultural crops. Quarantine is a technique under PPA to check the introduction of plant pests and pathogens. PPA does not address adequately the IAS that belongs to higher groups of plant and animal species. Similarly, the **Seed Act** 1988 (first amendment 2002) developed a National Seeds

Board to implement policies relating to the seeds and to give necessary advice to the Government of Nepal to execute the Act pertaining to the seeds. The Act also promoted the introduction of grasses/forage seeds. There are some examples of grasses/forages such as ipilipil (*Leucaena leucocephala* (Lam.) de Wit.), a fodder tree, turning out to be invasive in foreign soil but the Act does not address such issue. Similarly, it fails to check the introduction of seeds contaminated with IAS. In totality, Nepal's Seed Act is silent about the adverse impact of IAS.

The **National Parks and Wildlife Conservation Act** 1973, amended various times, laid a strong foundation for the biodiversity conservation (endangered species) in Nepal. The Act has no direct provisions to check the introduction and spread of IAS, but the various restrictions like grazing, cutting, clearing, cultivating inside the protected areas indirectly help to minimize the introduction of IAS. Similarly, the **Forest Act** 1993 has number of provisions for the conservation of forest biodiversity, but alien invasive species have not been specifically dealt with. The Forest Act categorized the forests into government managed forest, protected forest, community forest, leasehold forest and religious forest. The aim of the leasehold forest is producing raw materials for forest based industries that allowed the cultivation of high yielding alien species which could exhibit adverse impact on native species.

There is a gap in the existing policies, acts and regulations for the control and management of IAS. Although, IAS is a multisectoral issue, but in lack of proper regulatory mechanism no one is responsible to deal the issues of IAS. The other important gaps are insufficient baseline data on IAS, lack of cost-benefit analysis of IAS management, insufficient human resource to identify the IAS, no effective coordination and collaboration between the government agencies, universities, NGOs/INGOs, and international conservation partners, as well as there is no provisions for punishment

to unauthorized introduction of alien species, and reward/acknowledgement for management of the IAS.

Conclusion and Recommendations

Problem of IAS has been overlooked in Nepal and it does not come under a national priority. In lack of any regulatory mechanism and responsible institution related to IAS, no one is working to coordinate the various sectors to address the multisectoral issues of IAS. Although the threat posed by IAS has been recognized in various government documents but the country has not formulated any specific strategy, program, plan, act and regulation. Therefore, the existing sectoral legal instruments such as acts, policies and regulations of agriculture, forestry including protected areas, trade and tourism should be reviewed to address the IAS issues.

IAS specific regulatory mechanism should be in place. It has been urgently needed to develop a national strategy for the management of invasive species in line of the Global Strategy on IAS (McNeely et al., 2001) as well as regional (e.g. Europe) and national strategies (e.g. Canada, USA, Finland, and Norway). Research and/or academic institutions should be supported to generate base line information. An effective networking between institutions and individuals (national and international) working in the field of IAS is urgent for collaborative work and information sharing. It is not possible to completely eradicate the IAS, if once established; so cost and benefit analysis, risk assessment and Environmental Impact Assessment (EIA) should be mandatory before the introduction of any alien species. Promotion for utilization of IAS should be encouraged. Status review of existing 'management' strategies of IAS should be documented. Focus on the public education on the issues of IAS and encouragements for public participation in the management/control

are essential. Prioritization of IAS (species wise or site wise) for the effective management/control is urgent.

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Impact of Invasive Alien Fish, Nile Tilapia (*Oreochromis niloticus*) on Native Fish Catches of Sub-tropical Lakes (Phewa, Begnas and Rupa) of Pokhara Valley, Nepal

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Abstract

This paper discussed the increasing trends of Nile tilapia (*Oreochromis niloticus*) in total fish catches and their possible effect on native fish species of three Lakes (Phewa, Begnas and Rupa) of Pokhara Valley. The fish catch landing data from the year 2006-2011 was analyzed to know the trends of Nile tilapia. Nile tilapia introduction was accidentally in the lakes of Pokhara valley and it appears in catches during the year 2003. In the year 2011, contributions of exotic fish species was 86.3%, 76.5%, 83.5% and native fish species was 13.7%, 23.5%, 16.5% in total fish catch of Phewa, Begnas and Rupa lakes respectively. There was increasing trends of Nile tilapia and decreasing trends of native fish species catches in total fish catches from lakes of Pokhara valley. The prolific breeding nature of Nile tilapia has contributed in increased total catch from three Lakes of Pokhara valley in recent years. In total fish catch, the invasive fish Nile tilapia (*Oreochromis niloticus*) contribution has increased by 40.1%, 65.0% and 12.02% in Phewa, Begnas and Rupa lakes respectively in 2011 compared to 2006. This indicates that Nile tilapia has now established and become invasive in these lakes. Nile tilapia may compete for food and space to native fish species. The native fishes of Pokhara valley are high valued and also provide livelihood to Jalari community living around the Lakes. The catch of native fish should be monitored in long run to evaluate the effect of invasive species. Stock enhancement program of native fish species should be enhanced to increase the population of these species. For protecting the native fish species, bio-security could be one of the strategies for controlling invasive species spreading out into other natural lakes, reservoirs and rivers of this country. It can only be ensured if all protocols of conservation of native fish diversity in natural resources are strictly adhered to and rigorously enforced in the country.

Keywords: Invasive fish, Nile tilapia, native fish, exotic.

Introduction

Alien species are organisms that have been introduced intentionally or accidentally outside of their natural range. Alien invasive species are regarded as the most detrimental to pristine ecosystems and their dependent biodiversity (MacNeely, 2001). The Nile tilapia (*Oreochromis niloticus*) is occurring naturally in many rivers of North and West Africa. Nile tilapia and other African tilapiine fish species have spread throughout Africa and the world for aquacultural purposes. Their popularity has resulted in their being called “Aquatic Chicken” by the World Fish Center. Invasion of freshwater ecosystems by Nile tilapia results in localized species extinctions among indigenous fishes (Wise et al., 2007). Nile tilapia (*Oreochromis niloticus*) was introduced in Nepal in 1985 for aquaculture. It is a prolific breeder and having omnivorous feeding habits. Over-recruitment with stunted growth is the major restriction in aquaculture of this species.

Capture fishery is an important sector of fisheries in Nepal and contributes approximately 38 % of the total fish production (49,730 mt) in the country. Capture fishery contributes 0.5% to national GDP (Gurung, 2012). There are 24 ethnic communities whose livelihood depended on fisheries in Nepal (Mishra and Upadhy, 2011). Native fish diversity in Nepal includes 228 indigenous fish species (Shrestha, 2012). Rivers (395,000 ha), lakes (5,000 ha), reservoirs (1500 ha), marginal swamps and ghols (11,100 ha) and irrigated rice fields (398,000 ha) are the main source of capture fishery in Nepal (DoFD, 2011/12). DoFD (2007/08) estimated that a total of about 107,000 families are involved in capture fisheries in natural waters. Capture fishery involve about 427,000 active members and no of direct beneficiaries approximates 580,000 peoples. About 6.6 % of economically active population in agriculture sector engaged in capture fisheries

(Wagle et al., 2011). The communities involved in fishing activities are mostly Tharu, Majhi, Malaha, Danuwar, Kewat, Bote, Mushar, Mukhiya, Darai, Kumal, Dangar, Jalari, Bantar, Rai and other poverty-laden ones (Gurung et al., 2005).

Phewa lake is largest (523 ha) followed by Begnas Lake (328 ha) and Rupa (128 ha) of Pokhara valley. The Capture fishery in these lakes is old tradition and wide expansion of capture fishery commenced after the gill nets were introduced in Pokhara valley in 1960s to increase daily catch for Jalari's livelihood (Rajbanshi et al., 1984). 23, 20 and 19 fish species were recorded from Phewa, Begnas and Rupa respectively out of which four fish species were exotic (Pokharel, 1999). Capture fishery of these lakes comprised of both indigenous and exotic fish species (Gurung, 2003). Jalari, a deprived ethnic minority having a history of nomadic life, depend on agriculture and capture fishery for subsistence. Approximately 200 families with a population of about 1000 are reported to live in the Kaski district (Nepal et al., 2011). Consequently, some indigenous fishes have become decline in catches and population diversity due to over exploitation coupled with habitat destruction, siltation and unintentional introduction of exotic fish species in these Lake (Wagle et al. 2007; (Wagle and Bista 1999). Indigenous fishes occupy valuable position and an inseparable link in the life, livelihood, health and the general well being of the rural people. Livelihood may be affected due to decline in indigenous fish catch as it fetch higher price in the market in comparison to exotic fish. In order to achieve sustainable utilization, appropriate planning for conservation and management strategies are of utmost importance. This paper discussed the increasing trends of Nile tilapia (*Oreochromis niloticus*) in total fish catches and their possible affect on native fish species of three Lakes (Phewa, Begnas and Rupa) of Pokhara Valley.

Materials and Methods

Study sites

Phewa Lake is situated in the south-western part of Kaski district (Figure 1) at 28.1 °N and 82.5 °E, and at 742 m above the mean sea level. The watershed area of the lake extends approximately 110 km² (Ferro and Swar, 1978). The total surface area of the lake is about 523 ha as reported in Rai (1998). However, Lamichhane (2000) has estimated the water surface area of only 443 ha, with the maximum depth of 23 m. Phewa Lake is fed by two perennial streams: Harpan Khola and Andheri Khola, as well as several seasonal streams. Begnas (650 msl) is the second biggest lake fed by a perennial stream - Syankhudi Khola - with the catchment area of 19 km².

The outlet of Begnas Lake - Khudi Khola - was blocked by a dam in 1988. The damming has increased the area of the lake from 224 ha to 328 ha. Its average depth has thus increased from 4.6 m to 6.6 m. The Lake Rupa (328 ha) is the third biggest lake and its watershed is located between

28°08'N to 28°10'N and 84°06'E to 84°07'E, at 600 m a.s.l. in central, Nepal. The Lake's total catchments area is 30 km². The surface area, maximum depth, and average depth of the lake are 1.35 km², 6 m and 3 m respectively. The main inflow of water is from the Talbeshi Stream, which flows from north to south (Rai et al., 1995).

Data collection and analysis

The fish catch landing data of three lakes (Phewa, Begnas and Rupa) from the year 2006–2011 was analyzed to know the trends of Nile tilapia. Daily catch records of fish species landing from Lakes of Pokhara valley were collected from these lakes landing sites. These data was summarized and graphs were plotted with the help of MS-Excel 2007. Fish yield and their percentage contribution in capture fishery of the lakes were analyzed using SPSS (version 15) statistical software package (SPSS Inc., Chicago). The fish catch yield and percentage contributions of indigenous fish species in the year 2006 were also compared to the year 2011 to find out changes of fish catch in these Lake.

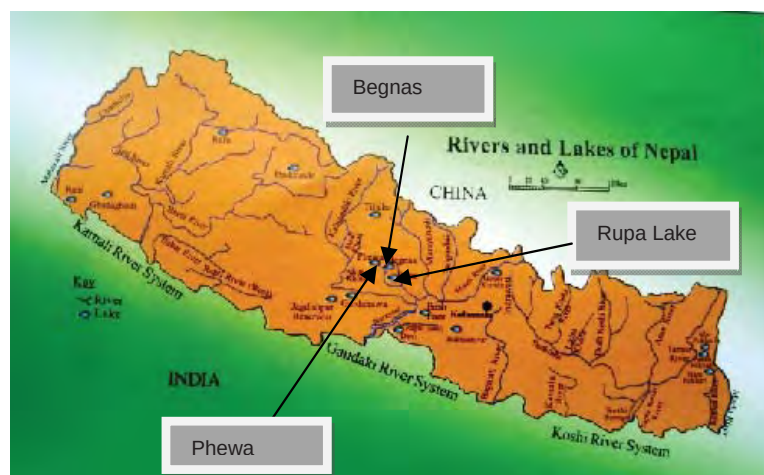
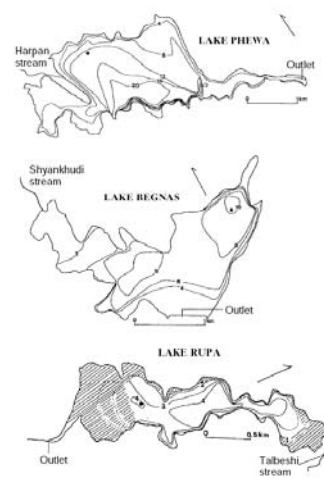


Figure 1. Nepal map showing Phewa, Begnas and Rupa Lakes of Pokhara Valley (Source: Shreshtha, 2008)



Bathymetric map of lakes of Pokhara Valley (Rai et al., 1995)

Table 1. Physico-chemical properties of Lakes

Physico-chemical variables	Phewa Mean±SD	Begnas Mean±SD	Rupa Mean±SD
Water temperature(°C)	22.7±3.9	22.3±4.5	22.2±4.8
Dissolved oxygen (mg/L)	4.9± 2.9	5.8±3.0	8.1±2.2
pH	7	6.7	6.9
Ammonium (NH ₄ ⁺) nitrogen (mg/ L)	0.004±0.009	0.019±0.036	0.010±0.016
Nitrate(NO ₃ ⁻) + Nitrite(NO ₂ ⁻) nitrogen (mg/ L)	0.022±0.039	0.031±0.066	0.035±0.082
Soluble reactive phosphorus PO ₄ ⁻ P(mg/ L)	0.003±0.011	0.002±0.002	0.002±0.002
Total phosphorus (mg/ L)	0.006±0.012	0.006±0.005	0.011±0.012
Chlorophyll-a (mg/m ³)	9.1±9.2	4.1±3.8	16.0±12.1
Transparency (m)	2.3±0.7	2.1±0.6	0.7±0.3

Results

Physico-chemical properties of Lakes are presented in Table 1. According to trophic classification based on chlorophyll a , Phewa Lake seems to be oligo-eutrophic, Begnas Lake stands for oligo-mesotrophic and Rupa Lake ranked as eutrophic in 2010 (Husen *et al.*, 2011).

Fishing gear and fish species

The major types of fishing gears used by Jalari fisher were gillnets, cast nets and fishing hooks in the Lakes of Pokhara Valley. The gillnet was the most

common fishing gear operated with an average number of holding is 18 with range 6–46 with different mesh sizes to capture small size to large size fish. Gill nets were usually set at afternoon and collect fish in the next morning. The most common size of gillnet operated in these lakes was between 350–450 m². The fish species in the catch of Pokhara valley lakes are presented in Table 2. There were 23 fish species appeared in catch of Pokhara valley lakes among which 17 were native fish and 6 were exotic fish species in year 2011. 23, 15 and 10 native fish species were appeared in catches of Phewa, Begnas and Rupa lakes respectively including six exotic fish species in each lake in 2011.

Table 2. Contributions of fish species in capture fishery of Lakes of Pokhara valley during 2011

SN	Scientific name	Local name	% contribution to total catch		
Indigenous fish species			Phewa	Begnas	Rupa
1	<i>Tor putitora</i> (Hamilton)	Sahar	++	++	+
2	<i>Neolissochilus hexagonolepis</i> (McClelland)	Katle	+		+
3	<i>Cirrhinus reba</i> (Hamilton)	Rewa	+	+	-
4	<i>Barilius barna</i> (Hamilton)	Lam Fageta	+	+	-
5	<i>B. bola</i> (Hamilton)	Fageta			
6	<i>B. vagra</i> (Hamilton)	Fageta			
7	<i>B. bendelisis</i> (Hamilton)	Fageta			
8	<i>Puntius sarana</i> (Hamilton)	Kande	+	-	+

SN	Scientific name	Local name	% contribution to total catch		
9	<i>P. sophore</i> (Hamilton)	Bhitte/Bhitta	++	+++	+
10	<i>P. titius</i> (Hamilton)	Bhitte/Bhitta			
11	<i>P. ticto</i> (Hamilton)	Bhitte/Bhitta			
12	<i>Cirrhinus mrigala</i> (Hamilton)	Naini	+	++	+
13	<i>Catla catla</i> (Hamilton)	Bhakur	++	+++	+
14	<i>Labeo rohita</i> (Hamilton)	Rohu	+	++	+++
15	<i>Mastacembelus armatus</i> (Lacepede)	Chuche Bam	++	++	-
16	<i>Xenentodon cancila</i> (Hamilton)	Dhunge Bam			
17	<i>Clarias batrachus</i> (L.)	Magur	+	-	-
Exotic fish species					
18	<i>Aristichthys nobilis</i> (Richardson)	Bighead carp	++++	+++	++++
19	<i>Hypophthalmichthys molitrix</i> (Valenciennes)	Silver carp	+++	++++	++++
20	<i>Ctenopharyngodon idella</i> (Valenciennes)	Grass carp	++	++	++
21	<i>Cyprinus carpio</i> (L.)	Common carp	+	++	+++
22	<i>Clarias gariepinus</i> (Burchell)	African magur	++	++	+
23	<i>Oreochromis niloticus</i> (Linnaeus)	Nile tilapia	++++	++++	+++

(Contribution to total catch + = <1%, ++ = 1-5%, +++ = 6-20%, ++++ = 20% and above and - = not appeared).

Capture fishery and catch trends

Total fish productions from three lakes (Phewa, Begnas and Rupa) have increased from 46.7 metric ton (mt) in 2006 to 145.6 mt in 2011. There was increasing trends of exotic fish species catch with major contribution by Nile tilapia in these lakes. Nile tilapia catch from these lakes have increased from 0.6 mt in 2006 to 58.1 mt in 2011 (Figure 2). Contributions of exotic fish species was

86.3%, 76.5%, 83.5% and native fish species was 13.7%, 23.5%, 16.5% in total fish catch of Phewa, Begnas and Rupa lakes respectively in 2011. The total estimated revenue from sales of fish from those three lakes capture fishery was NRs.38.97 million of which Nile tilapia was NRs.13.51 million in 2011. Likewise, from native fish and exotic revenue estimated was NRs.8.97 million and NRs.30.00 million respectively in 2011.

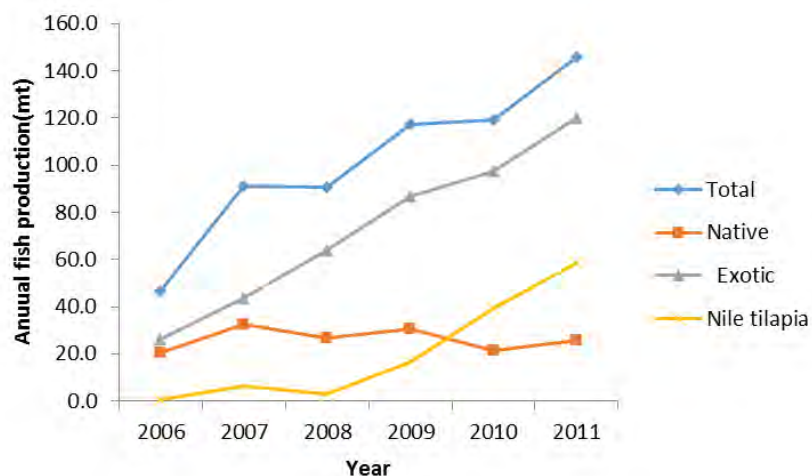


Figure 2. Annual trends of fish catch from three lakes (total of Phewa, Begnas and Rupa) of Pokhara valley

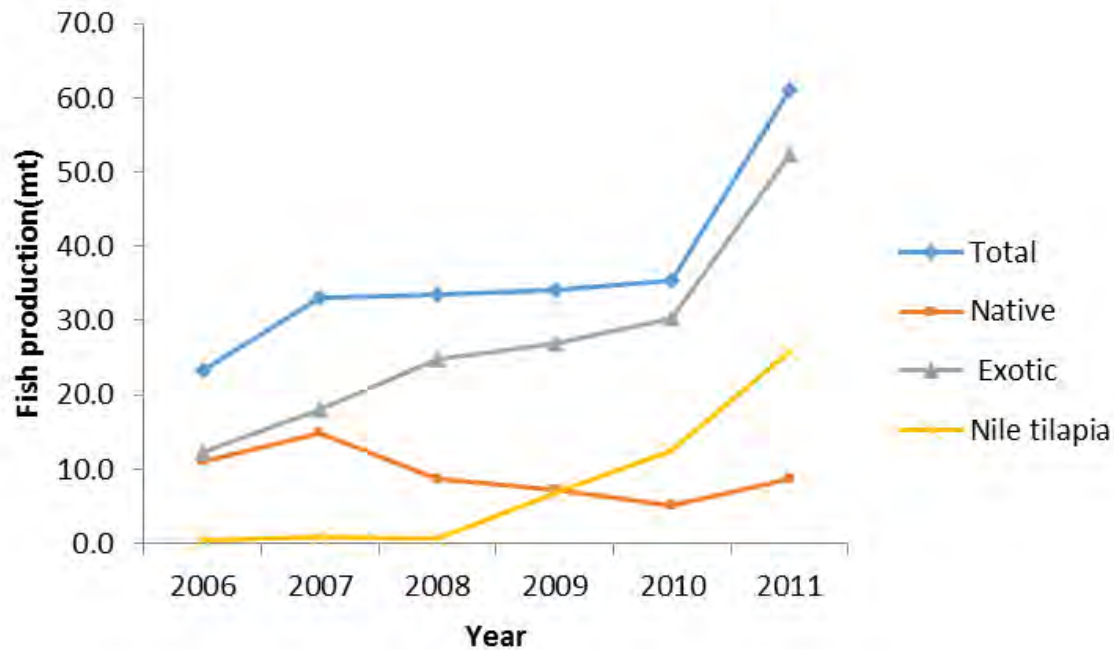


Figure 3. Annual trends of fish catch (mt) from Phewa Lake

Exotic fish production with Nile tilapia was in increasing trends in Phewa Lake (Figures 3, 4). There was decreasing trends of native fish in fish production as well as in percentage contribution to total fish production from Phewa Lake. The contributions of native fish to total fish production have declined by 32.8% while the contributions of Nile tilapia have increased by 40.1% in 2011 as compared to 2006 (Figure 4). Nile tilapia fish production has increased from 0.5 metric ton (mt) in 2006 to 25.3 mt in 2011.

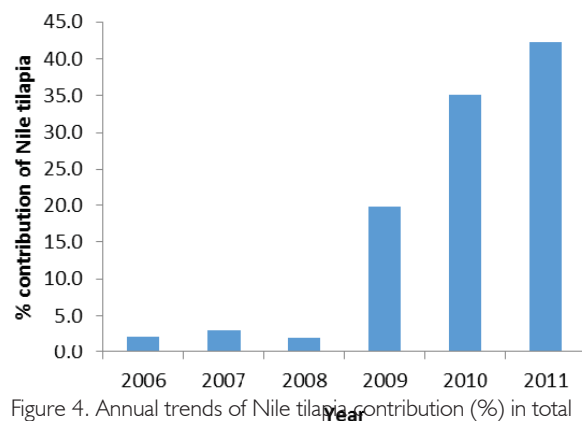


Figure 4. Annual trends of Nile tilapia contribution (%) in total fish catch from Phewa Lake

Of the total fish production, exotic fish production with Nile tilapia was in increasing trends in Begnas Lake (Figure 5). There was decreasing trends of native fish production in recent years. The Nile tilapia fish production has increased from 0.11 mt in 2006 to 27.77 mt in 2011. Its contributions to total fish production have increased to 65 % from the catch of 2006 to 2011 (Figure 6).

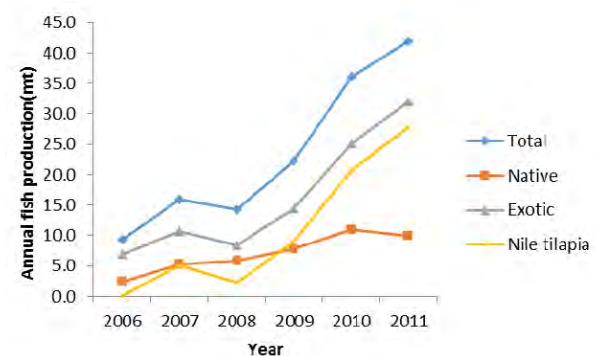


Figure 5. Annual trends of fish yield from capture fishery in Begnas Lake.

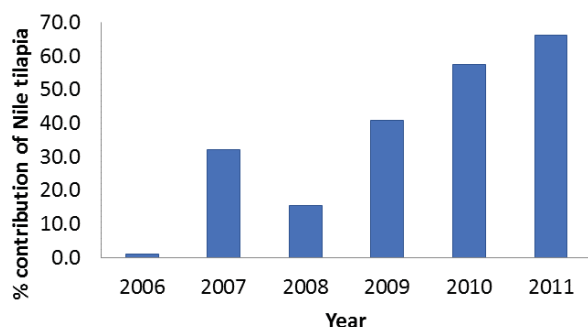


Figure 6. Annual trends of Nile tilapia contribution (%) in total fish catch from Begnas Lake

There was decreasing trend in total fish production in Rupa Lake but contribution of exotic fish in total fish have increased by 33% in recent years. The Nile tilapia fish production increased from 0.01 mt to 5.15 mt in 2011. Nile tilapia contributions (%) to total fish production was in increasing trends but there was decreasing trends of native fish in Rupa Lake (Figure 7 and 8).

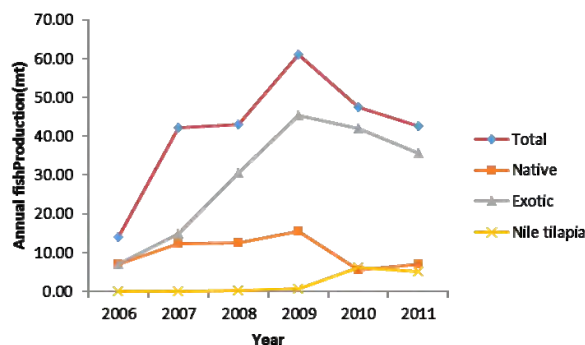


Figure 7. Annual trends of fish catch from Rupa Lake of Pokhara valley

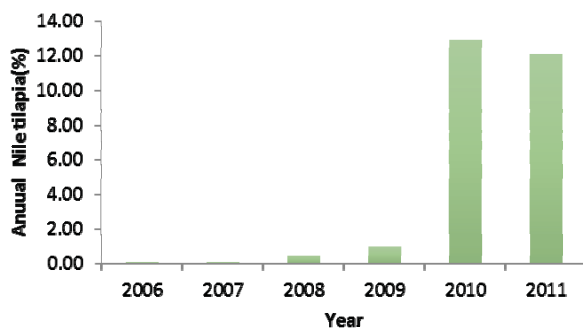


Figure 8. Annual trends of Nile tilapia contribution in total fish catch from Rupa Lake

Discussion

Nile tilapia introduction was accidental in the lakes of Pokhara valley and it appears in catches during the year 2003 (Nepal, 2008). There was increasing trends of Nile tilapia and decreasing trends of native fish species in catches from lakes of Pokhara valley. In total fish catch, the invasive fish Nile tilapia (*Oreochromis niloticus*) contributions has increased by 40.1%, 65.0 % and 12.02% in Phewa, Begnas and Rupa lakes respectively in 2011 as compared to 2006. This indicates that Nile tilapia has now established and become invasive in these lakes. The prolific breeding nature of Nile tilapia has contributed in increased in total catch from three Lakes of Pokhara valley in recent years. Nile tilapia may compete for food and space to native fish species as well as feeding on larvae of native fish species. The major diet ingested by Nile tilapia was algae (57%), insects (24%) and fish (18%) in Kenyan portion of Lake Victoria (Nirju et al., 2008). The invasive nature of *O. niloticus* in Lake Victoria, East Africa, however, is well known and its impacts there have been described as including competition with, and consequent elimination of, other *Oreochromis* species, other Cichlidae and possibly other types of fish as well (Pitcher and Hart, 1995). Many literatures have reported that introduction of Nile tilapia into freshwater ecosystems affects local species negatively (Tweddle and Wise 2007; Wise et al., 2007; Canonico et al., 2005; Shipton et al., 2008). It should be noticed that the extinction of *O. esculentus* took 30 years in Lake Victoria, while the replacement of *O. mortimeri* took only 10 years in the smaller Lake Kariba (Wise et al., 2007). Therefore, the effects of Nile tilapia on native species should be monitored regularly in the lakes of Pokhara valley. Nile tilapia also found to modify nutrient regimes by increasing nitrogen and phosphorus availability in a reservoir via excretion, promoting algae growth, and contributing to eutrophication (Figueredo and Giani, 2005). There was 42% reduction of *Puntius sp* and *Mystus sp* in

Lake Begnas due to impact of exotic species (Swar and Gurung, 1998). At present no heavy incidence of impact of exotic fish on indigenous species has been experienced in Nepal but cases of elimination and reduction of population of the indigenous species has been coming slowly from those water bodies where open water stocking of exotic fishes are practiced (Shrestha, 2012).

However, Nile tilapia (*Oreochromis niloticus*) has been providing much in monetary to Jalari community of Pokhara valley in recent year. It is due to increased in total fish production from these lakes with major contributions by Nile tilapia. Present study showed that Nile tilapia was providing revenue of NRs. 13.51 million in 2011 to the Jalari Community. The livelihood of the Jalari community of Pokhara valley has enhanced by capture fishery with their risen income and other indicators of well-being (Wagle et al., 2012). Besides, it is impossible to calculate in that way for native fish value. The native fishes of Pokhara valley lakes are high valued, fetch high price in the market and also it provides direct livelihood to two hundreds of Jalari community living around the Lakes (Gurung, 2003; Wagle et al., 2007). Small indigenous species (SIS) such as *Puntius sp.*, *Barilius sp.* is nutrient rich fish which could help to reduce malnutrition of women and children (Rai et al., 2011) of the Pokhara valley. Sahar (*Tor putitora*) have known to be important fish for recreational as well as for sport fishery. *Mastacembelus armatus* (Lacepede) Chuche Bam have also used as medicinal purpose by peoples of Pokhara Valley.

To mitigate the increasing trends of Nile tilapia in total catch, stock enhancement program of native fish species should be enhanced to increase the population of these species. One way to mitigate is to increase the population of Sahar (*Tor putitora*) by stock enhancement which is found to be natural control over-recruitment of tilapia (Shrestha et al., 2011). Invasions in lakes, rivers,

floodplains, and wetlands are especially problematic because they are difficult to manage. The best form of management for invasive species, Nile tilapia is prevention from introduction to new natural resources such as lakes, reservoirs and rivers of Nepal. Fish diversity and conservation is one of the neglected areas of research and development in fisheries sector. For conservation of the aquatic life the "Aquatic Conservation Act-1961" was promulgated. However, due to insufficient enforcement, the effectiveness is almost zero (Gurung, 2003). Short-term gains must be balanced with long-term impacts that could threaten or remove sources of survival for people and biodiversity. To ensure native fish conservation, significant improvement in law enforcement with high level of wisdom is prerequisite (Gurung, 2012).

Conclusions

The catch of native fish should be monitored in long run to evaluate the effect of invasive species in these lakes. Stock enhancement program of native fish species should be done regularly to increase the population of these species. Bio-security could be one of the strategies for controlling invasive species spread out into other natural lakes, reservoirs and rivers to protect the native fish species in Nepal. It can only be ensured, if all protocols of conservation of native fish diversity in natural resources are strictly followed and rigorously enforced in Nepal. The impact of Nile tilapia on native fish could not be verified by the catch landing related to data only. Public awareness is needed to further expansion in natural systems. Further study should be done to know the present status of fish species diversity in these lakes of Pokhara valley as well as their conservation measures.

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An Integrated Framework for Monitoring Plant Invasion in Tropical India

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Abstract

Over the past few hundred years, biological invasions have increased the rate of extinction by about 1,000% and caused many irreversible environmental damage. Moreover the landscape faces new economic burden by losing ecosystem services and putting extra budget for management of invasives. To deal with the damage caused by biological invasions, evidence based conservation policy is required. However the scientific evidences answering different questions are spread in pockets while the policies are made by the central agencies for entire country. Hence an integrated approach answering the status, ecology, effects, management and future predictions of invasive species at national scale and park scale is needed. Based on the same theme we have been monitoring plant invasions in tropical India.

The study is accomplished in national monitoring after every three years and annual regional management surveys. This address four major questions regarding the most noxious invasive plants in India: 1) what is the spatial and temporal trend of plant invasion in tropical India? 2) what are the ecological effects and responses to it? 3) What would be the effect of predicted climate change on invasive plants? and 4) What are the suitable strategies for managing invasive plants in tropical India? For addressing the questions we intend to combine primary field surveys, secondary database (published and unpublished), remotely sensed data, meta-analysis and questioner survey. The answers will provide insight on the parameters responsible for successful invasions, parameters resisting invasions, invasion risked areas, cost benefit analysis of invasive management and relation of plant invasion with changing climate. The result will help national policy regarding habitat conservation and long term sustenance of endangered species that are risked by invasion. Such resource effective monitoring strategies could be used by countries interested in long term monitoring and adaptive management of plant invasions.

Keywords: Biological invasions, invasive species management, climate change, Tropical India.

Introduction

Non-native species that have negative impact on environment, human health or economy are termed as invasive (Alpert *et al.*, 2000; Colautti and MacIsaac, 2004). Due to the accelerating rates of international connectivity, biological invasions have become the second largest threat to biological diversity after habitat destruction (Diamond *et al.*, 1989). It has increased the rate of extinction (Gurevitch and Padilla, 2004) and caused irreversible environmental damage. Invasive plants, animals and microbes causes annual loss of 55 billion to 248 billion USD to the world's agriculture (Bright, 1999). At the same time societal dependencies on the natural ecosystem have intensified, causing degradation of the native habitat and resulting in 'niche opening' for the invaders. Hence the whole dynamics of biological invasion becomes complex and as E. O. Wilson (1999) puts it is "Extinction by the invasion of exotic species is like death by disease: gradual, insidious, requiring scientific methods to diagnose."

India is a developing nation with nominal Gross domestic product (GDP) of \$1.842 trillion that ranks ninth largest in the world. The developing sectors are established in the tropical India that harbours the diverse environment thus forming a mosaic of forest patches and the developing economy. Most of the forested areas in tropical India are however analogous to small islands in the vast sea of ecologically unsustainable land uses of varying degrees (Jhala *et al.*, 2011). Different types of human modifications of forests have promoted the introduction and propagation of invasive alien species (IAS). India accounts for 8 % of the global biodiversity existing in only 2.4% land area of the world and this biodiversity is vulnerable to the increasing magnitude of invasive species. As the Indian tropical landscape is affected by fragmentation, plant invasion have been accelerated. As a result majority of the studies

addressing biological invasions have been focused on plant invasions. Sharma *et al.*, (2005), Love *et al.*, (2009), Kannan *et al.*, (2012) Reddy, (2008) Negi and Hajra, (2007). Sundaram and Hiremath, (2011) and Ramaswami and Sukumar, (2011) have recently addressed different aspects of plant invasions in India. Majority of the studies regarding invasive species have addressed only *Lantana*. Other species like *Parthenium* occupied the studies due to the impact on agriculture. Although affected by biological invasions with a lot of resources being spent for their control, study of any invasive species at the national scale is lacking in India (Varma, 2005).

Exotic species can become naturalized in the new environment (Richardson *et al.*, 2000). These naturalized species have important role in the ecosystem and eradicating them could result in negative impacts on the ecosystem functions. Therefore such decisions needs to be made at site specific needs. However, frontline stakeholders involved in managing biological invasions are trapped in dilemma of understanding the science and applying the knowledge on ground. Hence an evidence based approach is needed to resolve this dilemma. For any amendments in the policies dealing with invasive species a detailed study about the distribution, reason for successful invasion, effect of invasion, assessment of best suited management strategy and forecasting the future trends is necessary. Information regarding these parameters for any species is presently lacking at national scale in India. Through the present study we propose an integrated framework that is used for studying invasive plants in tropical India which could help in policies for proper management and conservation of habitat.

Invasions 'Knowing and Doing'

Due to gap in the existing knowledge, ecological monitoring of invasive species is essential. While,

owing to limitations of the present management strategies, effective management programs are needed. But, most of the tropical countries have diverse landscapes with diverse magnitude of invasions (Lövei and Lewinsohn, 2012). And as a result of limited resources, priority is usually given to small scale ecological studies and discreet managerial interventions. Such efforts lacks the link between research and management and hence results into limited success (Bhagwat *et al.*, 2012). This could be attributed to the “mismatch between the scale of management and the scale of the ecological processes managed” (Cumming *et al.*, 2006). This mismatch have been highlighted by many experiences (Esler *et al.*, 2010).

One need to integrate the crucial ecological questions for prioritizing management. This integration could be achieved by analysing four dimensions of biological invasions viz. Pattern of invasion, Ecological impacts and response, Future scenario and Management. All these dimensions have spatial and temporal scales e.g. Temperature may affect invasion at landscape scale but its effect at park level would be insignificant, similarly burning treatment for invasive plants could have varying effects with the frequency and interval of treatment. Hence, monitoring all the dimensions at different spatial and temporal scale is essential.

The pattern of invasion comprises spatio-temporal trend including invasion level (Chytrý *et al.*, 2009) and invisibility (Alpert *et al.*, 2000). It will at macro scale (landscape level) examine the parameters supporting and resisting invasion; particularly the role of native competition, climatic extremities and human modifications. Quantifying and monitoring invasion level could evaluate the invasion meltdown (Simberloff and Holle, 1999). This dynamics (at macro scale) should be considered with periodic variation. While at micro scale (park level) yearly monitoring in order to check population trends and introduction of new invasive species is required.

Hence periodic assessment of landscape and yearly monitoring of conservation areas is essential.

For analysing the ecological response to biological invasion, changes within the invasive species (e.g. niche expansion, trait change, etc.) (Pyšek and Richardson, 2006) and changes due to invasive species (e.g. effect on the native biodiversity, change in the fire regime, etc.) should be quantified. These changes together contribute to the success of invasion i.e. replacing the native ecosystem by establishing self-monotony. For monitoring at macro scale effective periodic variation should be considered to account the ecological responses. While at micro scale for avoiding any severe damage to native ecosystem, yearly monitoring is essential.

The third dimension is understanding the future consequences of biological invasions. Each 1 °C of temperature change moves ecological zones on Earth by about 160 km (Thuiller, 2007). The ability of species to respond to climate change will depend on their ability to ‘track’ shifting climate (temperature and precipitation) through colonizing new territory, or to modify their physiology and seasonal behaviour (Hughes, 2000). These needs long term periodic monitoring at macro level that accounts for ecological changes.

The fourth dimension, management is the application of above understandings for conservation. Stakeholders are trying to manage biological invasions in different ecosystems like agriculture (Yaduraju *et al.*, 2005), forests (Love *et al.*, 2009), fresh water (Kumar, 2011) marine (Anil *et al.*, 2002) etc. However, the major drawback was failure in restoring native ecosystem and absence of comparative study that could guide policy. Most of the micro scale management schemes like bio-control, burning, etc. have failed (Bhagwat *et al.*, 2012). Hence, presently every park have its own way to deal with invasions. Though

this is partially effective, resources are spent for trying different technique and on the other hand ecosystem suffers irreversible damage. Hence this dimension of invasions need a special consideration for linking different scale of processes with micro scale regular monitoring in the park. This could be achieved by using a set of treatment for each species in all the parks and analysis the effect of ecological processes on these techniques. For example, in North East India, situated on the fringe of *Prosopis juliflora* distribution, where uprooting the species could be effective, but *P. juliflora* in Western India has invaded thousands of hectare and uprooting is not feasible nor effective (Pasicznik *et al.*, 2001). However participation of local communities has been economical at both the scales and should be considered in the policy.

An integrated initiative in India

One can either preserve a 'natural condition', or 'natural processes', but not both, preservation of natural processes requires acceptance of change (Botkin, 2001). Most of the protected areas in India including Tiger reserves intend to conserve the 'natural condition' that are threatened by human population sprawl outside of the park. Hence, controlled burning of grasslands, captive breeding, water source management, etc. which do not go

with the 'natural process' ideology is practised. Preserving these natural conditions demand complete eradication of human modification in any form including biological invasions. Forests out of such protected areas forms the secondary priority and needs a threshold beyond which an invasive species should be controlled. Thus the micro scale regular monitoring should be operated at tiger reserves and macro scale long term monitoring should be implemented for national level studies. On this background National Tiger Conservation Authority (NTCA) and Wildlife Institute of India (WII) initiated 'All India Tiger Monitoring Project' (AITMP). Under which, country wide assessment of habitat status is done after every four years (this temporal scale considers ecological dynamics) since 2006. Moreover, yearly monitoring scheme has been recommended for important tiger reserves that holds flagship biodiversity of respective landscape (Jhala *et al.*, 2011). Hence a macro scale monitoring of invasive plants is done at national scale after every four years. And micro scale monitoring is done annually for all tiger reserves in India. The total efforts invested for monitoring plant invasions are given in the Table 1. This probably constitutes an unprecedented effort for any monitoring of IAS conducted in the world.

Table 1. Efforts invested for invasive plants monitoring in tropical India under AITMP.

Scale	Year	Surveyed plots (15m radius)	Significance
National	2006	460,920 plots	Habitat assessment for forested areas in 17 states of India by professional biologists and forest department staff
National	2010	716,808 plots	
National	2014	Ongoing	
Tiger reserves	2010	ca 200 plots per park	Habitat assessment of important Tiger Reserves by trained staff of forest department. Management of invasive plants in the park.
Tiger reserves	2011	ca 200 plots per park	
Tiger reserves	2012	ca 250 plots per park	
Tiger reserves	2013	ca 250 plots per park	
Tiger reserves	2014	ca 250 plots per park	

National surveys

The national level assessment was done in 2006, 2010 and 2014. Trained staff of Forest Department and professional biologists from Wildlife Institute of India surveyed the forested areas of tropical India for ecological status. The database is collected according to the phase I & III protocol (Jhala and Qureshi, 2008). A spatial grid of 10 X 10 km was generated for India in GIS domain. For systematic sampling of invasive species, 1 to 5 transects of 2 km were laid in the forested area of every grid. On each transect at every 400m a circular plot of 30m diameter was sampled. Within each plot 3 most abundant invasive species were recorded in order of their abundance (1- very high, 2- high, 3- low and 0- absent). Similarly 5 abundant tree species and shrub species were recorded in order of their abundance within the same plot. Habitat parameters that includes canopy cover, ground cover and human disturbance signs were recorded at each plot. In case of human disturbance; observer recorded number of lopped trees, number of cut logs, number of people seen, number of livestock seen, foot trails, fire and human settlement. On an average 478,016 sq. km of forest was surveyed for every national level survey (70% of total forested area in India). The spatial coverage of sampling effort are depicted in the figure 1, where each blue dot represents 1 to 3 line transects

Management interventions

Phase IV of the AITMP incorporates regular assessment of habitat of different tiger reserves that harbours diverse ecosystems. The survey design is same as for national survey however limited within the boundaries of tiger reserves and operates each year. Most of the Tiger Reserves have limited patches of grasslands which are invaded by different plants, hence the park management has to eradicate such species. Burning of grassland is

the most common practice followed by uprooting. Some parks have tried bio-control (e.g. *Mikania* control, Ellison et al., 2007), site modification (e.g. Water hyacinth control, Kumar, 2011), adaptive restoration (e.g. *Lantana* control, Babu et al., 2009) and community harvesting (e.g. *P. juliflora* control, Hiremath and Sundaram, 2013). This data is collected from the respective parks.

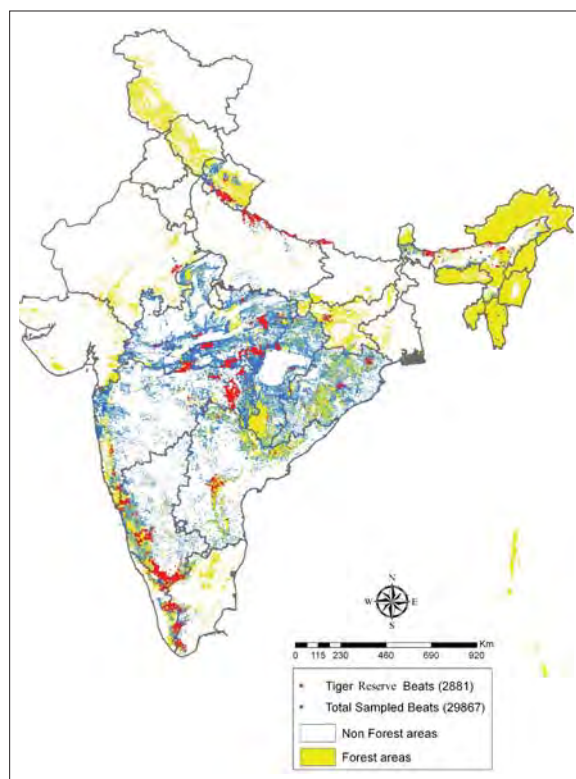


Figure 1. Map depicting the spatial coverage of invasive plants monitoring in India that happens after every 4 years. Blue and red locations represent 1 to 3 survey transects.

Remotely sensed datasets

The information regarding presence of invasive species in its native area will be generated from different data sharing portals and published literature. The spatial covariates explaining climate, resource, terrain and hydrology will be generated by using rigorous algorithms from the remotely sensed data. Human disturbance index will be generated by analysing the changes in Land Use

Land Cover (LULC) pattern in past 50 years, trend in the socio economic status of the landscape and the published dataset explaining the human footprint on the forest. The plot data from AITMP survey was extracted to the 25 sq. km grid. The habitat status and human disturbance data was averaged for the all the plots falling in a single grid. The presence – absence, abundance for each species, habitat status, human disturbance data and all the covariates was extracted for all dominant invasive species in India at scale of 25 sq. km. The 4 dimensions of invasion with framework of analysis is given below.

Analytical framework

1. What is the spatial and temporal trend of plant invasion in tropical India?

Spatial Mapping: For estimating the spatial distribution, available dataset of 2014 will be used. The vegetation plot data from Phase I and Phase 3 of AITMP will be used. Based on the average values calculated from the surveyed plots, invasion level will be calculated for every grid. This will provide an estimate of total area invaded by invasive species.

Distribution modelling: Potential distribution will be estimated at different scales; micro scale (park level), meso scale (landscape level) and macro scale (national). However there are different modelling strategies out of which the most popular are presence only, presence absence and abundance modelling. All of these will be used to get the most rigorous estimate.

- a. Presence only modelling – Presence points from the study area will be used. Presence only modelling like MaxEnt (Phillips *et al.*, 2006), etc. will be used. This approach estimates the space entropy in which the study species can invade (Elith *et al.*, 2011).

- b. Presence & absence modelling – Presence and absence of particular species will be used. Multivariate logistic regression will be used. This approach explains the parameters that supports or resists invasion at particular site.
- c. Abundance modelling – The abundance of invader in different landscape will be evaluated using statistically rigorous approach like Ordinal regression. This approach explains parameters causing differential influence on the success of invasion.

Temporal Distribution:

- a. From the presence data available (2006, 2007 and 2014) and using island biogeography theory, colonization rate, invasion rate and extinction rate will be deduced.
- b. Temporal pattern will be quantified at different scales that represents park, landscape and nation. This will minimize the probability of false absence.
- c. The temporal difference in invasion will be analysed by time series analysis different scales. Using the temporal fluctuations and invasion rate for last 10 years, forecasting for next 10 years will be done.

2. What is the ecological response to biological invasion?

In the present study we will estimate 3 fundamental parameters that explains the response to biological invasion.

- a. **Relation with the native flora:** Every plot has data of native flora and invasive flora for each cycle. The relative trend in distribution of native vs. invasive flora and its abundance will be estimated using time series analysis. This

analysis would considering invader as replicator (Schuster and Sigmund, 1983; Roca *et al.*, 2009) and the abundance at site would be the payoff. Set of rules could be function of the growth and environment. This will represent the response of environment to invasion.

b. Niche expansion: Escape from predators, empty niches, competitive ability, novel weapons and different parameters in the novel area contributes to the success of invasion (Richardson and Pysek, 2006). As a result species expands its niche beyond what it utilized in its native area. This successful conquering of new habitat territory while establishing its monoculture is termed as range change. We will use species occurrence and environmental covariates representing habitat condition at their native area, to build a model of habitat suitability for invader. This species-environment relationship will then be projected to India that predicts habitat suitability of every invasive species in India. Presence data from the survey will then be used for modelling species observed habitat. For every species the covariates will be kept same for modelling predicted habitat and observed habitat.

c. Trait changes: However the native distribution of a species is result of the realized niche while in novel area, escape from predator and other ecological consequences can result in expansion of ecological fitting. Thus, presence of the species in the novel area is the function of optimum combination of resource, climate, competition and disturbance. So it becomes crucial to understand the magnitude of the changes with respect to every parameter and the reasons for it. For quantifying the changes in the traits we used environmental response traits (Lavorel and Garnier, 2002) that explains changes in response to environment. The change in the response norm will be

quantified. Then a comparative analysis of the direction and magnitude of the response norm will be done for the native and naïve area. The divergence in the median and extent of distribution represents the change in the relation of species with that environmental parameter.

Adding the results would give us the environmental parameters responsible for the growth of invasive (Site specific), change in the response traits of invasive species (Species specific) and the success rate at which they are replacing the native flora. This will give us an insight on the factors governing the success of biological invasions and the ecological response to it.

3. What will be the effect of predicted climate change on invasive species?

Climate envelopes are commonly used techniques that assumes present species – climate relation to be stable and then project it to varying climate that is expected to occur in the climate change scenario (e.g. 4 ° rise in temperature by 2070). However species association and dependencies are equally altered and some species are more adaptable for it than others. Hence, considering these variations in species – environment relation is crucial for predictions (Peterson *et al.*, 2008). This requires long term monitoring data. Such data is present in pockets for many case studies and published. Meta-analysis of such published data gives an important tool for future predictions. In the present study I intend to do meta-analysis on effect of climate change on invasive plants through published research.

The output that is generated by meta-analysis, will be used as frame work for India where the present status of invasive plants are projected to the future scenario provided by the Intergovernmental Panel on Climate Change (IPCC) and the process

will be formulated through the output of meta-analysis. Bayesian analysis that considers variability of independent and dependent variable will be used for forecasting. This approach explains differential influence of variation amongst the species – environment relationship and hence statistically more robust.

4. What methods are practised for managing invasive plants in tropical India?

Invasive species are being managed for about a century in India (Bhagwat *et al.*, 2012). It is essential to integrate different approaches and evolve a framework based on the knowledge of status, effects, reasons, and future. In the present case these parameters will be deduced as explained in the questions above, what remains is the efforts and methods invested by different stakeholders for managing invasive species. It will be achieved by a questionnaire survey of the involved people followed by ground validation. In case of the current study, forest department is responsible for managing invasive species. The questionnaire will evaluate the awareness about status of different invasive plants in park, perception regarding the effects of invasive plants, case studies about effects, case studies about the control measure, efficiency and limitation of the existing policy guidelines and research findings in the park.

Different methods will be compared for involved efforts, time, cost, ecological response and limitation using Analysis of variance (ANOVA). Based on the environmental and economic loss by different invasive species in every park and the most effective method, a cost – benefit analysis will be done to evolve with the most effective and economical methods of controlling every invasive plant in the park. A single method cannot be expected to resolve the invasion in all landscapes. Hence, the approach will provide more regional and case

specific management method for invasive plants.

Conclusion

The study would generate status and map the most noxious invasive plants in India. It will explain the environmental parameters responsible for invasion at a particular patch and the parameters resisting the biological invasion. Both of these are very important in terms of conservation. Furthermore the study provides ecological understanding of why certain species are more successful invaders thus providing an insight on species specific and site specific parameters. The study will provide a forecast about the future in the scenario of climate change that is expected to trigger the biological invasions. And against all these evidences we would then analyse the efficiency of present methods of managing the invasive plants. And evolve with the best suited technique. As cross-sectoral stakeholders, ranging from forest department, research communities, etc. are involved in the process, it provides an opportunity to fill the gap in 'knowing' and 'doing'. Moreover, as the exercise is part of a national project for conserving an umbrella species (AITMP), not much other resources are needed. These guideline could then be implemented across country and after analysing the effects it could be considered in the national policy for wildlife and forest conservation. As many other countries execute national exercise for flagship species conservation, integrated approach for adaptive monitoring of biological invasions like in the present study could be used.

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Factors Affecting Alien Species Invasion and their Impacts on Different Ecosystem in Panchase Area, Nepal

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Abstract

The Convention on Biological Diversity (CBD), 1992 underlines invasion of invasive alien plant species (IAPS) as the second worst threat to biological diversity, even if management of IAPS remains less priority. This study attempts to assess the impact of IAPS on the Panchase area in Nepal. Methods used were literature reviews, household interviews, group discussions, key informant interviews, transect walks, and soil test. An Importance Value Index analysis on 13 randomly selected sample plots recorded 9 major IAPS were prevalent, where *Ageratum conyzoides* and *Ageratina adenophora* were the most abundant and problematic species. The trend analysis over the last 25 years and climatic data analysis of 30 years revealed a rapid expansion of both species. *A. adenophora* has been distributed homogeneously whereas, *A. conyzoides* highly invaded in low altitudes. Among two species *A. adenophora* found to be more harmful. Nevertheless, the economic potential of these species cannot be ignored.

Keywords: Invasive alien plant species, climate change, ecosystem types, impact, management practices.

Introduction

Climate change and the emergence of invasive alien plant species (IAPS), which are commonly referred as weeds, are two of the greatest threats to biodiversity and ecosystem services (Burgiel and Muir, 2010). IUCN (2000) defines IAPS as plants that have become established in natural or semi-natural ecosystems or habitats, an agent of change, and threatens native biological diversity. A study of IPCC (2007) identified that climate change is one of the factors for emergence of invasive species. Increase in atmospheric temperatures and CO₂ concentrations are likely to increase opportunities for the introduction of invasive species because of their adaptability and ability to disturb a broader range of biogeographic conditions and environments (Mooney and Hobbs, 2000).

A study by Lodge *et al.* (2006) showed that IAPS endanger the environment, the economy and human welfare. It also reduces biodiversity, replaces important native species and increases investment in agriculture and silviculture operations (Ricciardi *et al.*, 2000), and disrupts prevailing vegetation dynamics and nutrient cycling (Richardson, 1998). The estimated damage from IAPS worldwide totals more than US \$1.4 trillion a year (5 percent of the global economy). Impacts affect a wide range of sectors including agriculture, forestry, aquaculture, transportation, trade, energy and recreation (Stern, 2006). Since the 17th century, IAPS contributed to nearly 40 percent of all animal extinctions for which the cause is known (CBD, 2002).

Although a list of IAPS is available for most regions in the world, the list needs to be updated and reviewed routinely. The fifth IUCN World Parks Congress, 2003, also considered the need to manage IAPS as an “emerging issue”. Nepal, being a signatory of Convention on Biological Diversity (CBD), is required to prevent the introduction of, control or eradication of invasive alien species (IAS)

that threaten ecosystems, habitats and species (CBD, 1992). However, initiative for management and control of IAS in Nepal is very limited. There are very few studies on IAS; one of such is Tiwari *et al.* (2005). Although the first study of the IAPS of Nepal was carried out five decades before by Banerji *et al.* 1958, further impacts and management studies of IAPS at species, ecosystem and socio-economic levels through eco-friendly approaches were parsimoniously carried out. Poudel and Thapa (2012) reviewed 43 studies so far conducted in Nepal related to IAPS, and recommended conducting further research on documentation and impacts of IAPS. A total of 166 IAPS of Nepal were noted by IUCN Nepal (Tiwari *et al.*, 2005). However, in a milieu of changing climate, the introduction and aggressiveness of IAPS is increasing, and more research and updates are being urged. In order to fill the gap, the study was carried out to assess the extent of invasion and its impact on the Panchase ecosystem of the western development region of Nepal. The study also attempts to identify ecosystem-based adaptation (EBA) options for building the resilience of nature and communities against climate change and biological invasions. Building optimum resilience against climate change and IAPS in both human and ecological systems could be the possible way of adaptation.

General Overview of the Study Area

The study was conducted in the Panchase Area of Nepal. Panchase is situated at the junction of Kaski, Parbat and Syangja districts. Geographically, it is located in the mid- hills of Nepal, between latitudes 28° 12' and 28° 18' N, and longitudes between 83° 45' and 83° 57' E. Altitude ranges from 815 m to 2517 m. Although it has a great diversity of ecosystems and plant species (Aryal and Dhungel, 2009), all 17 Village Development Committees (VDCs¹) are highly invaded by invasive alien plant species namely *A. adenophora*, *A. conyzoides*,

¹ Smaller administrative boundary, each district has several VDCs. There are 3915 village development committees in Nepal. (2012).

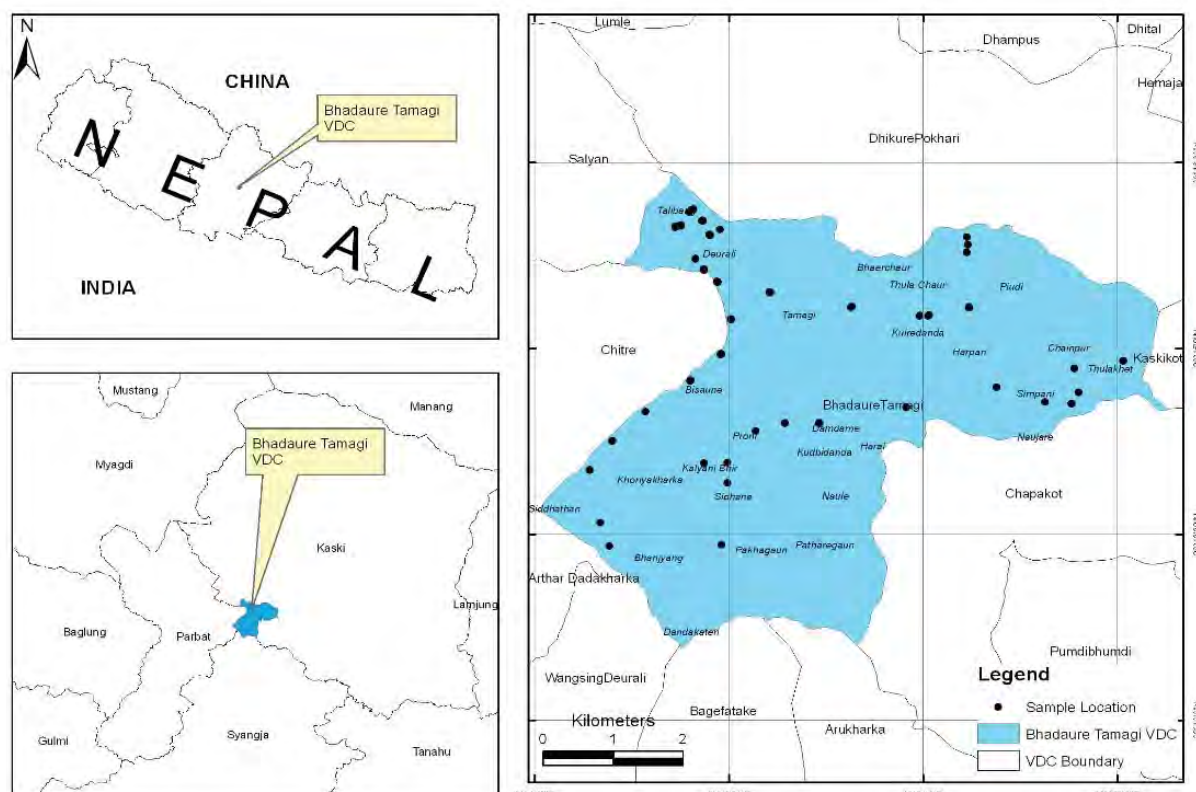


Figure 1. Study Area

Chromolaena odorata, *Eichhornia crissipes* and *Lantana camara*.

Four major ecosystems: agriculture, forest, water and rangeland ecosystem (illustrated in figure 2) were found in the study area. Forest was found to

be the dominant ecosystem, which covers more than three-quarters of the study area followed by agroecosystem. Khahare Khola and Harpan Khola are two major river systems that constitute the major part of aquatic ecosystem, and then followed by rangeland ecosystem.

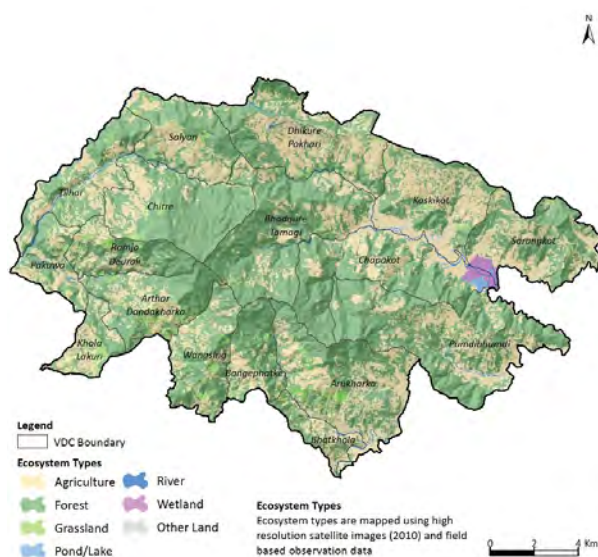


Figure 2. Ecosystem Types

Bhadaure-Tamagi VDC was selected for the study while considering; size of VDC (large), biodiversity, altitudinal variation, outmigration, extent of fallow land, intensity of invasion, and consultation with key informants such as elderly people living in that area for long time, DFO, Panchase Development Committee Members, mother's groups, clubs and CFUG members etc. VDC covers 2,504.3 ha and provides home for 3,257 people. Average size of family member is four members (UNDP, MDO, 2006), which is less than the national average 4.88 (GoN, 2012). This is due to the outmigration of more than 50 percent of the working age group for various purposes. As a result, the village labour

force is greatly reduced. The remaining elder age and children depend on agriculture and forests for their livelihoods. The lower belt of study site is used for settlement and agriculture land use, whereas the upper belt is covered by forest and pasture.

Study Approach and Methods

The required information was collected through a desk review, community consultation, field observation and individual interview. The collected information was analysed by participatory cluster mapping, GIS mapping, and ecological assessment to assess distribution of IAPS and its impact on the resident species.

Information Collection for Social Assessment

A checklist was prepared beforehand to collect social perspective regarding IAPS. A total of 28 households were interviewed. Six focus group discussions were conducted with farmers, community forest user groups, clubs members, NGO representatives, Panchayat Development Committee members and mother's groups in December 2012. Altogether 58 respondents were consulted and participatory mapping was prepared to know the existing colonies of the IAPS including: their introduction, establishment and spread, impacts, management measures, etc. Recall and historical timeline methods were prompted to elucidate the history of introduction and contemporary trend of invasion and distribution. Information from consultations was further cross-checked and verified using key informants in particular, school teachers, elders, women, village representatives and forest guards and authors as well.

Information Collection for Ecological assessment

Following participatory mapping of species, rapid ecological assessment was carried out in 13 randomly selected sites with transect A-A' of 10–20

m width and 50–100 m long based on terrain. Altogether 54 perpendicular and parallel transects were laid within 10–100 m distance from either sides of earthen road. Perpendicular transects were meant for smaller size IAPS study and parallel transects were subjected for bigger size IAPS. Quadrants measuring 10 m x 10 m were laid in each transect at either side ensuring the requisite distance and spiral in spinning (Figure 3), therefore, one quadrant was feasible in perpendicular transects and two in parallel one. In each quadrant, two micro quadrants measuring 1 m x 1 m and 2 m x 2 m were laid, respectively for study of smaller size and bigger size IAPS.

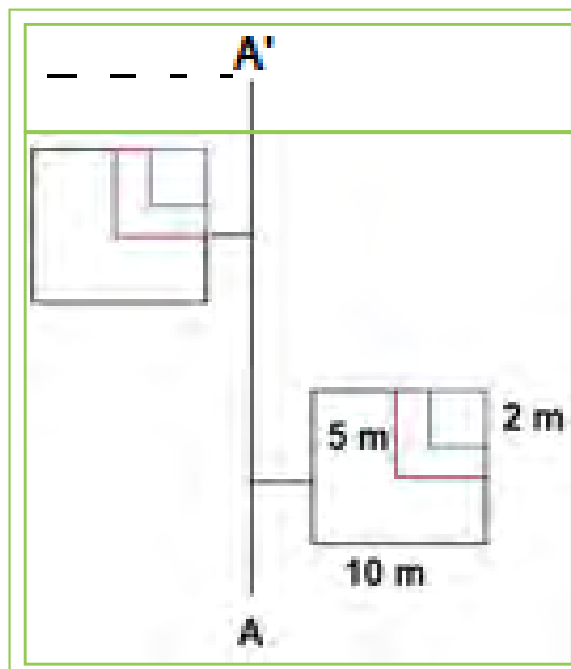


Figure 3. Layout of transect and sample

For physiochemical properties, five soil samples were collected (texture, pH and moisture) to determine whether the selected species correlated to soil characteristics or not. To analysed precipitation and temperature 1981–2011 records of Lumle meteorological station were collected. The geo-coordinates were also synchronized with Global Information System (GIS) mapping to locate the study area, sites and to trace the distribution of

species and model the potential area of invasibility. Likewise, Landsat TM satellite imagery of 2012 used for land-use classification and ArcMap 10 were used for potential sites of IAS invasion.

Species distribution analysis was done by using the Importance Value Index (IVI) as introduced by Cottam and Curtis (1956) for the comparison the species dominance. The IVI for a species is calculated as the sum of relative dominance, relative frequency and its relative density. IVI provides a quantitative basis for the classification of community which reflects the overall importance of a species. IVI for the selected species was calculated by;

Relative frequency is frequency of a species in relation to other species.

$$\text{Relative Frequency\%} = \frac{\text{Frequency of a Species}}{\text{Total Frequency of all the Species}} * 100$$

(Adapted from Raunkiaer (1934))

Relative density is the density of a species with respect to the total density of all species.

$$\text{Relative Density\%} = \frac{\text{Density of individual species}}{\text{Total density of all the species}} * 100$$

(Source Zobel et al. (1987))

Finally, IVI is calculated by using following formula;

$$IVI = \text{Relative Frequency (RF)} + \text{Relative Density (RD)} + \text{Relative Dominance (RDo)}$$

Data analysis

Data was analysed using both quantitative and qualitative methods. The quantitative data obtained from the household interviews were analysed using the SPSS 16.0 software. Climatic characteristics of the study area were assessed in terms of average

annual maximum and minimum temperatures and annual precipitation by analyzing the data recorded by DHM from Lumle station. GIS mapping was used for a graphical presentation of distribution and potential of the selected species. Field ecological sampling of vegetation and soil was carried out to see the relationship between soil and invasive species. Suitability analysis was carried out on the basis of distance and frequency of existing species in relation to land-use, river and road. A potential invasion map of major IAPS was prepared from the analysis performed and further classified into four categories such as highly, moderately, less and least potential site of IAPS.

Results and Discussion

Invasive alien plant species

Among the 21 IAPS found in Nepal, 14² are known to be the worst, and (Lowe et al., 2000 and Tiwari et al., 2005) out of which, nine species, namely *Ageratina adenophora* (banmara), *Ageratum conyzoides* (nilo gande), *Chromolaena odorata*, *Eichhornia crissipes*, *Imperata cylindrical*, *Lantana camara*, *Leucaena leucocephala*, *Parthenium hysterophorus* and *Rubus ellipticus* were prevalent at the study site.

An importance value index was calculated for the nine IAPS found in study site (Table 1). The result showed that IVI indexes for *Ageratina adenophora* and *Ageratum conyzoides* were higher than that of others. The higher IVI values indicate that these species were the most abundant and problematic species in the study site. The field observation and discussion with the communities also indicated the abundance of those species in the area.

2 *Ageratina adenophora*, *Ageratum conyzoides*, *Arundo danax*, *Chromolaena odorata*, *Eichhornia crissipes*, *Hedychium gardnerianum*, *Hiptage benghalensis*, *Imperata cylindrical*, *Lantana camara*, *Leucaena leucocephala*, *Mikania micrantha*, *Opuntia stricta*, *Parthenium hysterophorus*, *Rubus ellipticus*

Table 1: Importance value index of the IAPS in the study site

Rank	Species name	IVI
1	<i>Ageratina adenophora</i>	43.39
2	<i>Ageratum conyzoides</i>	31.91
3	<i>Chromolaena odorata</i>	28.83
4	<i>Eichhornia crissipes</i>	21.23
5	<i>Imperata cylindrical</i>	19.29
6	<i>Lantana camara</i>	17.00
7	<i>Leucaena leucocephala</i>	11.34
8	<i>Parthenium hysterophorus</i>	10.52
9	<i>Rubus ellipticus</i>	8.62

Detail analysis of IVI in the study area showed that *A. adenophora* was found invaded throughout the study site. However, it is mostly available at higher altitude of the study site. The transition lands between agriculture and forests, fallow lands and roadsides above 2,000 m of study site were the most invaded areas where preventive and controlling measures were not in place. The lower altitude of the study site was either dominated by *A. conyzoides* or co-existence with *A. denophora*. Nevertheless, there was few areas where the affect of these species was very less, it could be because of weeding in forest and uprooting in agriculture land.

Invasion trend of alien plant species

Impact of IAPS was apparent for over a period of three decades in the study site when salah jhar (*Conyza japonica*) was problematic about 25 years ago. According to local communities, *Conyza*, *Phalaris*, *Borreria*, *A. adenophora*, *A. conyzoides* and *Chromolaena* are invading the study site and its periphery. Agricultural land was first affected by *Conyza* and the problem was exacerbated by the invasion of *Phalaris minor*. Later, agricultural productivity was hindered by the establishment of *Borreria*. Roadsides, forests and the agricultural periphery close to wetlands, ponds, streams and wells were invaded by *A. adenophora* about 15 years ago and its impact continued to increase (Figure 4).

Factors affecting invasion

Determinants of plant invasiveness *per se* are extremely complex (Rejmanek *et al.*, 2005). Both anthropogenic and natural factors are responsible for introduction and spread of alien species.

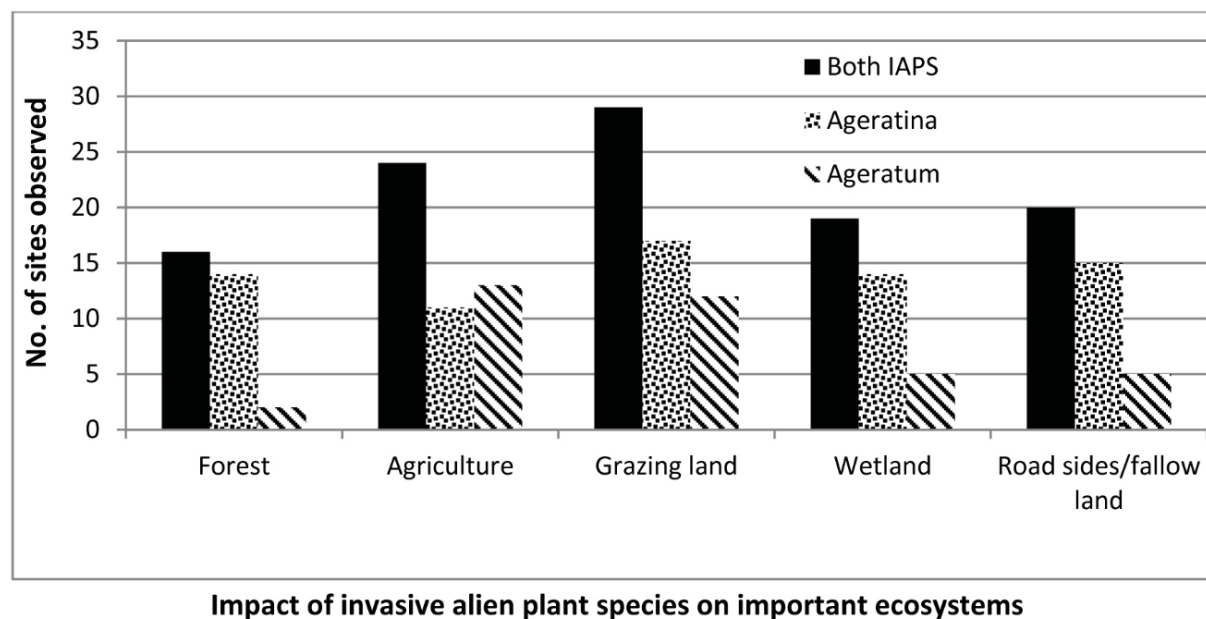


Table 2. Factors for invasion in percent (N = 28)

SN	Factors	Respondent (10%)	
		<i>A. conyzoides</i>	<i>A. adenophora</i>
1	Biology of IAPS and their adaptability	78.6	85.7
2	Outmigration and shift in occupations	92.9	89.3
3	Agronomic practices	78.6	53.6
4	Topography and soil characteristics	78.6	82.1
5	Climate change	64.3	78.6
6	Unplanned road construction	53.6	85.7

Source: (Field survey, Dec 2012)

More than two thirds of the respondents claimed that all the factors except climate change and unplanned road construction were responsible for invasion of *A. conyzoides*. Likewise, all the factors except agronomic practices were reported by more than two third respondents as factors of *A. adenophora* invasion.

i. Biology of invasive plants and their adaptability

Understanding the causes of biological invasions due to flowering phenology is a key trait for high invasion of IAPS (Cadotte and Lovett-Doust, 2001; Lake and Leishman 2004; Pysek and Richardson, 2007). A study conducted by Jianghua (2005) showed that each plant of *A. adenophora* produces 30,000–45,000 seeds annually, and sometimes as many as 100,000. Wind, flowing water, vehicles, people and livestock are means of seed spreading. Although seed germination requires sunlight, the seeds can germinate in shade too and the plant can grow quite well. On the other hand, *A. conyzoides* roots and rootlets are densely fibrous and branched, which tightly anchored the soil. It grows in all ecosystem types, such as agricultural land, disturbed sites and degraded areas. It reproduces mainly by seeds, which are dispersed by the hairs of livestock and wild animals, human clothes, water and agricultural machinery. It can complete its life cycle (germination to flowering) in less than two months, which shows its wide extension and high adaptation capabilities.

ii. Outmigration and shift in occupations

There is high outmigration of male youths from the villages in search of jobs. The existing population in the study site consists mainly of elderly, women and children. The site has an acute scarcity of human resources for agriculture. As a result, most of the agricultural lands are abandoned. The abandonment of the lands provides space for invasion of alien plant species.

Shifting of occupation from traditional agriculture to the business and service industries can be seen in the study site, as there are plenty of small grocery shops and stalls in the village. It indicates that villagers are more interested in commercial enterprises than in traditional agribusiness. The cooperatives and other small financial institution in the study site are prevalent which showed the shifting in occupation. As a result of this agriculture land remain fallow, which provide opportunity for the plant to colonize. Fast growing characteristics of the plant further supports to this.

iii. Agronomic Practices

The use of organic compost manure in agricultural ecosystems is decreasing every year. On the other hand, local communities are using excessive amounts of chemical fertilizers for agriculture crops. This has depressed the soil quality and provides the opportunity for IAPS to spread as these species perform better in poor quality soil

compared to garifulture crops. Likewise, poor quality and adulterated seeds were another most prominent cause of invasion. Nevertheless, there are few agronomic practices that have contributed to control invasive species to some extent. Few villagers have started using *A. adenophora* to produce manure; the practice not only helps to control the IAPS but contributes in improving soil quality by the use of manure.

iv. Topography and Soil Characteristics

Soil pH, moisture content and altitude facilitates or hinders for expansion species. Invasion of IAPS increases with increase on moisture content and soil pH value but decrease with altitude. Soil pH in the study area ranges from 4.6 to 6.5, which is suitable for growth of the IAPS (Borland et al., 2009) This species is mostly abundant on lower elevation (100–1500) and growth is relatively high in the area. The negative coorelation value between altitude and IVI shows that the plants are abundant in lower altiture and vice versa (Table 3).

v. Climate change

Climate change is promoting further invasion of IAPS, which causes changes in phenology and species ranges (Walther et al. 2002 and Root et al. 2003). Although *A. adenophora* and *A. conyzoides* prefer warm and wet environments, its ability to adapt to wide environmental conditions is very strong. It grows in a wide range of temperature ranges from 5 °C to 42 °C (Barrett, 2000). In recent years, climate change is providing a favourable environment for the invasion of invasive species.

Interacting dynamics with climate change and invasive species ranges from global patterns to local sites and communities of species (Burgiel and Muir, 2010). Climate change may include alterations in species distributions and changes in abundance within existing distributions resulting from direct physiological impacts on individual species, changes in abiotic factors, changes opportunities for reproduction and recruitment and alters interactions among species (Karieva et al., 1993). Invasive species may find that changes in climate produce more conduits for their establishment and spread (McNeely, 2000). Climate change is therefore a pervasive element of the multiple forcing functions which maintain, generate and threaten biodiversity and induce biological invasion.

For the last 30 years, maximum temperatures have increased from 19 °C to 20.5 °C and rainfall increased from 5300 mm to 5600 mm per year in the study site. At the same times, according to the local communities, there was an exponential increase in IAPS. Increasing temperatures and changes in precipitation compounded by invasion of alien species posed additional impacts on agricultural productivity, rangelands, and forest biodiversity. Climate change therefore, could alter almost every facet of invasion dynamics and every interaction between different factors (Thuiller et al., 2007).

vi. Unplanned road construction

The study area has a number of earthen roads, which were constructed without planning and using heavy machines. Most of the roads were constructed a few years prior, but seldom see use. The unveiled soil, as a result of road construction, provides opportunity for

Table 3. Relationship between IVIs of IAPs and topographic and soil characteristics

Indicators	Average	Range	Correlation coefficient
Altitude	1307	1000–1500	-.900*
Soil PH	5.2	4.6–6.5	.577
Soil moisture content	42.%	34–45%	.738

*. Correlation is significant at the 0.05 level (1-tailed).

IAPS to grow. The IAPS that has a capacity to establish in new soil quickly covered the roadside. Fast growing opportunistic alien species benefited because of their mode of reproduction and greater adaptability.

vii. Improved forest management practices

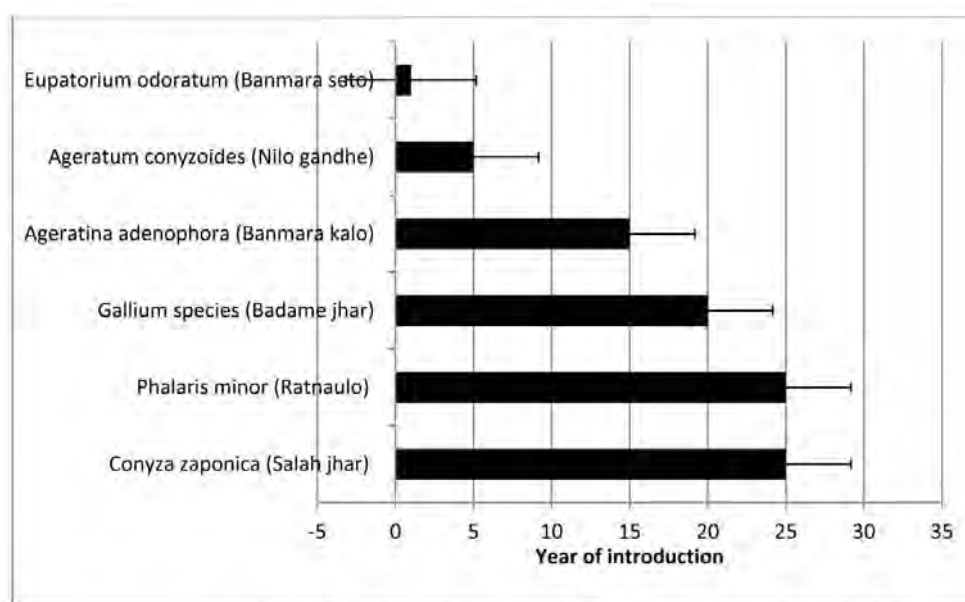
Among the identified factor, this is an only factor that hinders invasion of IAPS. Improved forest management practices in community forests have helped to control the spread of IAPS. In the study site there are 10 community forests, which cover 382.43 ha i.e. 19% of total forest area of the VDC. Many non-governmental and governmental organisations are training the local communities on scientific forest management. They used to do regular silviculture activities, such as thinning, pruning and weeding. In performing such activities, the communities used to remove IAPS from the forests, and have contributed to the control of the population of IAPS to some extent.

Impacts and Effects on ecosystem

Studies by Lodge *et al.*, 2006 and Ricciardi *et al.*, 2000 found that IAPS threaten the environment,

reduce biodiversity, replace economically important plant species and increase the investment in agriculture and silviculture practices, prevail vegetation dynamics and alter nutrient cycling (Richardson, 1998). They can promote hazards like forest fire. Plant invasions dramatically affect the distribution, abundance and reproduction of many native species (Sala *et al.*, 1999). In the study area too, impacts of invasive alien plant species *A. conyzoides* and *A. adenophora* were well observed and none of the ecosystems were free from their impact. Edges of forests, agricultural lands and wetlands had severe IAPS intrusion.

Although all ecosystems are susceptible to invasion, ecosystems entwined with higher level of human interventions (Yelenik *et al.*, 2007) (e.g. forestry, agriculture, wetland and rangelands) are likely to pose greater susceptibility. In the study site, rangeland, agriculture land as well as fallow lands and roadsides were highly susceptible to invasion of IAPS (Figure 5). Forests of the study site were least affected ecosystem as they are more diverse (Bhattarai *et al.*, 2012) and close canopied.



History of introduction of invasive alien plant species in Bhadaure Tamagi VDC

Figure 5. History of introduction of Invasive alien plant species in Bhadaure Tamagi VDC

Although both the IAPS were found to appear in all ecosystem types, the results show that *A. adenophora* dominated in all ecosystems except in agricultural land. However, all types of soil, including gravel and fecund, were supportive in the establishment of *A. adenophora*. Therefore, their diversity and distribution were homogenous throughout the study site. It is also the first species to colonise in degraded areas and prevent other plants from establishing. The high invasion proliferation in rangeland was because both domestic and wild animals frequently grazed the land. According to the participants in a focus group discussion, it was appeared about seven years ago in the study *Hypoxis aurea* has aggressively spread in agricultural fields because of application of excessive nitrogen chemical fertilizer, according to local communities.

Impacts on Forest Ecosystem

Household surveys revealed that edge of the forest, roadsides and fallow lands previously dominated by *Artemisia*, *Solanum*, *Urtica*, etc. were invaded by IAPS. *Artemisia*, *Solanum* and *Urtica* failed to maintain their biomass in the changing climate and their dominance was fairly slacked off by IAPS. *Ageratina* contains *cadinene sesquiterpenes* which plays a role of allelopathy and controls associated vegetation. It is also poisonous to horses (Bohlmann and Gupta, 1981; Baruah et al., 1994). IAPS are shaded out by trees and lianas in forests (Rouw, 1996) and their invasion is slow down (Tjitrosemto, 1996). As a result, dense and diverse forests are more resistant to ecological invasion (Pimm, 1984). However, forests in studied area has invaded about 20% area particularly forest edges and plantation forests of the studied ecosystem.

Impact on Agricultural Ecosystem

IAPS are also considered biological polluters (Westbrook's, 1991) and are capable of hybridising with native plant relatives that result in genetically

modified to a plant's genetic make-up results into great peril of biodiversity, which has also same impact in the study site. *A. conyzoides* has adverse impacts on most of the agricultural crops as nutrients and fertilizers supplied to the main crop are being exploited by this species. Agricultural crops, particularly ginger, millet, rice and grasses, were outcompeted by *Ageratum* and their productivity declined. Reduction in production of cereals and grasses in Kaski district as a result of invasion by *A. conyzoides*, *A. adenophora*, and *C. odorata* was also discussed (Bhusal, 2009). According to Oerke et al. (1995), there was a loss of 13 percent of agricultural outputs due to weeds. According to local communities, there was about 273 kg of rice produced in a *ropani* (500 m²) of agricultural land in Chainpur, but after invasion by *A. conyzoides*, the production reduced to about 182 kg.

In agricultural fields, IAS, precisely *A. conyzoides*, *Borreriaalata*, *Phalaris minor*, etc., were known to replace native species as well as prevent their natural regeneration. Many grasses species, such as *Artemisia spp*, *Solanum xanthocarpum* and *Urtica sp.* of fallow lands and *Scrophularia species*, *Hypoxis aurea* etc of agricultural lands were threatened by invasion of *A. conyzoides*, *Borreria alata*, and *Phalaris minor* invasive alien plant species in the study site.

Impact of *A. conyzoides* on livestock is more severe in the study site. There are a number of livestock mortalities, particularly of buffaloes. In the last five years, there were five cases of livestock mortality. In general, buffalo and other livestock, except goat, did not forage *A. conyzoides*, but sometimes they inadvertently fed *A. conyzoides* while being fed other grasses. The cases generally happened in the spring when the plant flowers are in full bloom. After feeding *A. conyzoides*, the abdomen is enlarged, and there is no defecation and rumination.

Similarly, IAPS affect the dynamics and composition of soil and have impacts on ecosystem functions, such as soil nutrient cycling (Yelenik et al., 2007)

and soil chemistry (Randall and Marinelli, 1996). In the study site, IAPS were growing in a wide range of soils but not flourishing in shade. Soil texture in agriculture land of the study area is silt clay. The highest population of *A. conyzoides* in agriculture land shows that they prefer silt clay whereas abundance of *A. adenophora* in roadside and rangeland shows that the species prefer coarse soil.

Impacts on Wetland and Rangeland Ecosystems

A. adenophora is distributed throughout the study site; it can be just in any type of soil and environment. Nearby wetlands and throughout the rangeland is the most favourable environment for the invasion of invasive species. Apart from those species, water bodies of the study area were invaded by Jalkumbhi (*Pistia stratiotes* L.) and unwanted water favouring plants. *A. adenophora* mostly prefer damps areas such as wetland margins, drainage lines and gullies. Mostly edge of rangeland dominated by *A. adenophora* and throughout *A. conyzoides* were distributed but in very low numbers.

Impacts on human ecosystems

The lower area of the study site is densely populated by subsistence farmers and livestock rearing is an integral part of their livelihood (Bhattarai et al., 2012). As livestock comprises a major part of agro-ecological system of the study site, fodder collection is the second most important biomass outtake, especially in dry and lean periods when on-farm fodder is particularly sparse. Preferred species for lopping fodder were *Brassiopsis heinla*, *Ficus lacoar*, *F. glaberrima*, *F. hispida*, *Streblus asper*, *Eurya accuminata*, *Prunus* species, *Quercus lamellosa* and *Q. semecarpifolia* (Bhattarai et al., 2012); however, their productivity was constrained by *A. conyzoides* and *A. adenophora* by outcompeting for nutrients.

The upper area of the study site is dominated by Gurung and other ethnic groups and their livelihoods differ from that of the inhabitants of the lower area. Out-migration is one of the characteristics of the study site and it is more common in the upper part of the site. Out-migration is less extensive in lower areas where Brahmin and Chhetri are dominant because these ethnic groups are less eligible for Gurkha recruitment. Inadequate labour in the study site led agriculture and grasslands to less nurtured and unattended, resulting in rampant spread of invasive species, which results encroachment in the human ecosystem as a whole.

Economic prospects and potential

Along with negative impacts, there are also several positive impacts of these two species that have been capitalized by local communities of the study site. *A. adenophora* has been explored for uses as a green energy resource, composting and income generation, promoting soil fertility of farmlands and complementing livelihood of the rural poor. The practice of using *A. adenophora* as green manure is an increasing trend in the study site. Increasing yield of rice and wheat was observed in other areas of the country where green manuring of *A. adenophora* was used (Bhattarai et al., 2006), because it contains 0.372 percent of total nitrogen, 0.062 percent of total phosphorus, and 0.580 percent of total kalium, as well as calcium, magnesium, iron, sulfur, silicon, zinc, boron (Sun et al., 2004). Therefore, promotion of the use of *A. adenophora* as green manure is important in the study site.

A. adenophora has long been used as a cattle-bedding material in other parts of the country (Shrestha, 1989). The apical leaves are crushed and paste and juice are used to control bleeding. *A. conyzoides* was also used to treat various ailments (Oladejo et al., 2003), but it was not practised in the study site. Bio-briquettes made from *A.*

adenophora were used as green energy fuel in the study site; however, it was merely a demo version. Production of bio-briquette is potential in the study site because it helps to arrest plant invasion, enrich biodiversity and supply employment and additional income to the locals.

Conclusion

Biological invasion of IAPS is the second worst threat after habitat destruction and set global priorities for management. The study area was also not different from other parts of the world. *A. adenophora* and *A. conyzoides* are the most abundant IAPS in the study area. Multiple modes of plant reproduction, large number of seed production, land use change, outmigration and occupation shift and agronomic practices are the major factor for its wide dispersion. The invasion is more serious in agriculture land followed by disturbed sites, such as newly constructed earthen roads. The invasion is seriously affecting agriculture productivity. However, the invasion was less in dense forests, implying the close canopy forests are less sensitive to invasive species. The soil preference of both species is different; *A. conyzoides* prefers silt clay soil hence is found abundant in agriculture land whereas all types of soil even gravel to fecund were supportive to establishment of *A. adenophora*. The invasion in agriculture land has reduced the productivity of crops. Nevertheless, the IAPs have an economic potential as well. A few households are using these species for making compost manure and producing bio-briquettes for energy. Promoting bio-briquette production and market linkage would help to improve the health condition of different ecosystems and provide additional income to local community. Furthermore, it supports controlling forest degradation and loss of biodiversity.

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Invasive Alien Species Management through Utilization for Application in Domesticated Livestock Species Raising

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Abstract

Alien species are microorganisms, plants and animals that are native of some part of the planet and have found their way beyond the defined natural range and established its presence in another ecosystem. The concern is for the invasiveness and pollution of diversity that these alien species create threatening the indigenous, native population even to the extent of extinction. However, the notion of “weeds being plants with yet to understand values” holds true to these invasive species. In the age when human survival through conventional ways of living is being doubted, anything available to be utilized at the level of over harvesting should not be a bane in the notion of sustainability. Humans have successfully eliminated many species of flora and fauna to extinction thanks to the practice of over harvesting, habitat loss, human mediated biotic interchange to name some. It is now clear that not all alien species can establish but those that have dominated usually have found a favorable climate, ability to out compete and grab resources that are in abundance, lack in number and strength of natural predators, parasites or diseases. However, human consumption pattern and greed have combined force of predation, parasitism and disease. This is where this paper aims to focus, i.e the human potentiality to over harvest and wipe out any species primarily flora and fauna species. Human culture have established sets of food culture, however insects, fishes, reptiles, birds and edible wild and exotic food are getting mainstream. In our opinion, in context of Nepal, we have no real problem with harvesting fauna species while for floras we have possibility to use in the management of domesticated animals. Goats called the poor man's cow have huge potentiality for food security and rural poverty reducing commodity in Nepal and is a robust machine that can consume variety of invasive plants species. Likewise, feed, fodder, bedding, fuel and manure roles for these species of invasive plants can bring rapid harvesting. In the same context, understanding the medicinal properties, timing of harvesting for maximum elimination, relaxed regulation on forest product harvest, encouragement of buffer communities to raise understood species of livestock to manage the menace of invasive alien species on the other side of the sense is possible. However, the big picture of the problem and solution has to be analyzed through trans sectoral approach. In conclusion, this paper aims to throw some light on how livestock demanded resource need for local communities can assist in managing the unwanted species.

Keywords: Management, livestock husbandry, alien-invasive species.

Introduction

Invasive and alien species (IAS) that are brought into a new environment, either on purpose or by accident, can quickly exploit ecological niches that are not fully covered by indigenous (local) species. They will then quickly spread and outcompete the local wildlife.

Alien species: A species introduced from outside its natural past or present distribution including any part, gametes, seeds, eggs, or other material of such species that might survive and subsequently reproduce. Introducing new pest and diseases, hideout for parasitic bugs and even to extent of altering physiology of native and host species is reported. There are examples of invasive species altering the evolutionary pathway of native species by competitive exclusion, niche displacement, hybridization, introgression, predation, and ultimately extinction. Invaders themselves evolve in response to their interactions with natives, as well as in response to the new abiotic environment. Flexibility in behavior, and mutualistic interactions, can aid in the success of invaders in their new environment (Mooney and Cleland, 2001).

Some related terminologies as mentioned by Padma, 2012:

Alien Invasive Species: An alien species which becomes established in a natural or semi-natural ecosystem or habitat, is an agent of change, and threatens native biological diversity.

Introduced Species: Any species transported intentionally or accidentally by a human-mediated vector into habitats outside its native range.

Organism: Any life form from the conventional plant and animal kingdoms and including fungi, bacteria and viruses.

Sanitary or phytosanitary measures:

These are designed to protect humans, animals, and plants from diseases, pests, or contaminants.

IAS are plants, insects, diseases, mollusks, fish, reptile, nematodes, aves, mammals, amphibians, crustaceans, arachnids, fungi and many other types of living entities in the wrong place. As per the Executive Order 13112 of National Invasive Species Information Center, United States Department of Agriculture: an "invasive species" is defined as a species that is: 1) non-native (or alien) to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health. The Invasive Species Specialist Group have made list of hundred worst invasive alien species global database. In such a list prepared by Napompeth Banpot from Thailand, he mentions; 14 mammals, 2 reptiles, 3 birds, 8 fishes, 3 amphibians, 17 land invertebrates, 9 aquatic invertebrates, 32 land plants, 4 aquatic plants, 8 microorganism. In one such study on the Invasive Alien Plants of Himalayan Region, Sekhar (2012) mentions a total of 190 invasive alien species under 112 genera, belonging to 47 families have been recorded. Among these, the dicotyledons represent by 40 families, 95 genera and 170 species; monocotyledons represent by 7 families, 17 genera and 20 species. The analysis of invasive species reveals that 18 species have been introduced intentionally, while the remaining species established unintentionally through trade. In terms of nativity, amongst 13 geographic regions, the majority of invasive plants reported from American continent (73%). While in life form analysis, the herbs (148 species) are dominant, followed by shrubs (19 species), Grass (11 species), Trees (4 species), sedges and climber (3 species each).

Nepal being a rich diverse land have reporting for over hundred non native plant species. In their presentation, Thapa and Kharal (2011) supported

that over hundred species of plants were non native to Nepal and in 2002/03 three category of high, medium and low risk bearing species tags were given to 21 IAS. Experts say that among invasive species, plants can be the most damaging, given their ability to alter entire ecosystems. However, it is not surprising to find reports of newer species viewing and do they constitute alien species is a different topic of discussion. Recently, Annapurna Conservation Area Project (ACAP) reported that in the last one and half decade nine new animal species were found. They include Tibetan Sandgrouse (*Syrrhaptes tibetanus*), Tibetan Argali, Eurasian Eagle-Owl, a rare species of Pallas' cat, new species of musk deer and two new species of butterfly. The nearly threatened small wild cat species, *Otocolobus manul*, a native to the grassland and steep regions of Central Asia was also reportedly sighted at ACAP. The other conservation and wildlife habitat including Chitwan National Park (CNP) is also contributing in reporting for newer species sighting.

Recent discovery called *Pithovirus sibericum*, a class of giant viruses that infects amoebas but does not attack human or animal cells is very interesting to link with IAS. These are all so large that, unlike other viruses, they can be seen under a microscope. And this one, measuring 1.5 micrometres in length, is the biggest that has ever been found. The last time it infected anything was more than 30,000 years ago, but in the laboratory it has sprung to life once again. Tests show that it attacks amoebas, which are single-celled organisms, but does not infect humans or other animals (Matthieu et al., 2014). Now, what are the status of these species and where were they hiding, or is it just part of the evolution where newer species begin to appear in changing ecological setting. Hence, how do any species become alien and invasive, do they all end up as notorious IAS, do climate change play any concrete role in

transforming landscape and ecology are some answer we need to obtain.

Is society like Nepal's at receiving end for the bigger ecological footprints elsewhere? Can, the menace perceived role of IAS be a boon, will it prove to be cash in the bartering of per-capita carbon dioxide (CO₂) emissions in metric tons by country, from the United Nations Millennium Development Goals Indicators? Research on the offsetting options at right, 90.9% goes to projects, the offsetting rate is USD 9.90 per tonne as mentioned in the COTAP projects (<http://cotap.org/per-capita-carbon-co2-emissions-by-country/#sthash.reKuB23d.dpuf>). In the indicator list Nepal have 0.13 points while in reference United States have 17.5 and is still not the top in the globe. Thus wide gap, like in this indication here is not disheartening, in the sense that our ecological footprint is small. Understanding if these IAS, aggravate the climate change brought physiological alteration, vector-parasite-prey, One Health dimension shift is an urgent issue to address. Are these the symptoms of ground effects results on ecology for climate changes? demands clear answers.

Science and technology advancement is the tool we can design and adopt in understanding the biology. Here in this purpose, the emerging role played by chemical probes in the modern plant and human biology is undeniable. Potent, selective and cell-permeable modulators of protein function ("chemical probes") are valued reagents in both fundamental and applied biological research. This technology along with others can assist in understanding the strengths and weak links in the biology of IAS. However, chemical probes are not widely available because they are difficult to produce without access to skilled medicinal chemists; they are also frequently targeted to the relatively few proteins that have already been the focus of industrial drug discovery efforts and are often encumbered by intellectual property and

restrictive material transfer agreements. Identifying possible bioactive compounds in these IAS, design optimum harvesting approach, prevent disease and pest transfer and create biological exclusion are some activities that can benefit immensely from the advancement of biotechnology. This technological intervention is necessary in light of changing roles; like the red turpentine beetle (*Dendroctonus valens*). It is mentioned that in North America, the beetle mainly attacks dead or ailing trees. But the beetles, which were introduced to China in the 1980s, have wiped out more than 10 million pine trees in northern provinces since 1999. Entomologists at the Chinese Academy of Sciences' Institute of Zoology in Beijing, found that the interaction between the beetles and their symbiotic fungus *Leptographium procerum* is key to their 'personality change' in China. They report that since its arrival, "the fungus has mutated into novel genotypes", one of these being to induce trees to release large amounts of the compound 3-carene which is a strong attractant to the beetles and not released in response to the North American fungal variant. Changes in human activities primarily the addition of chemicals and intensification in agriculture is precipitating new invasions (Qiu, 2013). New Zealand is facing an invasion of Argentine ants (*Linepithema humile*), which compete with native southern ants (*Monomorium antarcticum*). It is now understood that use of some chemicals alters the behavioral changes that have been associated with sublethal neonicotinoid exposure in other insects affect how the two species interact.

This is alarming as human use of chemicals in agriculture is on a rise and any changes in behavior of one or more species creates potentially impact in the structure of the entire community. In the case of apiculture, researchers have found that two diseases harbored by honeybees are spilling over into wild bumblebees. In the last few decades, many species have suffered steep declines, and some, such as Cullem's bumblebee (*Bombus cullumanus*)

in the UK, have gone extinct. Scientists believe that the destruction of their habitats (particularly wildflower meadows), introduction of genetically modified crops has driven much of this loss, but the latest research suggests that disease too could play a role. Insects infected with deformed wing virus and a fungal parasite called *Nosema ceranae* were found across England, Scotland and Wales. The wild Himalayan bees famous for the "honey hunting" activities in Nepal that produces one of the finest honey have too suffered at the hands of the parasite contacted from domesticated bees. Diseases, rather than pesticides, are suspected of driving that decline. And although there have been dramatic falls in the numbers of managed honey bee *Apis mellifera* colonies in some countries, it remains a widespread and common bee, not in imminent danger of extinction. Problems caused by IAS (especially plants) have been increasingly reported from different ecosystems throughout the country in the last decade, experiencing differing degrees of invasion. They pose a threat primarily to biodiversity by influencing and displacing native species in their home range. In addition, they are hurting the economy and the health of humans and cattle. Likewise, livelihood is at risk due to the multidimensional impacts and recently fodder trees, vegetables being infested by invasive caterpillars have created havoc to farmers in Dhading, Ilam areas of Nepal.

Despite the ubiquity of invasive organisms and their often deleterious effects on native flora and fauna, the consequences of biological invasions for human health and the ecological mechanisms through which they occur are rarely considered. Allelopathic activity is also demonstrated by some IAS and is defined as any indirect or direct, beneficial or damaging effect, from a plant to other, resulted from the production of chemical products which are released into the environment. IAS grow very fast and affect the native biodiversity and the livelihood of the people in a negative way. In

addition, they are a source of hybridization with native species (gene pollution), major losses to the economy, water loss from watersheds and a vector for many diseases, including human ailments. They are much more difficult and costly to control once they establish their presence because of their better survival strategies like rapid population growth, high dispersal ability by wind and water and tolerance of wide environmental conditions. Reported incidence with Amur honeysuckle (*Lonicera maackii*), and its increase of human exposure risk to ehrlichiosis, an emerging infectious disease caused by bacterial pathogens transmitted by the lone star tick (*Amblyomma americanum*). It was found that white-tailed deer (*Odocoileus virginianus*), a preeminent tick host and pathogen reservoir, more frequently used areas invaded by honeysuckle. This habitat preference translated into considerably greater numbers of ticks infected with pathogens in honeysuckle invaded areas relative to adjacent honeysuckle un-invaded areas. Hence, biotic mechanism using an experimental removal of honeysuckle, which caused a decrease in deer activity and infected tick numbers, as well as a proportional shift in the blood meals of ticks away from deer (Brian *et al.*, 2010). Nepal is considered endemic for at least ten Parasitic Zoonoses (PZ), neurocysticercosis and congenital toxoplasmosis among them are likely to impose an important burden to public health. Nepal is probably endemic for trichinellosis, toxocarosis, diphyllbothriosis, foodborne trematodosis, taeniosis, and zoonotic intestinal helminthic and protozoal infections with considerable risk for health impact. Sporadic cases of alveolar echinococcosis, angiostrongylosis, capillariosis, dirofilariosis, gnathostomosis, sparganosis and cutaneous leishmaniosis may occur (Deveesschauwer *et al.*, 2014). The association of IAS and PZ is another area that needs immediate research in Nepal as it is felt that the complex one health issue needs transdisciplinary approach (Min *et al.*, 2013).

Likewise, one particular disease taking a heavy toll on amphibian populations throughout the world is caused by *Batrachochytrium dendrobatidis* (Bd), or amphibian chytrid fungus. It is one of the main reasons why more than one-third of the nearly 6,000 known amphibian species are threatened with extinction. Chytrid does not affect all amphibians equally, and some species can harbor the fungus without showing symptoms. Nonetheless, in infected populations, mortality rates of up to 90 percent have been observed, and researchers are desperately scrambling to control the fast-spreading disease. The American bullfrog is the most commonly farmed frog species worldwide and is highly adaptable to different conditions. Consequently, it has become an invasive species in many countries, competing with and eating native wildlife. In this case a native species is commercially traded American bullfrogs and legs often enter the U.S. from overseas and in one report it mentioned that 62 percent of live American bullfrog specimens imported into the U.S. were Bd carriers. This is an evidence to conclude that changing human eating and recreational activities can also be blamed for the introduction of IAS.

Is there any part of the planet that is free from the impact of IAS, the answer will be negative. Even the Antarctic is reported to be suffering from invading midge *Eretmoptera murphyi*, and they reportedly appear to be speeding up the rate at which decay occurs in Antarctic soil. Originally from the sub-Antarctic South Georgia Island, with the ecosystem on that island is very different from the one on the Antarctic Peninsula, where the midge has now established itself. In spite of the remoteness of Antarctica and the Southern Ocean from civilization, but they are at great risk of losing their unique qualities due to human activities. Warmer temperatures and human visitation are increasing the likelihood that invasive species can take up residence in the Antarctic, and potentially cause major changes. Two studies (Christian, 2013) have

found evidence of invasions both on land (from a midge) and at sea (from crabs *Neolithodes yaldwyni*, a species of king crab). The remoteness of the Antarctic can no longer protect it from potentially destructive invaders. Antarctic, cold water has long kept out crustaceans like crabs and lobsters, which cannot survive at temperatures below 1 °C (just under 34 °F). Hence, the discovery closer to the Antarctic Peninsula (one of the fastest warming areas in the world) is an alarming news. This indicates that the crabs are more firmly established, and have become truly invasive. It is estimated that there are 1.5 million crabs in the Palmer Deep. As warming of ocean water increases, the range of these crabs is bound to expand further.

Global Context and Technological Interventions

Hence, an explosive population growth especially in developing and emerging countries that is expected to cross billion in the mid of this century. Increasing numbers of middle class and purchasing capacity is bound to increase demand for animal derived protein by more than 50 percent in couple of decades from now. The increased trade and transportation across the open border, which can be a reason that it has been difficult to implement the available laws, enhance public awareness and implement the use of local resources to control IAS. Unsustainable anthropogenic impacts can all be cited as fueling factors in the problem caused by IAS. It is now clear that sustainable management of the planet's oceans, forests, mountains, and biodiversity is "vital to enable future food security, surmount rural poverty, and ensure much-needed environmental services": Quoted by FAO Assistant Director-General Eduardo Rojas-Briaies at the UN Open Working Group (OWG) consultations on the Sustainable Development Goals (SDGs) in New York on 4 February 2014. Scientific cooperation to reduce the use of IAS is necessary, for example, to conduct studies regularly to find which alien species

is becoming invasive in the concerned localities and find alternative native or non-IAS that can be used to produce the necessary food. The responsible authorities, therefore, have a catalytic role in controlling IAS. Under the heading "Traditional Knowledge, Innovations and Practices" in article 8 (j) under CBD states for as far as possible and as appropriate, subject to national legislation, respect, preserve and maintain knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity and promote their wider application with the approval and involvement of the holders of such knowledge, innovations and practices and encourage the equitable sharing of the benefits arising from the utilization of such knowledge innovations and practices'. To ensure that the planet is able to sustain life: "Wealthy countries must move away from export-driven agricultural policies and leave space instead for small-scale farmers in developing countries to supply local markets". There is also an urgent must to restrain their expanding claims on global farmland by reining in the demand for animal feed and agrofuels, and by reducing food waste and utilizing non conventional livestock feed sources including IAS.

The narrowing of diversity in crop species contributing to the world's food supplies has been considered a potential threat to food security. However, changes in this diversity have not been quantified globally. We assess trends over the past 50 years in the richness, abundance, and composition of crop species in national food supplies worldwide. Over this period, national per capita food supplies expanded in total quantities of food calories, protein, fat, and weight, with increased proportions of those quantities sourcing from energy-dense foods. At the same time the number of measured crop commodities contributing to national food supplies increased, the relative contribution of these

commodities within these supplies became more even, and the dominance of the most significant commodities decreased. As a consequence, national food supplies worldwide became more similar in composition, correlated particularly with an increased supply of a number of globally important cereal and oil crops, and a decline of other cereal, oil, and starchy root species. The increase in homogeneity worldwide portends the establishment of a global standard food supply, which is relatively species-rich in regard to measured crops at the national level, but species-poor globally. These changes in food supplies heighten interdependence among countries in regard to availability and access to these food sources and the genetic resources supporting their production, and give further urgency to nutrition development priorities aimed at bolstering food security (Khoury *et al.*, 2014).

Likewise, efforts like the International Barcode of Life Projects funded by the Canadian agencies with recent support of \$35 million in new funding for a 26-nation effort to collect specimens, sequence their DNA, and build an informatics platform using digital bar codes to store and share information for species identification and discovery. Efforts like these add up to the understanding of existing and newer species with an initiative that will transform humanity's relationship with other living organisms. By 2015, iBOL aims to gather DNA barcode records for 5 million specimens representing 500,000 species. This is a sort of global positioning system for plant and animal research at exactly the time when humanity is threatening to provoke the sixth mass extinction. Biotechnology has advanced a lot and have reached levels like of genetically engineered gene editing techniques at the level of smallest of DNA mutations - a single deletion of one out of the 3 billion chemical "letters" of pigs genome as reported recently. Likewise, technology is making us understand the impact of climate change and historic events like: decreasing size

in length of fishes in seas as a result of increasing water temperature is reported. By analyzing snail shells from the ancient lake Kotla Dahar in Haryana, India, researchers were able to decipher how much rain fell when the snails lived thousands of years ago. Developments like these will surely help us understand their historical association, evolution and manage AIS. However, evolution and its miracle are getting better understanding as 180-million-year-old fossil suggests fern genomes haven't changed much. While in some, unique ways like the South American milkweed that appear to have developed hornlike extensions on their pollen sacs. These helps to keep the pollen from being tangled with sex cells from other plants of the same species. The tactic could boost the chances that a single plant spread only its pollen to another one.

Nepalese scenario

Nepal is a complex society with no idea as to where the future is? Industrialization, agriculture, tourism, energy or remittance there is own opinion and efforts in promoting perceived savior of Nepalese future. This country of ~33 million people have over 8 million under poverty line and per-capita hovering around 600 US\$. In 1974/75 the national GDP had 70% contribution from agriculture and in 1984/85 it was 50% while currently it hovers around 35%. Remittance is one area that have been holding the national economy at ~24 %, but the bloodied money and social cost is now beginning to be realized. Nepal is at substandard level in research, journals and international publications. Increase in spending in agriculture research from 520 million rupees in 2009 to 1.75 billion (USD 17.6 million) now a god sign. Development vs Conservation is at risk because of vested interest and political mileage games. Recently there is growing concern over the expansion of the proposed East-West Railway line through the Chitwan National Park (CNP), one of the world's best natural refuges for flagship

species such as tigers, rhino, elephants and birdlife. Though the current Minister in charge of forests, Mr. Acharya asked the concerned authorities to consider the project's possible impact on the local environment and explore other alternatives and stressed that- "We should not allow development at the expense of environment", his concern are genuine that on one hand, we are concerned over the depleting forest cover and diversity loss across the country, while on the other, are allowing infrastructure development activities along the most important protected areas. Failure to plan the sustainable development by striking a balance between environment and developmental activities has been our weakness. Sadly, Nepal's political and social instability have had its serious impact in environment and forest resources. Though, the globally shared knowledge now is that measures applied at the initial stages and involving local communities are more effective in controlling IAS we are too busy elsewhere. In addition, most of the IAS, especially the plants found in Nepal, exhibit air or water dispersal mechanisms, which make laws against introducing them to new areas worthless. Public awareness and community involvement are, therefore, necessary to locate and control these species. The general public may not be aware of the harm being caused by the alien species on ecosystem functions. They may complain of declined production, but may not know that invasive species compete with their fellow crops and lead to their loss. Hence, the need for education of the general public including policy makers is a growing urgency. A conscious public would inform the responsible authorities of the occurrence of any invasive species, which they should try to remove or control by using local resources and try to use local and non-invasive species to prevent their reappearance. In support, they should provide alternative ways to maintain the local production of food; otherwise the local community would not withstand the temptation to use invasive species to meet the growing need

for resources. Community led total transformation is one tool that can be used in incorporating the management of IAS (Kaphle, 2013). In one of the works by Rai *et al.*, they mentioned how the local community is eager to work, provided some monetary incentive is included. Likewise, Lions Clubs and other social clubs are eager to volunteer for the cause and social responsibility of many corporate houses can be channelled in the management of IAS. Thankfully, individuals like Chanda Rana are seen to be involved to uproot Mikania, and the proximate analysis report of samples sent to Australia will assist us in formulating ways as how best it can be utilized. Several scholars have worked their thesis will be interesting to understand where. Former Prime Minister Madhav Kumar Nepal in his capacity as the executive head of the nation had first hand experience with the menace of several invasive alien species in Chitwan National Park. It is mentioned that over hundred non native plant species are flourishing in Nepal and Eichhornia speices, Mikania macrantha, Ageratina adenophora, Chromolaena odorata, Lantana camara are the worst offenders. According to an IUCN-Nepal report of 2005, out of the 166 alien plant species recorded in Nepal, 21 species are problematic with respect to the local environment and the livelihood of the people. Water, grassland, forests, copped lands have all been preys to various species of flora and fauna which are being investigated. However, microorganisms as IAS are still areas of investigation in Nepal.

The Lahare Banmara (*Mikania* sps.), Banphada (*Lantana* sps.), Thakal (*Argemone mexicana*), Gandhe, Tapre, Kuro, Pati etc are some common problems and names understood to be nuisance by common people. Like elsewhere, the alien species recorded in Nepal compete with native species for resources and space, and are either unpalatable or less preferred by cattle. Besides influencing native species, they have already caused immense losses to agricultural and pasture lands and forests.

The marginal and main lands in these areas are densely populated with the IAS making these areas less productive and unsuitable for grazing. Until now, they have created problems especially in the lower hills (Mahabharat) and the Tarai where some species are confined to specific areas; for example, the Lahare Banmara occurs from the central to the eastern Tarai in the country. Mikania is one species that has demonstrated its hostility by covering up to 80 percent of the buffer zone community forests in Chitwan National Park and Koshi Tappu Wildlife Reserve with possible creation of monoculture destroying biodiversity, particularly in the Terai region (Rai et al., 2012 a, b). Nepal has a long history of introducing non-native (alien) species to improve agro-forestry production and for recreational use. For example, the Jal Kumbhi which has been difficult to remove from almost all the lakes where it has spread. Nepal's efforts in formulating a legal framework (for example, the Plant Protection Act which came long ago in 1972 to provide effective laws and quarantine regulations) and signing many international conventions (for example the Convention on Biological Diversity), rather than doing scientific studies to find effective techniques, have not been sufficient to control them.

Livestock as ways to manage IAS

With proper management, livestock can be used to develop and maintain desirable vegetation conditions and help prevent invasive plants from establishing. Grazing at the early stages of plant invasion can help reduce colonization and slow the rate of invasion. Moderate densities of invasive plants may be suppressed through prescribed grazing. Selective grazing applied over the long term can gradually reduce the invasive plant's competitive ability within the plant community. Grazing applied at the appropriate growth stage can prevent flower and seed production, thereby containing plant populations that spread by seed.

Once a plant community is dominated by an invasive plant, realistic grazing goals may be to use the invasive plant as forage while taking care to prevent expansion of infestations (Huntly, 1991). The growing demand for food of animal origin in developing countries represents a major opportunity for poverty reduction. Livestock ownership is recognized as a significant contribution, and in multiple ways, to households' livelihoods, including through the provision of cash income, food, manure, hauling services, savings, insurance and even social status. Modern day livestock raising demands that judicious care is provided to ensure that wilderness do not get compromised, even during life saving initiative (Lin et al., 2003; Cuthbert et al., 2014).

Researchers and managers are finding creative ways to use goats, sheep, and cattle to control invasive plants in a variety of environments. Although non-domesticated herbivores (i.e., grass carp (*Ctenopharyngodon idella*) have been introduced to control aquatic plants, current knowledge and practice of prescribed grazing is generally limited to terrestrial habitats. It is now getting clear that livestock animals can be used to restore degraded lands by breaking up the soil surface and incorporating seeds of desirable plants, as the practice is evident in highlands of Nepal. Grazing can be used to manipulate fire intensity by deferring (to increase fuel load) or increasing defoliation (to decrease fuel load) (DiTomaso and Johnson, 2006). Forest fire are common features and intentional flare ups by herding communities is a prevalent practice even here in Nepal. The use of fire to stimulate regrowth and increase palatability of some invasive plants is in itself an encouraging in control of IAS. However, desirable plant populations may also be more vulnerable to the negative effects of grazing following a burn event. Positive and negative interactions between grazing and biological control agents have been documented (Walker, 1994).

Grazing may be applied either before or after herbicide treatments to enhance the effectiveness of either treatment. Evidence on spotted knapweed- (*Centaurea maculosa*)-infested rangelands in western Montana, USA showed that spring-applied herbicide treatments enhanced sheep grazing by shifting knapweed populations from mature, less-palatable plants to juvenile plants preferred by sheep (Sheley et al., 2004). Grazing leafy spurge during spring and summer can reduce canopy and stimulate shoots to grow in the fall. A fall application of an appropriate herbicide then acts on the rapidly developing regrowth. Few environmental issues in agriculture have driven as much interest and debate as the global discussion around greenhouse gas (GHG) emissions. Livestock production, particularly with ruminant animals, is identified as a contributor. There is mounting pressure to better understand and find ways to reduce the livestock GHG footprint, to meet new expectations and improve the sustainability of livestock industries for a successful future. Given utilization of IAS and other low quality forages, livestock can partly compensate for the “Long Shadow” impact on climate change blamed on it.

Conclusion

The negative roles of IAS can be turned into an asset. In our opinion non plant IAS will surely be controlled if given right address and included in priced food or feed items. The issue with plant species is more grave, as if they were palatable as food they would have never established themselves in first place. Their non native status mostly keeps them away from list of priced resources be it for medicine, social or religious application. Direct human consumption looks unlikely but if there is high value treasure in form of bioactive compounds it can be discovered using techniques like new pharmacologically active molecules via High Throughput Screening (HTS) and/or Encoded

Library Technology (ELT). Likewise, possible application as feed, fuel and bedding material is another area that is getting some attention. Herbal medicine is considered an important component for boosting economy of Nepal (Kaphle et al., 2007). Even the worst offender genus *Mikania*, where out of 450 species 55 of them provide over 300 different chemical compounds, among terpenes and derivatives, some alkaloids, saponins, sterols and flavonoids. From its extensive use as herbal medicine, it was identified several of these compounds as being of highly pharmacological interest due to its actions. Besides the activities already identified other actions were not tested yet, once new studies are carried out it may indicate other interesting features of the molecules already extracted from this genus. The high variability in *Mikania* composition among different species and batches may contribute to equally high variability in activity. In the future, widespread interest in *Mikania* genus seems certain to ensure continued research with this herb. Moreover, interdisciplinary research and the development of modern combinatorial techniques make possible the discovery of novel agents from these species (Rufatto et al., 2012). The situation where food and feed deficit is grave on one hand makes the equilibrium favorable for maximum use of IAS. However, the antinutrients, palatability issues and above all economics of harvest need to be addressed. Given the scenario, livestock raised by communities around protected and community forests that have seen the destruction by IAS can serve as controlling means. Research, training on value addition, and trans-sectoral approach is a must if we are to control IAS. Does IAS have potentialities to assist in soil, water air purification, especially in heavy metal contaminated soils is another area worth investing. Hence, IAS do livestock have any role to introduce and does it provide solution to utilize is something this paper aims to discuss.

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Implementing Management of Invasive Alien Species: Learning from Global Experiences with Invasive Plants to Optimize the Way Forward

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Abstract

Invasive alien species (IAS) are now recognised as one of the major agents of global change. However, efforts at management (here considered to include prevention and control), and the success of these efforts, have at best been patchy in most regions across the globe. Thus IAS poses a serious threat to agriculture and the environment in most countries. The basic general tools (awareness raising, risk assessments, mechanical, cultural, biological etc) being employed for IAS management have been in use by many countries since the first part of the 20th century; these tools have largely been developed in the agricultural sector for crop protection. The underlying principle of the tools is sound; the main problems for the management of IAS have been in the lack of frameworks for support for tool development and in the adaption and application of one or more tools against particular IAS. Here, scientific issues surrounding control tools are reviewed and discussed with a focus on experiences of invasive plants, particularly the South American species, *Mikania micrantha*. This review is used to suggest optimal paths forward to improve the use of management methods at local and national levels.

Keywords: Management; invasive alien plants, factors driving invasions, adaption of control methods, cultural control, mechanical control, biological control.

Introduction

The basic general methods and tools potentially appropriate for the management of IAS have been known for a long time and these were largely developed in the agricultural sector for crop protection mostly during the second half of the twentieth century (Wittenberg and Cock, 2005). These methods and tools commonly cover: prevention, surveillance and control (including eradication). Many aspects of some of these tools are covered in guidelines under the International Plant Protection Convention (IPPC) of FAO for plant health in agriculture: the International Standards for Phytosanitary Measures (see www.ippc.int). These tools are underpinned with much research over the years and are quite 'sound' scientifically and technically. Nonetheless, there are issues in achieving effective management of many IAS both at local and regional scales in many parts of the globe because of the complexity of invasions and the wide range of sectors affected (see for example, Mooney and Hobbs, 2000). The constraints fall into two main groups: the lack of comprehensive response and management frameworks and policy at national and regional levels (for example, India - Reshi and Khuroo, 2012); and the full and correct (i.e. technical and socioeconomic) assessment of the suitability, adaption and application of one or more tools against particular IAS and this is in despite there being guidelines available on this topic (see for example, Bhagwat *et al.*, 2012). The first of these subjects was covered on day one of the conference; here the focus is on the second of the above topics and specifically those related to the 'control' part of the management spectrum. So we will address species that have already invaded; the focus is also on invasive plants to exemplify the issues.

Scientific, technical and socioeconomic issues

Looking at the control tools commonly discussed or in use against invasive plants there are Wittenberg and Cock, 2001):

Physical controls – usually the most common method used by farmers; e.g. hand weeding, digging, cutting and slashing. For example, these form up to 60% of total pre-harvest labour input in sub-saharan Africa;

Herbicides - most pesticide use globally is directed at weeds native and alien; over 47% of the world market in pesticides comprise of herbicides;

Habitat management – the burning and grazing of habitat are quite common in the developing world;

Utilization – the economic exploitation of the biomass of invasive plants. The use of this activity is very patchy across the globe but there is much discussion on the topic and some research;

Introduction biological control – use of introduced host specific natural enemies (herbivorous insects or plant pathogens) from the area of origin of the IAS. There has been some use of this technology in developing countries.

These tools have been applied with little regard of the nature of invasive alien plants. So what are the general experiences of these efforts? Taking the controls in the same order as above, in general:

Physical controls – these can be effective on a very local scale but major problems occur with invasive plants that reproduce vegetatively, for example the accidental spread of cut stems after cutting (for example, Wang *et al.*, 2003). There are also issues of the time inputs needed to apply these type of controls and the impacts on overall rural livelihoods;

Herbicides – the main problems are the high cost of the chemicals which are usually beyond the means of most rural poor and also the non-target impacts of herbicides (Herrera-Estrella, 2000);

Habitat management – some of the major invasive plants that affect agriculture and protected

areas, e.g. *Mikania micrantha*, are fire adapted and fair better in disturbed habitats (Swamy and Ramakrishnan, 1988);

Utilization – overall the commercial uses are limited and there are no examples of sustainable full scale exploitation but nonetheless some plants are being used on a local scale, e.g. water hyacinth (*Eichhornia crassipes*) in Indonesia. More importantly, local use will not result in ‘control’ and there is also a real danger of encouraging the growth and spread of species (Ramakrishnan, 2001);

Introduction biological control – this technology has been highly successful in some countries, especially in developed countries (e.g. Australia) but there have also been failures. Success at control is largely (but not always) linked to the amount of baseline research on the target (e.g. correct identification of the source population) and the efficacy of natural enemies before releases (there are many reviews of biological control but one the best is on weed biological control in Australia – Page and Lacey, 2006; also see Hong et al., 1999 and Bhagwat et al., 2012).

Overall, the central problem is that the application of control tools and methods that is undertaken is done without regard to the nature of the biology of the invasive alien plant under target, the scale of the invasion or the landscapes invaded. This is not the fault of those trying to clear their land or resource from an invasive species as sound advice is often lacking or misleading. A fundamental problem, which is emerging, is the complexity of the biology of invasions and the factors that drive the invasions. Frequently control tools are used that do not target the root causes of an invasion and indeed, some control tools can actually exacerbate invasions such as cutting and removal; as we have seen, some invasive plants can regenerate from small cuttings such as *Mikania micrantha* (Wang et al., 2003).

Needs to achieve effective invasive plant management

Important information that can be used to optimize strategies for the control of invasive plants can learnt from studies of the biology of the invasions (Rejmánek et al., 2005). Over last few decades much if this has come from scientists working in the environment sector. We need to look at factors important for the growth of the populations and for their dispersal to new areas.

Growth of populations

A number of ideas have been published to ‘explain’ the biological invasions of some introduced species and a number of factors have been implicated (Daneshgar and Jose, 2009). These will not be reviewed here but to summarize, it is now recognized that a combination of factors are involved. Dominant among these are:

- The relative diversity of natural communities under threat. There is a body of theory that suggests that diverse plant communities are less prone to invasion. Whether or not this is true, the fact remains that many natural communities are now ‘disturbed’ or degraded through human activity, e.g. cutting, burning and grazing, and these are open to invasion. Agricultural systems form a special case but as many are relative ‘monocultures’, they tend to be at high risk from invasive plants;
- Several major invasive plants are allelopathic (Chengzu et al., 2011) which means they can kill neighboring native plants which might compete for resources and space;
- Introduced species generally lack coevolved host specific natural enemies in the area of origin and this absence contributes to the free growth of the plants in the introduced ranges (Daneshgar and Jose, 2009).

Dispersal

This is an important part of the invasion process. Many authors have suggested that high 'propagule pressure' is a major determinant of invasion 'successes' (Lockwood *et al.*, 2005). In real life many invaders have good natural dispersal mechanisms but now human - mediated pathways and vectors are important and helping invasive plants to move around at faster rates than they would naturally. Of course, much of the human movement of plant material is not intentional.

As can be seen, the human dimension is dominant in unwittingly exacerbating alien plant invasions and is now a major factor that needs to be taken into account when designing control options. Thus for effective control we need to target factors driving invasions and usually human factors are dominant. To identify such factors it is important to examine the pathways and vectors of spread, the nature of the landscapes invaded and other factors such as the role of natural enemies in the area of origin of the IAP. Single based control solutions are only likely to work under limited conditions; e.g. in the case of all the major invasive plants, a variety of landscapes are invaded (e.g. agricultural, protected areas) and it is not necessarily the case that not all the control methods available will be suitable for all landscapes. Thus there is a need for 'integrated controls' (Wittenberg and Cock, 2005), based on key factors driving the growth and dispersal of populations. But as a large part of the population affected by invasive plants are the rural poor, the components of integrated management need to be appropriate for these 'end users'. In other words we need to aim for engagement of these communities in strategies and plans for control and the controls need to be affordable and thus low technology. It is also frequently the case that the communities themselves have some existing technologies available from traditional knowledge

but have not been widely spread to other communities.

There are published guidelines on appropriate control tools and methods for invasive alien plants but these are not widely publicized to the stakeholders who need the information the most.

To illustrate some of these points, we will turn to the case of the highly invasive plant, *Mikania micrantha*. This Neotropical species was introduced into Asia early last century (Choudhury, 1972) but has now become a major problem in many countries; e.g. India, China and here in Nepal.

The case of *Mikania micrantha*

Let us start with a brief review of the ecology and biology of the plant. Much has been written on this (see for example Tripathi *et al.*, 2012). This perennial climber vine has a very wide distribution in its native region in South America and Caribbean. It largely inhabits damp to wet habitats where there is water for a reasonable length of the season. It is now known from molecular analysis that there are several 'biotypes' of the plant present in South America but these are not incompatible. Reproduction is either sexual or asexual (vegetative), the former by seeds at prolific levels and the latter largely from rooting from stem nodes which end up as ramets and/or perennating rosettes. During the growing season (normally during a rainy season) individual plants can grow very fast – almost several centimeters per day resulting in over 40 cm in one week. *Mikania micrantha* is also known to have allelopathic properties and is fire adapted. New plants in burnt habitats can uptake nutrients (e.g. nitrogen, potassium and phosphorus) very efficiently when these are abundant. Finally, several studies have shown that there are many coevolved natural enemies present in the native range of the plant and it seems that these cause heavy mortality.

What have been the implications of the ecology and biology of the plant in the regions that it has been introduced? The first is that, given the plant's wide tolerance of environmental conditions, the plant has been able to spread into several types of habitat, agricultural and natural, that are generally damp in nature. Much habitat is now burnt extensively in rural areas in Asia and this creates ideal conditions for *Mikania* growth; and the allelopathic properties of the plant have almost certainly helped it survive and spread in some areas. In many rural areas, the main attempts at control are by cutting and pulling out; material is also transported over various distances for disposal. This activity is very likely to have contributed to the spread of the plant because as we have seen, it can grow vegetatively from small sections of stem which get dropped unwittingly by farmers and field workers. Many natural enemies (invertebrate herbivores and pathogens) have been recorded from the plant in Asia but none have been reported as causing mortality of any significance. Finally, it is also known from the molecular studies referred to above that there have been several separate introductions of the plant into Asia that form distinct biotype populations at the genetic level.

Most effort at controlling this plant to date has been done by: rural people using mechanical controls with little guidance from natural resource advisors or extension services; by forest departments using herbicides; and biological control by a few countries but this has been relatively recent. The first two efforts have largely been unsuccessful in all countries where these activities are going on. Mechanical controls fail for the reasons given and from the fact that the plant can survive through perennating rosettes. Herbicides fail for the same reasons and thus need to be re-applied in successive seasons thus costs become prohibitive. Biological control efforts, through the use of host-specific natural enemies, failed initially for a number of reasons including not the full understanding of biotypes but more recent

attempts are now beginning to produce results as we shall see below.

Thus the situation with *Mikania* illustrates the need to develop integrated control measures based on the biology and ecology of the plant. From what we know about the plant, the following general components for control would be important in the short to medium-term:

1. Assessment, monitoring, evaluation and awareness-raising. The important activities here would be impact assessments (where these have not been done although a reasonable amount is now known about the impacts of *Mikania*). Mapping is to establish 'baseline' conditions for interventions and for surveillance awareness-raising with stakeholders. Much of this would be done at an institutional level; by appropriate government institutions or relevant NGOs. This information would be important to justify further actions involving controls.
2. Addressing the burning of habitats. From what is known about the ecology of some major invasive plants from South America, it is important to attempt reducing burning regimes in grassland and forest areas. This will be especially important in natural habitats/protected areas. One idea would be to introduce rotational burning every two - three years but this would need to be balanced against the regeneration of important natural grasses and herbs and local needs. However, clearly such moves would need the full engagement and awareness of local communities and forest department personnel as it these stakeholders who largely contribute to the annual burning of habitats.
3. Physical controls including use of these methods in agricultural areas. These types of controls are important for small areas that need to be

kept clear of *Mikania*. But given the issues already mentioned, physical controls need to be implemented with care including careful removal for disposal because of the danger of cuttings being dropped.

In the longer term, the use biological control through the use of coevolved host specific fungal pathogens from the native range of *Mikania* would be important. Briefly, the history of this is as follows. In the late 1970s though to the early 1990s attempts were made to utilize insect herbivores – a thrip, *Liothrips mikaniae* was released in the Solomon Islands in Malaysia but the efforts failed because of heavy predation of the thrip by local natural enemies in the Old World (Cock *et al.*, 2000). But in 1996 fungal pathogens were first investigated for the control of *Mikania* for India but the work extended to other countries in later years. From pathology surveys in the Neotropics, the rust fungus *Puccinia spegazzinii* was selected for further investigation (Ellison *et al.*, 2008).

In summary, several rust isolates have been collected in native range of *Mikania* and these have been tested for virulence against the invasive weed populations in the various countries. Understanding the differences in the virulence of these isolates and their suitability for different climates has been very important part of the studies. Studies and risk assessments have also shown these isolates of the rust to be highly host specific; 200 plant non-target species have been tested. Overall, results showed that the isolates could only infect a few species in the genus *Mikania*, including the east Asian native *Mikania cordata* but this last species was considered by participating countries not to be important economically compared to the threats of *Mikania micrantha*.

A number of release projects of the rust have been undertaken: some successful, others not so to date.

The successful release of individual isolates have been made in Taiwan by Taiwan National University in 2008 and in Papua New Guinea (PNG) and Fiji in 2009 under an ACIAR-Australia funded project; in all three countries the rust has established and spread (for PNG and Fiji see Day *et al.*, 2013). In PNG there is a rust monitoring and evaluation programme where three sites in East New Britain have been evaluated on monthly basis. The rust has been released at 550 sites in 15 provinces and has established in 12 of these; the establishment rates have been better at higher altitudes than in lowland areas. In some areas it has spread up to 40 km. Also, as predicted, the rust infects *Mikania cordata* in PNG but there have been no other non-target impacts.

The factors identified as leading to the success of these releases have included: the projects being well resourced; properly designed release strategies - large numbers of plants (100's) put in the field, at many sites and in different habitats; and also a dry season adapted rust isolate used in all these cases and all three countries experience a dry season. The lack of some of these factors has also been suggested for the release failures in other countries.

Conclusion

IAS plants are an increasing threat to countries and this especially so in the developing world where resources and expertise to address the issues are scarce or completely lacking. Of those affected by invasive plants, rural communities are the most vulnerable because the resources they rely on for livelihoods are at high risk from the invasions. Many communities have been attempting 'control' but with little or no help from government or NGO institutions because these same institutions lack the relevant expertise.

Control tools and methods for 'weed control' are well known in the agricultural sector and were

developed during the course of the last century. However these controls need to be adapted in relation to the factors driving invasive plant invasions. There are published guidelines and advice on methods for invasive plant control based on traditional methods of weed control but this information is not widely publicized. These factors need to be taken into account in the strengthening or development of national comprehensive response and management frameworks to address the threats of IAS.

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ABSTRACTS

(The following pages contain abstracts for papers which were presented at the conference, but for which the authors have chosen not to prepare a full written paper.)

Patterns of Plant Invasions: A Synthesis at Multiple Spatial Scales

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In an arena of global change biology, alien species invasions are considered to be the second major driver of biodiversity loss, after habitat destruction. More worryingly, recent scientific evidences have established the detrimental impacts of invasive alien species (IAS) on ecology, economy and public health. As a scientific response to address these mounting risks of invasions, documentation of the IAS at local, regional and global scales has emerged as one of the priority areas of research because it can offer practical insights in the development of systematic management strategies. It is in this backdrop that here we present a synthesis of the patterns of plant invasions at multiple spatial scales, using a standard terminology and methodology. Starting from the provincial scale, an operational characterization of invasive alien flora and management of plant invasions in Kashmir Himalaya is described. Then, up-scaling to the Jammu and Kashmir state, the taxonomic, biogeographical and altitudinal patterns in the alien species in relation to native ones are explicated. Expanding to the scale of country, an integrated research and policy framework on plant invasions for India is outlined; and main results and management implications of a recently published inventory of alien flora of India are discussed. The critical role of correct taxonomic identification and updated nomenclature, particularly synonymy, in the scientific inventory and management of IAS is underscored. Finally, at the global scale, the pooling together of regional data and management expertise to meet the challenge of plant invasions in world's mountains is described. Looking ahead, adoption of such a multi-scale approach will help in stemming the tide of biological invasions with wide implications for biodiversity conservation and sustainable development.

Invasive Plant Problems and Need for Risk Assessment in India

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Invasive plants include weeds and cultivated species, which cause detrimental effects on agriculture as well as natural habitats. Introduced species are the principal threat to the Indian ecosystems and several species of alien plants are seriously damaging native habitats and threatening native species in the ecosystem. *Chromolaena* invasion in Tenmailai region of Javadi hills in northern Tamil Nadu replaced several plant species and threatens the existence of thatch grass (*Cymbopogon* sp.). *Lantana camara* invasion replaced several forage grasses in terrestrial ecosystem including plains and hilly regions, waste lands, open forests etc. This is even reported to be the chief problem for shortage of fodder in Tamil Nadu consequently which led to the failure of milk producers cooperative at that place. Similarly, *Mikania micrantha*, another invasive weed popularly known as 'Mile-a-minute' is creating havoc in most of the plantation crops in Kerala. Every vegetation including tall trees is covered with a thick canopy of *Mikania* in the entire north-east region of India. *Prosopis juliflora* is yet another exotic species that invaded the waste lands and abandoned housing sites. Reclamation of lands invaded by this species either for agricultural or house construction is cost prohibitive thereby causing serious economic losses. *Parthenium hysterophorus* invaded in most of the urban waste lands and agro ecosystem causing serious problems to human and animal health. Water hyacinth (*Eichhornia crassipes*) is another glaring example of invasive species, which threaten the fresh water ecosystem causing serious economic losses for fish production, navigation and irrigation system. An estimated 8000 species of plants are believed to behave as weeds in agriculture, out of which about 250 species are considered to be potentially dangerous. In the era of free trade and globalization, it is a herculean task to keep these weeds at bay. Risk assessment is a tool that can be used to support the exclusion of potential invasive alien species from being introduced, as well as to assess the potential impact of those invasive species that have already become established. The risk assessment is a question based scoring system containing 49 questions. The questions include plant's climatic preferences, biological attributes, reproduction and dispersal methods. The risk assessment uses the responses to the questions to generate a numerical score that is positively correlated with weediness. The assessment also indicates whether a species may be a weed of agriculture or the environment by a grouping of characters commonly found in weeds of these ecosystems. In the past five years approximately 50% of the 672 species assessed have been accepted, 30% rejected and remaining require further evaluation. The risk assessment system with explicit scoring of biological, ecological and geographical attributes is a useful tool for detecting potentially invasive weeds in other areas of the world.

Monitoring and Control of Invasive Species in the Grassland Ecosystem of Manas World Heritage Site, India

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Manas World Heritage Site (MWHS) is located at the foothills of Eastern Himalayas in Baksa and Chirang districts (26°35'-26°50'N, 90°45'-91°15'E) of Assam province of northeast India. Grasslands cover about 30% of the MWHS and provides important habitat to one-horned rhinoceros, swamp deer, hispid hare, pygmy hog, hog deer, Asiatic wild buffalo, Asian elephant, tiger and Bengal florican. Due to its unique geographical location it is the only place in Asia, where such many grassland dependent species can be found in a single habitat. However, existence of these species is dependent on upon survival of good grasslands. Invasive species, uncontrolled burning and livestock grazing are the main threats to grassland of Manas.

The invasive alien plants *Chromolaena odorata* and *Mikania micrantha* are among the world's most invasive plants. There has been a strong recommendation from UNESCO for development and implementation of a invasive species management plan for Manas. Keeping this in mind, a study has been initiated since November 2013 with the following objectives- i. *Baseline data collection and mapping*; ii. *Establishment of surveillance scheme*; iii. *Implementation and validation of immediate control measures* and iv. *Institutionalization of monitoring protocol in the management practice*. In this abstract we discuss the preliminary results for objective No. I.

A systematic grid based (2 × 2 km) approach was followed to survey the presence and intensity of invasive plant species in grassland of MWHS. Each grid was surveyed intensively with the help of a five person team. *Chromolaena odorata* and *Mikania micrantha* are two major IAPs identified in MWHS. GPS co-ordinates of presence of *Mikania* and *Chromolaena* were recorded. Furthermore, the spread of each species was classified as: 1-3, 3-5, 5-10, 10-20, 20-50 & >50 m radius plot and the areas with high intensity of invasion was mapped in the field using *GPS map 62s*. Preliminary results showed that 205.1 hectare area of grassland has been completely invaded by *Chromolaena* (where not a single blade of grass was found) in the southern boundary of central and eastern range of Manas. In addition to that, the invasion of both *Mikania*

and *Chromolaena* found to dominate along roadside within MWHS. It has been observed that *Chromolaena odorata* invasion is greater in a stretch of 1–2 km along the southern boundary of the Park.

It is now widely accepted that the control of alien invasive species is not a short-term or isolated effort. It requires the long-term application of efforts aided by constant monitoring and investigation. Some of the major outcomes of this study are- identification of most vulnerable area under threats of invasive species, rate of invasion, impact of invasive species on the distribution and abundance of grassland obligate wildlife like hog deer and successful in setting up of controlled plots.

The Current and Potential Geographic Distribution of Invasive Parthenium Weed in South Asia

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Parthenium hysterophorus L., commonly known as parthenium weed, is an invasive weed of global significance that has become a major weed in South Asia and many other parts of the world. Within South Asia, this invasive weed is threatening natural and agro-ecosystems, and the Indo-Pak subcontinent is the area badly affected. In Pakistan, parthenium weed is now present in all States. Studies conducted prior to 2000 indicated that parthenium weed was only present in the northern districts of the Punjab. However, a 2010-11 and 2013 survey has shown the distribution to have increased rapidly spreading from the northern to the southern districts of the Punjab Province, and more recently into the Sindh and Azad Jammu Kashmir Provinces. A process based predictive model, CLIMEX has been developed for the current and potential distribution of parthenium weed in South Asia. The current distribution of the weed in South Asia lies well within the projections provided by this predictive model. The model indicates that there are many more areas within South Asia that are suitable for parthenium weed growth, both under the present and under a future climate. This model demonstrates that the northern regions of Pakistan, the whole of Bangladesh and Sri Lanka, the southern parts of India, Nepal and Bhutan are also highly favourable for the growth of the weed. The model also predicted that the southern regions of Afghanistan are also climatically suitable for weed growth. Another model run to simulate climate change scenario (+3 °C) indicates that parthenium weed could expand its range in to the northern regions of India, Pakistan, Nepal and Bhutan, while southern regions of these countries would become less suitable. When an irrigation scenario was laid over the CLIMEX model, more parts of the subcontinent (especially within the Indus river basin) became suitable for parthenium weed growth. These studies suggested that parthenium weed has not yet reached its full potential range and is likely to undergo a range expansion and become more aggressive in the future under climate change, hence this weed deserves a regional effort to stop its further spread and reduce its presence in already invaded areas

Distribution, Spread and Status of Parthenium Weed and its Biological Control Agent in Nepal

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Biological invasion has threatened native biodiversity and ecosystem process worldwide. Parthenium weed (*Parthenium hysterophorus* L., Asteraceae), a native of central and south America, is a noxious invasive weed of global significance which has created environmental, economic and health problems. In Nepal, the history of introduction is nearly of five decades old but the weed has only started spreading rapidly in the last two decades. Despite increasing negative impacts on biodiversity, pasture and crop productivity, and human and livestock health, the management strategy planning for this weed has been limited by the lack of geo-referenced data on distribution and abundance. We conducted a nationwide survey of the parthenium weed and its biological control agent the leaf feeding beetle *Zygogramma bicolorata* Pallister in the 2013 monsoon season within roadside vegetation. During the survey 762 locations were examined for the occurrence of the weed and the beetle, for the abundance of the weed, and for the damage inflicted by the beetle on the weed. The survey of both the weed and the beetle was followed by CLIMEX modelling for the climatic suitability of both the weed and its biological control agent in Nepal. The survey revealed that both the weed and the beetle are already widespread, with former in the front and the later lagging behind. The distribution pattern of the weed also indicates entry through multiple sites from India. The weed is more frequent in Terai and Siwalik than in Mid Hills with invasion in estimated 8,000 ha area under diverse land uses with the highest frequency on the grazing and fallow lands, followed by agro-ecosystem. The weed has also entered into all six protected areas of the Terai and Siwalik regions. Vehicle movement, including transport of construction machinery and road works, agriculture products, livestock, and water movement are thought to be the main means of seed spread. The CLIMEX projection has revealed the presence of additional areas in Mid Hills which are climatically suitable for parthenium weed. While the frequency of the beetle was relatively high in Terai, Siwalik, and the central region of Mid Hills, the damage inflicted to the weed was insignificant at 57% of the locations due to small populations of the beetle. Since the current distribution of the beetle is well within the climatically suitable region, as projected by CLIMEX modelling, populations of the beetle are likely to increase in the future with appreciable damage to growth

and fecundity of parthenium weed. This natural building of populations can be complemented by the mass rearing and release into climatically suitable locations where parthenium weed is present but the beetle has either small populations or is altogether absent. Given the widespread distribution, management of parthenium weed is already a challenge. As an immediate response, the management of the weed can focus on preventing further spread and reducing its negative impacts. Successful implementation of these strategies largely depends on community participation at local level and effective coordination among concerned Departments of the Government at national level.

Plant Species Composition and Soil Seedbank in *Parthenium hysterophorus* L. Invaded Grassland of Hetaunda, Central Nepal

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Parthenium hysterophorus L. (Asteraceae; common name: parthenium weed), a native of South and Central America, is an invasive alien weed of global significance. Impacts of the invasion by this weed on the herbaceous plant species richness and composition, and its abundance in the total germinable soil seedbank were monitored for two years in a grassland of Hetaunda Municipality. The study also dealt with the impacts of defoliation caused by the leaf feeding beetle *Zygogramma bicolorata* Pallister on the germinable soil seedbank density of *P. hysterophorus*. Field sampling included vegetation and soil sampling. The vegetation samplings were carried out in September and the soil samplings in October for the two successive years 2009 and 2010 representing 1st and 2nd year of defoliation by *Z. bicolorata*, respectively. A total of 30 transects, 10 in each of the three study sites, selected subjectively were sampled. On each transect, 3 quadrats of 1 m × 1 m were sampled in such a way that they represented >90%, 40–60% and 0–10% cover of *P. hysterophorus*, indicating high, medium and low levels of weed infestation, respectively. Altogether 90 quadrats (3 on each of the 30 transect) were sampled. In each quadrat, vascular plant species richness, density of *P. hysterophorus*, its coverage, maximum height and the coverage of other species were recorded. For the estimation of germinable soil seedbank density, soil samples were collected from the plots having high infestations of *P. hysterophorus* at two different depths (0–5 cm and 5–10 cm) by using soil core sampler. The collected soil samples were then kept for germination in greenhouse for eight months and soil seedbank was estimated by counting germinating seedlings. Density of the weed in plots with high infestation was 433 stem/m². There were no significant difference in the herbaceous plant species richness at different levels of *P. hysterophorus* infestation but we found change in the species composition. The soil seed bank density of *P. hysterophorus* was 11084 and 10716 seed/m² in 2009 and 2010, respectively, and the weed contributed 4/5th of the total germinable soil seed bank. We did not find significant change in the germinable soil seedbank density measured for 2009 and 2010. The study suggests that *P. hysterophorus* invasion is affecting the species composition of grassland. Defoliation caused by the *Z. bicolorata* has not been effective in reducing the soil seedbank density owing to the recent event and persistent nature of its soil seedbank. Thus, for effective control of the weed, classical biological control has to be complemented by other management approaches.

Effect of Invasive *Mikania micrantha* on Greater One-Horned Rhinoceros Conservation in Chitwan National Park, Nepal

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Mikania micrantha is a multi-branched scrambling highly invasive perennial vine belonging to family Asteraceae and is native to Central and South America. This weed was accidentally introduced in Chitwan NP in mid 1990s and posing threats to rhino and native biodiversity. However, there have been very limited studies across globe on impacts of invasive plant species on native fauna. Therefore, to understand how the rhinos have been affected by the invasive *Mikania* in Chitwan eight adult rhinos were radio-collared and intensively monitored. Fine *Mikania* distribution map was prepared on ArcGIS by using intensive ground survey data (N = 2,696 plots in 63 km² area). Daily tracks of rhinos during peak foraging hours were buffered (15 m both side) and overlaid on the *Mikania* habitat map. Compositional analysis was performed to see how the rhinos were preferring *Mikania* invaded and non invaded habitats during foraging peaks. Data generated from clipped quadrates (N = 50) within the vegetation grazing exclosures (n = 10) were used to estimate species richness and biomass production at different level of *Mikania* invasions. The results showed that 21% of the study area was free of *Mikania* invasion, 49% of the habitat had mild level of invasion (<20%), 23% had intermediate level of invasion (20–40%) and 7% of the habitat had severe invasion (>40%) of *Mikania*. There was a negative effect of *Mikania* especially on grasses, herbs, shrubs and small trees. Simple linear regression equation depicted that with the increment in the percentage cover of *Mikania*, the biomass (Native biomass (gm) = 6819 (±290.3) - 74.22 (±7.4) * % of *Mikania*; R² = 0.68, p < 0.0001) and percentage cover of native forage plants (% Native cover = 79.80 (±1.7) - 0.87 (±0.1) * % *Mikania* cover; R² = 0.89, p < 0.0001) of rhinos decreased significantly. Species richness reduced significantly as *Mikania* cover increased (F_{4,22} = 10.10, p < 0.0001) and the effect was very severe after 80% coverage of *Mikania*.

Habitat preference during foraging peaks was decisively for lower percentage cover *Mikania* across all seasons: i) Annual preference ($\chi^2_{(6 \text{ df})} = 115.27, P < 0.0001$) was 10–20% > 20–30% > 1–10% > 0%

> 40–50% > above 50%. ii) The cool dry season preference ($\chi^2_{(6 \text{ df})} = 64.55, P < 0.0001$) was 10–20% > 20–30% > 30–40% > 1–10% > 0% > above 50% > 40–50%. iii) The hot dry season preference ($\chi^2_{(6 \text{ df})} = 67.39, P < 0.0001$) was 10–20% > 1–10% > 20–30% > 0% > 30–40% > above 50%. iv) The order of preference for the monsoon season was same ($\chi^2_{(6 \text{ df})} = 75.56, P < 0.0001$) as of hot dry season. This preference to lower invaded habitat was correlated with the availability of rhino food plants. *Mikania* invasion was detrimental to rhino forage availability by reducing native forage diversity and biomass. *Mikania* was likely to affect all ungulate populations and have cascading effects affecting all higher trophic levels.

Antimicrobial Activities and Phytochemical Screening of Leaf Extract of *Mikania micrantha* H.B.K

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Antimicrobial activity and phytochemical screening of the leaves of invasive alien plant species *Mikania micrantha* was carried out. Pathogenic bacteria *Bacillus cereus*, *Enterococcus faecalis*, *Escherichia coli*, *Klebsiella pneumonia*, *Proteus mirabilis*, and *Staphylococcus aureus*; and phytopathogenic fungi; *Alternaria brassicae*, *Botrytis cinerea*, *Fusarium oxysporium*, *Phytophthora capsici*, and *Sclerotium rolfsii* were used for microbial study.

Aqueous and methanolic extracts of *Mikania micrantha* at five different concentrations viz. 50 mg/ml, 100 mg/ml, 150 mg/ml, 200 mg/ml and 250 mg/ml were tested on the bacteria and fungi. The antibacterial properties of secondary metabolites of *M. micrantha* has been tested by using disc diffusion method by taking the Zone of Inhibition (ZOI) on 24 h of incubation; while antifungal activities were tested by Poisoned food technique, measuring the linear mycelium growth on the 7th day of culture for fungi. *In vitro* antibacterial and antifungal activity were screened by using Nutrient Agar (NA) and Potato Dextrose Agar (PDA) respectively. The qualitative phytochemical analysis depicted the presence of saponins, alkaloids, glycosides, flavonoids, and tannins in the leaf.

For fungus, the reduction of mycelium growth was significantly effective for methanol at all concentrations of *S. rolfsii*; but for *P. capsii*, aqueous extracts was significantly more effective only for 100% concentration, while for *A. brassicae* aqueous extracts was significantly more effective for both 100% and 250% concentration while for *F. oxysporium* and *B. cinerea* aqueous extracts was significantly effective for only 200 % extract's concentration. Similarly, significant result was obtained in all concentrations of aqueous and methanol extracts in determining the Zone of Inhibition for the test bacteria. The mean ZOI at 250% for *K. pneumonia* was found highest (11.5 mm) in distilled water and 18.5 mm in methanol for *E. faecalis*. Results showed broad spectrum antimicrobial activity against the Gram-negative and Gram-positive bacteria. Methanol extract was found more effective in inhibiting the growth of test microorganisms than the aqueous extract. The results obtained shows that *M. micrantha* has both antibacterial and antifungal properties.

Germination Response of Fallow-Land Plant Species of Central Nepal to Allelopathic Effect of *Parthenium hysterophorus* L.

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Allelopathic effect is one of a few strategies by which invasive alien weeds out-compete the native species. The effect of aqueous extract of *Parthenium hysterophorus* L. (Asteraceae) on the germination of the fallowland plant species were analysed. Altogether 59 seed samples (41 plant species) were collected from the five study areas (Kathmandu, Hetauda, Chitwan, Butwal and Pokhara) in 2009 and 2010. They were kept for germination in 5% aqueous extract of leaf and inflorescence of *P. hysterophorus*. Germination of 21 plant species were either very low (<33%) or none at all in control; therefore they were excluded from the analysis. Out of the remaining 20 species, 6 were sensitive species (i.e. high reduction in seed germination; e.g. *Amaranthus spinosus*, *Calotropis gigantea*, *Urena lobata*), 3 moderately sensitive (e.g. *Cynoglossum lanceolatum*, *Solanum nigrum*, *Solanum xanthocarpus*), and 11 tolerant (e.g. *Bidens pilosa*, *Cassia tora*, *Hyptis suaveolens*) to the inhibitory effect of the aqueous extracts. All plant species of the resident vegetation, therefore, were not equally sensitive to allelopathic effect of *P. hysterophorus* extract on seed germination. The alien weed species appeared to be more tolerant to allelopathic effects of *P. hysterophorus* than native plant species.

Invasive Alien Fauna of Nepal: Problems and Future Perspectives

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Invasive alien species (IAS) occur in all major taxonomic groups such as micro-organisms, fungi, plants, invertebrates, fish, amphibians, reptiles, birds and mammals. These species are introduced either accidentally or intentionally by human agencies. Problems resulting from introduction of IAS have become serious global issue for the last few decades. Although invasion by alien species has been considered as one of the major conservation threats, scientific studies based on systematic approach are still lacking in Nepal particularly for fauna. Studies on plant invasive species have been comparatively well initiated than the faunal invasive species. Among the top global invasive species faunal group contain higher (56 percent) than the plant (36 percent) and rest are fungi and microorganism. Till date there are 27 alien fauna reported from Nepal including some well established species. Few examples of such species are African Giant Land Snail *Lissachatina fulica*, Veronicelid Slug *Laevicaulis alte*, the Marsh Slug *Deroceras leave*, insect pests - Potato Tuber Moth *Phthorimaea operculella*, San Jose Scale Insect *Quadraspidiotus perniciosus*. They are becoming serious threats for native fauna as well as commercial crops. The present paper deals with all known introduced faunal species and highlights the impacts of some most damaging invasive fauna of Nepal.

Environmental Bad to Good: Exploitation of *Mikania micrantha* for Compost

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This study examines the possibility of making compost from *Mikania micrantha* aiming to reduce the cost of manual cutting and encouraging farmers to involve in the removal of vines. An experiment was carried out using three composting techniques including pit, heap and vermi-composting in Chitwan District of Nepal. Two types of materials were prepared for composting - *Mikania* only, and mixture of *Mikania* and other vegetation. The results suggest that *Mikania* can be used to produce compost mixing with other native vegetation. Heap method produced more effective results compared to other two methods as *Mikania* has high moisture contents. The reports of lab test indicate that *Mikania* manure has 0.6–1.9 % nitrogen, 0.6–0.5% phosphorous and 0.2–2.5 % potassium. These values suggest that *Mikania* compost are nutritious to plants similar to other bio-fertilizers including animal manure. Higher nutrients concentration and fast decomposition was observed in the mixed vegetation treatment compared to *Mikania* only. Mixture of *Mikania* and other native vegetation also helps to lower the allelopathic effects. This study concludes that open semi pit (*Malkhad* in Nepali) nearby cattle shed is more suitable strategy to prepare the compost, however, a cautious is required not to spread the vines in other places.

The Biology and Management of *Mikania*: An Impact Assessment on Crop Production Systems in Viti Levu, Fiji

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The purpose of this study was to assess the current and potential impacts of *Mikania* on crop production systems in Viti Levu, Fiji. To help such an assessment, the distribution and infestation density were assessed, as were aspects of its asexual and sexual reproductive biology, the germination and establishment requirements of its seeds and the soil seed bank dynamics of the weed were investigated. In addition, farmers' views on its management and potential losses caused by *Mikania* were also assessed. The distribution survey demonstrated that *Mikania* is widespread in Viti Levu and is to be found in 18 other islands in Fiji. A study on the growth potential of the vegetative stem sections of *Mikania* revealed that long stem sections ($\geq$ two nodes) had a greater chance of survival than shorter stem sections. Mature *Mikania* stem sections (with nodes) had a greater chance of survival than young stem sections when buried horizontally or vertically with a node exposed. A study on the sexual reproductive capacity of *Mikania* revealed that the flowering season in Viti Levu occurs between April to September coinciding with the cool, drier period of the year which presumably favours insect pollination. It was found that the honey bee (*Apis mellifera* L.) was the most frequent insect floral visitor. The number of seed produced in each flower head (capitulum), ranged from one to seven with the highest proportion of capitula (95%) carrying four seeds. The number of viable seed produced per m² was determined to be 90,825 and 98,134 for the high and the moderate rainfall regions, respectively. When determining the conditions for germination, it was found that the optimum constant temperature was in the range of 14 to 29 °C, with between 87 to 94% of the seed germinating in this temperature range. Under alternating temperature regimes, *Mikania* seed germination was best at 30/20 °C (97%) and possessed no primary dormancy. It was observed that c. 50% more *Mikania* seed germinated in a salt solution (150 mM) than did *Bidens pilosa* L. or *Synedrella nodiflora* (L.) Gaertn.) seeds indicating a moderate tolerance to germination inhibition in saline soils. There was greater species richness in the soil seed bank in the high than in the moderate rainfall region suggesting that rainfall had a role to play in this variation. Sixty percent of the germinable *Mikania* seed emerged more rapidly (within the first 8 days of imbibitions) than *A. conyzoides* and *Ludwigia* spp. There were greater

numbers of germinable *Mikania* seed and a greater species richness in the traditional, as compared to the mechanised taro plot, indicating that *Mikania* was effectively controlled in the mechanised cropping system. Seed longevity studies demonstrated that seed could live for at least 3 years in the soil seed bank and this was seen for three contrasting collection environments. Finally, the questionnaire and the interview survey indicated that *Mikania* had been present in the root crop and sugarcane farming systems for between 20 to 50 years. Chemical control was the most frequently used method for controlling *Mikania* and farmers controlled the weed to prevent crop losses. Beneficial aspects of *Mikania* mentioned by farmers included the improvement of soil fertility, use as a traditional medicine, use as a livestock feed and as a ground cover. The presence of *Mikania* has caused losses of c. AUD \$0.21 million for root crop production and for sugarcane production c. AUD \$0.99 to 2.10 million. The findings of this research and its implications on *Mikania* management justify the need to formulate a cost-effective and sustainable management of the weed in Fiji.

From Weeds to Wealth: A Case Study from the Wetland Project, Nepal

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Recognizing the importance of wetlands in terms of socio-cultural, ecological and economic value, nine wetlands have been designated as Ramsar sites of International Importance. Despite the importance given to wetland conservation in the past, their loss and degradation is continuing at a rapid rate. Among many, Alien Invasive Species (AIS) is one of the major threat to biological diversity and freshwater. Wetlands are considered to be the most vulnerable to AIS. Wetlands AIS management is an emerging as well as challenging issue in Nepal to address the issues of wetland degradation and loss on the long run. Therefore, this study is a review of experience and lessons learnt through interventions carried out by “Conservation and Sustainable Use of Wetlands in Nepal” project (executed by Ministry of Forests & Soil Conservation, funded by GEF & UNDP) during the past years (2009–2013) in order to better manage AIS at one of its field site, Koshi Tappu Wildlife Reserve (KTWR), Eastern Nepal. Water hyacinth (*Eichornia crassipes*) locally known as Jalkumbhi, a fast growing AIS at the adjoining wetlands in KTWR, the project explored best options for proper management of this species towards a wide range of use. The project piloted the use of the species as supplements for methane digesters. Similarly, with the rise in the cost of chemical fertilizers and its adverse effect on local biodiversity, farmers’ best utilized the species as mulch for making compost fertilizer. Most importantly, the project supported to enhance the skill of *Bantar* women, one of the traditional wetland dependent communities towards harvesting, drying and processing the species into artifacts. All these interventions have been instrumental to change weeds to wealth thereby empowering the communities socially and economically and maintaining the ecological integrity of the adjoining wetlands at KTWR.

CONFERENCE DECLARATION

“CHITWAN DECLARATION”

International Conference on Invasive Alien Species Management (ICIASM)

March 25–27, 2014, Sauraha, Chitwan, Nepal

We the participants of the above conference, from the countries of Australia, India, Nepal, Pakistan, South Africa, UK and USA

Recognize:

The detrimental impacts of invasive alien species (IAS) on ecology, environment and the socio-economic status of every country on the globe. IAS are the major drivers of biodiversity loss. As a result of increased trade and travel in recent times, IAS have now spread and established on all continents. In short, IAS are running riot with dire consequences not only for agriculture, livestock productivity, forests, wetlands, and water scarcity but also for fisheries, wildlife conservation and human health.

IAS will have an increased impact in the future due to climate change and ever increasing land use changes by creation of new favourable habitats for IAS causing their rapid spread and south to north movement. The negative impact of *Mikania micrantha* (mile-a-minute weed) on the endangered greater one-horned rhinoceros in Nepal is a good example of how invasive alien plants affect the wildlife.

The situation is “now or never”. Since the adverse impacts of IAS are multidimensional, coordinated efforts of all stakeholders concerned are necessary

to prevent new incursions and manage those which have already invaded our ecosystems. In order to develop suitable strategies to manage IAS, it is necessary to know the identity of the alien species, its origin, pathways of introduction, habitats invaded and the potential natural enemies in the native ranges. Moreover, it is essential to raise awareness on IAS among all the stakeholders, policies need to be framed, capacity to deal with IAS is to be strengthened or developed and provisions in the quarantine measures are to be reviewed and improved.

Therefore, we:

Conclude that -

There is an urgent need to develop comprehensive national strategies to prevent new incursions of IAS and to manage the negative impacts of those that have already invaded ecosystems and through these actions protect livelihoods, especially the poor, and our native ecosystems.

Thus, we:

Encourage -

Support for regional and global level coordination of activities against IAS and to build capacity of all stakeholders in IAS management.

Establishment of partnerships among various stakeholders including Government, conservation and development partners, non-Government and community-based organizations, private sector, academicians and the general public, at local, national and international levels for developing and implementing IAS management strategies.

Young people to take up research programs on biology, ecology, and management of IAS.

Develop National IAS strategies in all countries to deal with IAS.

Call upon -

National, Regional and International Research and Development Agencies to make resources available to coordinate activities to prevent new incursions of IAS, to build capacity of developing countries to fight the threats posed by IAS and to develop and/or review national strategies, policies and action plans for biodiversity conservation.

Greater attention to the habitat shift of mega-faunal species including rhinoceros and tiger due to quality erosion and fragmentation of habitats caused by IAS invasions and climate change.

Identifying and providing livelihood opportunities for women, socially excluded, and vulnerable communities affected by IAS invasions.

Devising appropriate strategies to protect and build the resilience of ecosystems and local communities against possible adverse impacts of IAS, climate change and land use change.

And for the future -

Commit to:

Integrate multiple stakeholders in IAS management,

Create local, regional and global networking,

Initiate IAS management at local level,

Adopt adaptive learning in IAS management,

Share Information on IAS,

Maintain native biodiversity and livelihoods.

ANNEXES

Annex I

Conference Schedule

Day 1: March 25, 2014	
08:00 – 14:00	Travel to Chitwan from Kathmandu
14:00 – 15:30	Hotel check in at Sauraha, Chitwan
15:30 – 18:30	Inaugural session (including key note session) of the conference
18:30 – 21:00	Reception dinner

Day 2: March 26, 2014	
07:30 – 08:30	Breakfast
First Session 09:00–11:10	Session Chair: Ms. Judy Oglethorpe Co-Chair: Mr. Ganga Jang Thapa Panelists: Dr. Steve W. Adkins, Dr. Sangita Shrestha
	1. Patterns of Plant Invasions: A Synthesis at Multiple Spatial Scales <i>Anzar A. Khuro, Zafar A. Reshi, Irfan Rashid, Akhtar H. Malik, G. H. Dar</i>
	2. Invasive plant problems and need for risk assessment in India <i>Mool Chand Singh, N. T. Yaduraju, Madhu B Priyadarshi, K. C. Bansal</i>
	3. Invasive plant threats to forests in the humid tropics: a case study from Kerala State, India <i>K. V. Sankaran, T. V. Sajeev, T.A. Suresh</i>
	4. Monitoring and control of invasive species in the grassland ecosystem of Manas World Heritage Site, India <i>Bibhuti P. Lahkar, Anukul Nath, Sonali Ghosh</i>
	5. Invasive alien species: threats and challenges for biodiversity conservation - A case study from Annapurna Conservation Area, Nepal <i>Neeru Thapa, Menuka Maharjan</i>
	Discussion, Question/Answer
11:10 – 11:25	Tea Break
Second Session 11:25–13:30	Session Chair: Mr. Gopal Prasad Upadhyaya Co-Chair: Mr. Ganga Jang Thapa Panelists: Dr. Sean T. Murphy, Dr. Maheshwar Dhakal
	1. The Biology and Management of Parthenium Weed: An invasive weed now affecting the native and agro-ecosystems of Nepal <i>Steve Adkins, Sangita Shrestha, Asad Shabbir, Bharat B. Shrestha</i>
	2. The current and potential geographic distribution of invasive Parthenium weed in South Asia <i>Asad Shabbir, Myron P. Zalucki, Kunjitapatham Dhileepan, Bharat B. Shrestha, Steve W. Adkins</i>

	3. Distribution, spread and status of <i>Parthenium</i> weed and its biological control agent in Nepal <i>Bharat B. Shrestha, Kusum Pokhrel, Nirmala Paudel, Sushmita Paudel, Asad Shabbir, Steve Adkins</i>
	4. Genetic diversity assessment of the alien invasive weed <i>Parthenium hysterophorus</i> L. in Nepal <i>Sangita Shrestha, Smita Shrestha, Jagat K. C. Shrestha, Bharat B. Shrestha, Steve W. Adkins</i>
	5. Plant species composition and soil seed bank in <i>Parthenium hysterophorus</i> invaded grassland of Hetaunda, Central Nepal <i>Jyoti Khatri-Chettri, Ambika Paudel, Bharat B. Shrestha</i>
	Discussion, Question/Answer
	Tea Break
Third Session 14:30–18:00	Session Chair: Mr. Ganga Jang Thapa Co-Chair: Mr. Arun S. Rana Panelists: Dr. K. Sankaran, Dr. Sean T. Murphy
	1. Effect of invasive <i>Mikania micrantha</i> on greater one-horned rhinoceros conservation in Chitwan National Park, Nepal <i>Naresh Subedi, Shant R. Jnawali, Babu R. Lamichhane, Rajan Amin, Y. V. Jhala</i>
	2. Invasive plants and rural livelihoods: an assessment of the effects of the invasion of <i>Mikania micrantha</i> in rural livelihoods in Nepal <i>Rajesh K. Rai, Helen Scarborough</i>
	3. Status of <i>Mikania micrantha</i> invasion in the rhino habitat of Chitwan National Park, Nepal <i>Babu R. Lamichhane, Naresh Subedi, Nawa Raj Chapagain, Maheshwar Dhakal, Chiranjibi P. Pokheral, Sean T. Murphy, Rajan Amin</i>
	4. Antimicrobial activities and phytochemical screening of leaf extract of <i>Mikania micrantha</i> <i>Anita Sahu, A. Devkota</i>
16:00–16:20	Tea Break
	5. Germination response of fallow-land plant species of central Nepal to allelopathic effect of <i>Parthenium hysterophorus</i> L. <i>Ambika Paudel, Jyoti Khatri-Chettri, Bharat Babu Shrestha</i>
	6. Vulnerability assessment of different land use types to invasion by <i>Parthenium hysterophorus</i> L. in western Chitwan, Nepal <i>K. Bhusal, M. P. Devkota, B. B. Shrestha</i>
	7. Changes in cropping patterns, resilience and invasive plant species in social-ecological systems: A study of the home gardens of Kerala, India <i>Kate L. Jones</i>
	8. An investigation into the compliance of selected nurseries and garden centres within Kwazulu-Natal Wthekwini and Umsunduzi geographical regions, South Africa <i>Astrid Beverley Badenhorst</i>
	Discussion, Question/Answer
18:30 – 20:00	Dinner

Day 3: March 27, 2014

07:30 – 08:30	Breakfast
First Session 09:00–11:00	Session Chair: Mr. Netra Sharma (Sapkota) Co-Chair: Mr. Ganga Jang Thapa Panelists: Dr. Asad Shabbir, Dr. Mool Chand Singh

	1. An overview of legal instruments to manage invasive alien species in Nepal <i>Mohan Siwakoti, Bharat Babu Shrestha</i>
	2. Invasive alien fauna of Nepal: problems and future perspectives <i>Prem B. Budha</i>
	3. Impact if invasive alien fish, Nile Tilapia (<i>Oreochromis niloticus</i>) on native fish catches of sub-tropical lakes (Phewa, Begnas and Rupa) of Pokhara Valley, Nepal <i>Md. Akbal Husen</i>
	4. An integrated framework for monitoring plant invasion in tropical India <i>Ninad, Mungi, Qamar Qureshi Yadvendradev Jhala</i>
	Discussion, Question/Answer
	Mikania Movie by Dr. K. Sankaran (15 minutes)
11:00–11:15	Tea Break
Second Session	Session Chair: Mr. Ganga Jang Thapa
11:15–13:10	Co-Chair: Ms. Keshari Rajkarnikar
	Panelists: Dr. Anzar Khuro, Dr. Dean Current
	1. Environmental bad to good: exploitation of <i>Mikania micrantha</i> for compost <i>Rajan Subedi, Rajesh K. Rai</i>
	2. The biology and management of Mikania: An impact assessment on crop production systems in Viti Levu, Fiji <i>Apai Macanawai, Michael Day, Tessie Tumaneng-Diete, Steve Adkins</i>
	3. Factors affecting alien species invasion and their impacts on different ecosystem in Panchase Area Nepal <i>Sony Baral, Anu Adhikari, Rajendra Khanal</i>
	4. From weeds to wealth: a case study from the wetland project, Nepal <i>Shalu Adhikari, V. N. Jha</i>
	5. Invasive alien species management through utilization for application in domesticated livestock species raising <i>Krishna Kaphle, Chiranjibi Pd. Pokheral</i>
	Discussion, Question/Answer
	Implementing management of invasive alien species – learning from global experiences with invasive plants to optimize the way forward <i>Sean T. Murphy, Naresh Subedi</i>
13:10–13:30	Announcements
13:30–14:30	Lunch Break
14:30–17:30	Field Trip
17:30–18:30	Closing Session
18:30–20:00	Dinner

Day 4: March 28, 2014

	Travel back to Kathmandu

Annex II

Proceedings of the Inaugural Session

The inaugural session of the conference was chaired by Mr. Govind Gajurel, Member Secretary of NTNC. Dr. Ganesh Raj Joshi, the Secretary of Ministry of Forests and Soil Conservation (MoFSC) inaugurated the conference by lighting the traditional Panas lamp. The chief guest Dr. Joshi, in his inaugural speech gave emphasis on the need of study and research to assess the impacts of invasive species and possible solutions to control it. He further appreciated the efforts made by the organizers of the conference as the stepping stone to formulate the new strategy on invasive alien species in the country.

Mr. Ganga Jang Thapa, Executive Director of NTNC and the Conference Coordinator welcomed the participants and invited dignitaries and also outlined the central purpose of the conference. The session was moderated by Dr. Naresh Subedi of NTNC.

Dr. Sean Murphy from CABI presented a Key Note speech on “Galvanizing Action for the Management of Invasive Alien Species” and highlighted the impacts of invasive species mainly in the forests and in agriculture sector including all major economic sectors within and between countries. He also emphasized the need for fully comprehensive management packages to be developed and implemented at national levels across the globe.

Mr. Bishwa Nath Oli, Director General of Department of Forests (DoF) highlighted the importance of key policies and programmes to deal with the invasive species management. Likewise, Mr. Megh Bahadur Pandey, Director General of Department of National Parks and Wildlife Conservation (DNPWC) also outlined a top priority on all national, regional, and global agendas for promoting international scientific cooperation to manage invasive species.

Mr. John Stamm, Director of USAID SEED Office said that the science and technology sector could play a vital role to develop the nation and holding gatherings of scientists frequently is important to institutionalize scientific achievements and make them pragmatic.

Ms. Judy Oglethorpe, Chief of Party of USAID funded Hariyo Ban Program said that invasive species are a problem common to all countries creating threats that have caused immense ecological and economic damage in many instances. Mr. Arun Rana of ADB also noted that the conference would provide a great opportunity to enhance cooperation on invasive species management and build broader collaboration among stakeholders.

The Chairperson of the ceremony and Member Secretary of NTNC Mr. Govinda Gajurel highlighted the significance of the conference to formulate the new strategy to control the invasive species in the country. He added that the NTNC is always ready to facilitate the appropriate platform for scientific activities. He concluded by thanking collaborative partners and noting the strong collaborative approach in organizing the conference.

Annex III

Proceedings of the Closing Session

Mr. Ganga Jang Thapa of NTNC chaired the closing session of the conference. On behalf of the conference organizing committee, Dr. Manish Raj Pandey, Master of Ceremony of the session, presented the conference declaration and all the participants agreed on this Chitwan Declaration.

On behalf of the international participants of the conference, Dr. Steve.W Adkins thanked the organizing committee for delivering such an enjoyable conference that he has attended for quite some time. He said that the conference floated some achievable ideas and highlighted the necessity of future cooperation and collaboration to deal with IAS.

Similarly, Dr. Mohan Shiwakoti, on behalf of the national participants thanked the organisers for providing such a wonderful platform for sharing ideas and findings between international and national researchers. He said that the conference paved an avenue for future collaboration in promoting a common understanding in regards to IAS.

Mr. Netra Sharma Sapkota of USAID found the conference relevant and timely and hoped all the innovative ideas and practices shared during the conference be documented and disseminated so that it can be helpful in strategy and action plan development. He said that the problem of IAS is not limited to country or region rather it is an international problem. So a combined effort is essential to combat this problem and informed that USAID is always ready to support government and stakeholders in developing strategy and action plans to combat the problems and threats posed by IAS.

Mr. Gopal Prasad Upadhyaya in his remarks reminded that there is no silver bullet to tackle the problem of IAS and emphasised the necessity to generate collective effort to combat this global problem. He said that he was very impressed by the efforts shown and ideas generated by the young researchers of Nepal and urged the necessity to translate the research into policy and policy into practice. Likewise, he requested all the participants to stay in continuous communication.

Mr. Kamal Jung Kunwar, Chief Conservation Officer of Chitwan National Park (CNP) thanked the organising committee for bringing such an international event to Chitwan that helped in showcasing to the global audience the problem faced by CNP due to IAS.

Likewise, Mr. Narendra Raj Sharma, Chief District Officer of Chitwan congratulated the organising committee for the successful completion of the international conference.

Last but not the least, Mr. Ganga Jang Thapa, the conference coordinator and chair of the closing session, thanked all the participants for their active roles during the conference and all the members of the organizing committee and support staff for making this event successful. He said that the conference was successful in bringing together global participants urged to create an effective team by bringing the private sector also on board.

Annex IV**Participants of the Inaugural Session**

SN	Name	Institution
1	Aastha Gautam	ZSL Nepal Office
2	Abdul Ansari	TAL
3	Alex Smith	University of Minnesota
4	Alicia Hill	University of Minnesota
5	Ambika Paudel	Central Dept. of Botany, TU
6	Ambika Pd. Khatiwada	NTNC-BCC
7	Ananda R. Thapa	NTNC-PCP
8	Anil Shrestha	Green Governance Nepal
9	Anita Sahu	Central Dept. of Botany, TU
10	Anthony Bodelson	University of Minnesota
11	Anu Shrestha	Kathmandu University
12	Anzar A Khuroo	Kashmir University, India
13	Arun Bagale	SANN International College
14	Arun Rana	ADB, Nepal Resident Mission
15	Asad Shabbir	University of the Punjab, Lahore, Pakistan
16	Astrid Badenhorst	Durban University of Technology, South Africa
17	B.P. Adhikari	NTNC-BCC
18	Babu Ram Lamichhane	NTNC-BCC
19	Bharat Babu Shrestha	Central Dept. of Botany, TU
20	Bibhuti Prasad Lahkar	Aaranyak, India
21	Bichitra Poudel	Beso Television
22	Bijay Kandel	NTNC-BCC
23	Bijaya Chapagain	NTNC
24	Bimal Khatiwada	Kantipur Daily
25	Bimala Poudel	Crystal TV
26	Binod Darai	NTNC-BCC
27	Binod Rijal	Journalist
28	Bishnu Pd. Poudel	District Forest Office
29	Bishwa Nath Oli	DOF - DG

SN	Name	Institution
30	Buddha Maharjan	Kathmandu
31	Buddha Chaudhary	CNP - Sauraha
32	Chanda Rana	SEF
33	Chandra B. Lama	
34	Chandra Sunuwar	NTNC-BCC
35	Chhatra Khadka	Chitwan National Park
36	Chinta Mani Paudel	Annapurna Post
37	Chiranjivi Prasad Pokharel	NTNC-BCC
38	Chitra Bahadur Khadka	DNPWC
39	Debaka Shiwakoti	NTNC-BCC
40	Dean Current	University of Minnesota
41	Dhananjaya Jayasawal	MSFP
42	Dip Pd. Chaudhary	NTNC-BCC
43	Dipak K. Shrivastav	NTNC-BCC
44	Dipendra Adhikari	Chitwan Post + Aviyan Daily
45	Dipendra Baduwal	Kantipur Daily
46	Emily Emart	University of Minnesota
47	Ganesh Jha	DFO Chitwan
48	Ganesh Raj Joshi	MOFSC - Secretary
49	Ganga Jang Thapa	NTNC
50	Gopal P. Upadhyay	Former DG- DNPWC
51	Govinda Gajurel	NTNC-Member Secretary
52	Govinda Ghimire	Hamro FM
53	Gwendolyn Evans	University of Minnesota
54	Harendra Chaudhary	NTNC-BCC
55	Hari P. Pokharel	FNJ Chitwan
56	Hari Prasad Upreti Bhuwana	Josh Weekly
57	Harka Man Lama	NTNC-BCC
58	Hiralal Chaudhary	NTNC-BCC
59	Homnath Sapkota	Synergy FM
60	Ishwar Joshi	NTV/BBC
61	Iswor Pd. Khanal	NAST
62	Ita Ram Tamang	NTNC
63	Jack Adin Rossites	NTNC
64	Jagat Krishna Chhipi Shrestha	NAST
65	Jamee Snyder	University of Minnesota
66	Jannu Mahato	Chitwan National Park
67	Jayandra Lama	US Embassy Kathmandu

SN	Name	Institution
68	John Stamm	USAID/Nepal
69	Judy Oglethorpe	Hariyo Ban/WWF
70	Jyodish Chandra Kuikel	WWF/Hariyo Ban Program
71	K. P. Gairhe	DNPWC
72	K.V. Sankaran	FAO
73	Kamal Chandra Bhagat	AVASS TV/Chitwan Khabar
74	Kamal Jung Kunwar	Chitwan National Park
75	Kate Jones	CABI
76	Keshav Giri	NTNC-BCC
77	Keshari Maiya Rajkarnikar	Department of Plant Resources
78	Khadananda Paudel	Bird Conservation Nepal
79	Kiran Bhusal	Golden Gate Int'l College
80	Krishna Acharya	Sagarmatha TV
81	Krishna Kaphle	TU - IAAS, Nepal
82	Kristin Seaman	University of Minnesota
83	Leiloni Nichols	University of Minnesota
84	Lisa Branellette	University of Minnesota
85	Logan Shina	UMN/University of Wisconsin
86	Maheshwar Dhakal	DNPWC
87	Manik Lal Shrestha	NTNC-BCC
88	Manish Raj Pandey	NTNC
89	Md. Akbal Husen	Nepal Agricultural Research Council
90	Megh Bahadur Pandey	DNPWC- DG
91	Megh Dhoj Adhikari	NTNC
92	Menuka Maharjan	TU - IOF, Hedauta
93	Mike Flynn	University of Minnesota
94	Mohan Bashyal	Ujyalo Network/Pardarshi
95	Mohan P. Devkota	TU
96	Mohan Rumba	Crystal TV
97	Mohan Siwakoti	Central Dept. of Botany, TU
98	Mona Engelmann	University of Minnesota
99	Mool Chand Singh	NBPGR, New Delhi, India
100	Nabaraj Mishra	Kantipur TV
101	Namrata Bhatta	Reporter
102	Nandu Ram Acharya	NTNC-BCC
103	Narayan Adhikari	RSS
104	Narendra Pradhan	WWF Nepal

SN	Name	Institution
105	Naresh Subedi	NTNC
106	Nawa Raj Chapagain	
107	Neeru Thapa	NTNC-ACAP
108	Netra Sapkota	USAID/Nepal
109	Nicolas Cruz	University of Minnesota
110	Nil Bdr. Maharjan	NTNC- Central Zoo
111	Ninad Mungi	Wildlife Institute of India
112	Numraj Khanal	NTNC
113	Om Prakash Chaudhary	NTNC-PCP
114	Pala Mourya	NTNC-BCC
115	Panilal Chaudhary	MSFP Cluster office Butwal
116	Parmanand Garg	NTNC-BCC
117	Pashupati Chaudhary	CNP Chitwan
118	Paul Folsom	University of Minnesota
119	Pheku Kachhadia	NTNC-BCC
120	Pradeep Khanal	WWF-TAL, Nepal
121	Prakash Gyawali	Avenues TV
122	Prakash Sigdel	Avenues TV
123	Prastab Subedi	Hamro FM
124	Prawin Dutta	Kantipur TV
3	Prawin Kumar	Kantipur TV
125	Prem Bdr. Budha	TU
126	Punte Gurau	NTNC-BCC
127	Rabin Kadariya	NTNC-BCP
128	Rajan Kumal	NTNC-BCC
129	Rajan Subedi	Institute of Forestry
130	Rajendra Acharya	Naya Patrika
131	Rajendra Khanal	IUCN
132	Rajesh Lamichhane	Sagarmatha Weekly
133	Rajesh Rai	SANDEE
134	Raju Bhattarai	FECOFUN Tanahun
135	Raju Chaudhary	NTNC
136	Raju Chaudhary	Image TV
137	Ram Bahadur Tamang (Gole)	NTNC-BCC
138	Ram Bdr. Mijar	CARE/Hariyo Ban Program
139	Ram Chandra Poudel	NAST
140	Ram Gurung	NTNC-BCC

SN	Name	Institution
141	Ram Kumar Aryal	NTNC-BCC
142	Rama Mishra	SMRCF
143	Ramesh Darai	NTNC-PCP
144	Ramesh K. Thapa	Chitwan National Park
145	Ramesh Kumar Paudel	Nagarik Daily
146	Rameshwor Rijal	Business Lahar Newspaper
147	Richa Bhattarai	WWF-Hariyo Ban Program, Nepal
148	Rita Ranjit	Kathmandu University
149	Ruby Adhikari	Kathmandu University
150	Sabita Devkota	Tri-Chandra Campus
151	Sagar Adhikari	News24 TV
152	Samantha Helle	University of Minnesota
153	Sandesh Singh Hamal	CARE/Hariyo Ban Program
154	Sangita Shrestha	NAST, Lalitpur
155	Santa Kumar Chaudhary	News24 TV
156	Santosh Sunar	AVASS TV
157	Sarita Jnawali	NTNC- Central Zoo
158	Sean T. Murphy	CAB International
159	Seeta Siwakoti (Olee)	Tri-Chandra Campus
160	Shalu Adhikari	WWF Nepal
161	Shankar Chaudhary	NTNC-BCC
162	Shant Raj Jnawali	WWF- Hariyo Ban Program
163	Shanta Adhikari	Gorkhapatra
164	Shova Pudasaini	News Reporter
165	Shree Narayan Dhami	NTNC-BCC
166	Shyam Kumar Thapa	NTNC
167	Smita Shrestha	NAST, Lalitpur
168	Sri Krishna Shrestha	Kathmandu
169	Steve W. Adkins	University of Queensland, Australia
170	Suk B. Kumal	NTNC - BCC
171	Sulav Bartaula	Kayakairan Daily
172	Sulove Silwal	Business Weekly
173	Tek Raj Bhatt	ZSL Nepal Office
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