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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Dr. Ganesh Raj Joshi, the Secretary of Ministry of Forests and Soil Conservation, inaugurating the conference

Dignitaries of the inaugural session on the dais

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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 *Micania macarantha* 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.

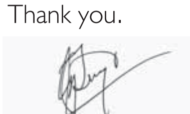
The different bioclimatic zones of Nepal favor the introduction of several alien species. Research, monitoring and management of biological invasions have not yet been a priority in Nepal. Very limited works have been initiated and, moreover, these activities are not well coordinated. On the other hand, 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 (*Dresissena 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 threath 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 steams 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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FULL TECHNICAL PAPERS

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	*Acacia mearnsii* De Wild.	Intentional	Afforestation	High	Tree	South–eastern Australia
2	*Ageratina adenophora* (Spreng.) R. M. King & H. Robinson	Intentional	Ornamental	Medium	Subshrub	Central America
3	*Ageratum conyzoides* L.	Intentional	Ornamental	Low	Herb	Central America
4	*Alternanthera bettzickiana* (Regel) G. Nichols.	Accidental	NA	Insignificant	Herb	Tropical America
5	*Alternanthera brasiliana* (L.) Kuntze	Intentional	Ornamental	Low	Subshrub	Central and South America
6	*Alternanthera philoxeroides* (Mart.) Griseb.	Unknown	Unknown	Insignificant	Herb	South America
7	*Amaranthus spinosus* L.	Accidental	NA	Low	Herb	South and Central America
8	*Asclepias curassavica* L.	Intentional	Ornamental	Insignificant	Herb	Tropical America
9	*Centrosema molle* Mart. ex Benth.	Intentional	Cover crop	Low	Climber	Central and South America
10	*Cestrum aurantiacum* Lindley	Intentional	Ornamental	Medium	Shrub	North and South America
11	*Chromolaena odorata* (L.) R. M. King and H. Robinson	Accidental	NA	High	Shrub	Tropical and subtropical America
12	*Clidemia hirta* (L.) D. Don	Accidental	NA	Low	Shrub	Central and South America
13	*Erigeron karvinskianus* DC.	Intentional	Ornamental	Low	Herb	South America
14	*Hyptis capitata* Jacq.	Intentional	Medicinal?	Medium	Herb	Central America
15	*Hyptis suaveolens* (L.) Poit.	Intentional	Medicinal?	Medium	Subshrub	Central and Tropical South America
16	*Ipomoea purpurea* (L.) Roth	Intentional	Ornamental	Medium	Climber	Central America
17	*Jatropha gossypifolia* L.	Intentional	Hedge plant	Insignificant	Shrub	Tropical America
18	*Lantana camara* L.	Intentional	Ornamental	High	Shrub	Central and South America
19	*Leucaena leucocephala* (Lam.) de Wit	Intentional	Social forestry	Low	Tree	Mexico and Central America
20	*Measopsis eminii* Engler	Intentional	Shade tree	Medium	Tree	West and Central Africa

S. N.	Species	Introduction	Purpose	Rank	Habit	Origin
21	*Merremia vitifolia* (Burm.f.) Hallier f.	Accidental	NA	High	Climber	South Asia
22	*Mikania micrantha* Kunth	Intentional	Cover crop	High	Climber	Tropical and subtropical America
23	*Mimosa diplotricha* var. *diplotricha* C.Wight ex Sauvalle	Intentional	Cover crop	High	Shrub	Central and South America
24	*Mimosa diplotricha* var. *inermis* (Adelb.) Veldk.	Intentional	Cover crop	Low	Shrub	Central and South America
25	*Mimosa pudica* L.	Intentional	Ornamental	Low	Herb	Tropical America
26	*Mucuna breacteata* DC.	Intentional	Cover crop	High	Climber	South and South-east Asia
27	*Parthenium hysterophorus* L.	Accidental	NA	Medium	Herb	North and South America
28	*Pennisetum polystachion* (L.) Schult.	Intentional	Ornamental	Medium	Herb (grass)	Tropical Africa
29	*Phytolacca octandra* L.	Intentional	Ornamental	Insignificant	Herb	Central and tropical South America
30	*Prosopis juliflora* (Sw.) DC.	Intentional	Fire wood	High	Tree	Central and South America
31	*Pueraria phaseoloides* (Roxb.) Benth.	Intentional	Cover crop	High	Climber	South and South-east Asia
32	*Senna hirsuta* (L.) Irwin & Barneby	Intentional	Ornamental	Medium	Shrub	Central and South America
33	*Senna occidentalis* (L.) Link	Intentional	Unknown	Low	Shrub	Tropical and subtropical America
34	*Senna spectabilis* (DC.) Irwin & Barneby	Intentional	Ornamental	Medium	Tree	Tropical America
35	*Senna tora* (L.) Roxb.	Intentional	Unknown	Medium	Subshrub	Asia and the Pacific
36	*Sphagneticola trilobata* (L.) Pruski	Intentional	Ornamental	High	Herb	South America and West Indies
37	*Synedrella nodiflora (L.)* Gaertn.	Accidental	NA	Insignificant	Herb	Tropical America
38	*Tithonia diversifolia* (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, allopathic 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 (Chandrashekara, 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 is 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 (Thattekkadu 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.

1. 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 m^2 for trees, 5×5 m^2 for shrubs and 1×1 m^2 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 × 20 m^2 for trees, 5 × 5 m^2 for shrubs and 1 × 1 m^2 for herbs were laid at 10 to 100m distance in adjoining forest from road and human settlement area. Nested plots 5 × 5 m^2 and 1 × 1 m^2 quadrates were allocated randomly in two corners of 20 × 20 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:

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 × 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 (Table1) 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.

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 fround 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 livestocks 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.*

Table 1. IAS observed in study area:

Scientific name	Local Name	Habit
Oxalis latifolia	Chari amilo	Herb
Mimosa pudica	Lajjawati jhar	Herb
Bidens pilosa	Kalo kuro	Herb
Ageratum houstonianium	Nilo gandhey	Herb
Amaranthus spinosus	Kande ludo	Herb
Lantana camara	Banmara	Shrub
Chromolaena odorata	Seto Banmara	Shrub
Ageratina adenophora	Kalo banmara	Shrub
Imperata cylindrical	Siru	Herb
Rubus ellipticus	Aaiselu	Shrub
Solanum xanthocarpum	Kantakari	Shrub

Source: *Field data 2013*

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 1) showed the mean maximum temperature is increasing per year which is favoring the easy establishment of IAS.

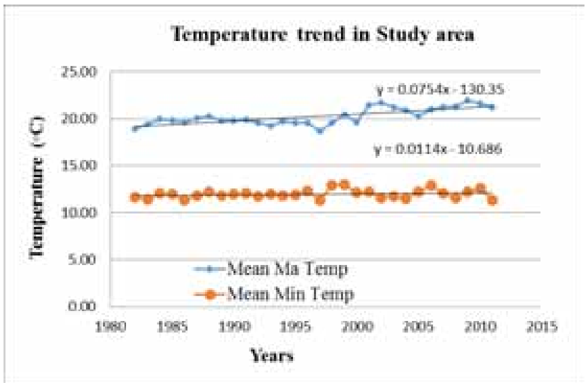

Chart 1. Temperature trend in study area

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
Epiblema strenuana Walker	Lepidoptera	Mexico	Australia, China[a]	Yes
Zygogramma bicolorata Pallister	Coleoptera	Mexico	Australia, Ethiopia, India, South Africa, Pakistan[b] Nepal[b]	Yes
Listronotus setosipennis Hustache	Coleoptera	Argentina	Australia	Yes
Smicronyx lutulentus Dietz	Coleoptera	Mexico	Australia	Yes
Contrachelus albocinereus Fiedler	Coleoptera	Argentina	Australia	Yes
Carmenta nr *ithacae*	Lepidoptera	Mexico	Australia	Yes
Bucculatrix pathenica Bradley	Lepidoptera	Mexico	Australia	Yes
Platphalonidia mystica Razowski & Becker	Lepidoptera	Argentina	Australia	No
Stobaera concinna Stal	Homoptera	Mexico	Australia	No
Puccinia abrupta var *partheniicola* (Jackson) Parmelee	Uredinales	Mexico	Australia, India[c], South Africa[c], Kenya[c], Nepal[c], Ethiopia[c], China[c]	Yes
Puccinia xanthii f.sp. *parthenium hysterophorae*	Uredinales	Mexico	Australia, South Africa, Sri Lanka	Yes

[a] First released as biocontrol agent against rag weed, *Ambrosia artimissifolia*
[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-born 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-born 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-acectic 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 ($MgCl_{2,}$ 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

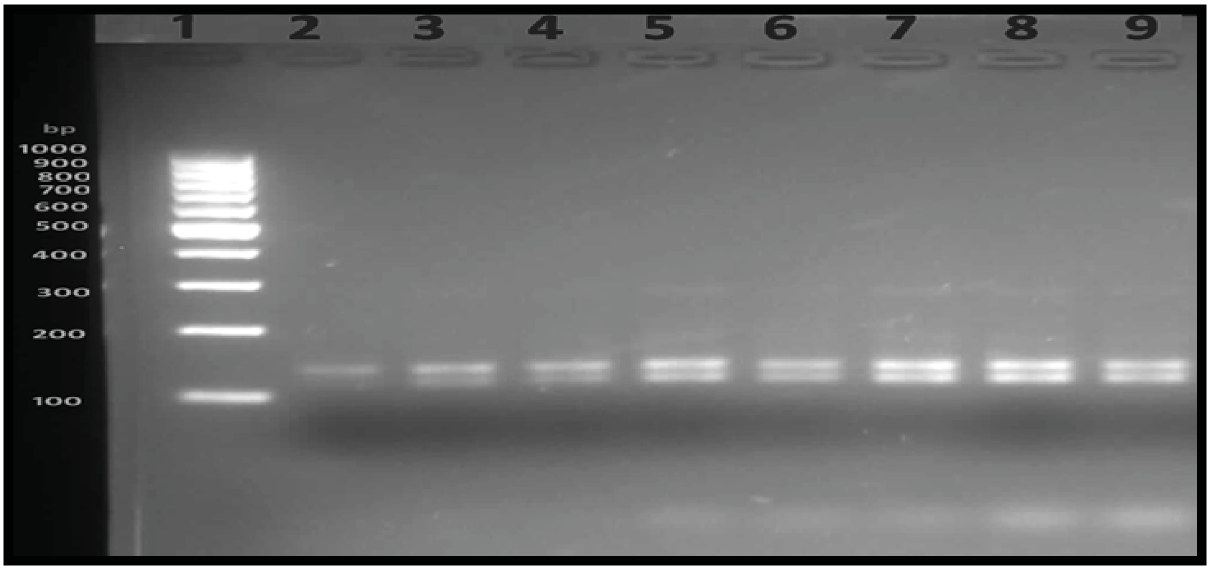

Plate 1. A gel picture of the optimization of primer concentration (Phys 01). Lanes 2 to 9 are primer concentration 0.1 pmol to 0.8 pmol, respectively and lane 1 is a 100 bp GeneRuler DNA ladder. The best concentrations were determined to be lanes 5 to 8 i.e 0.4 to 0.8 pmol.

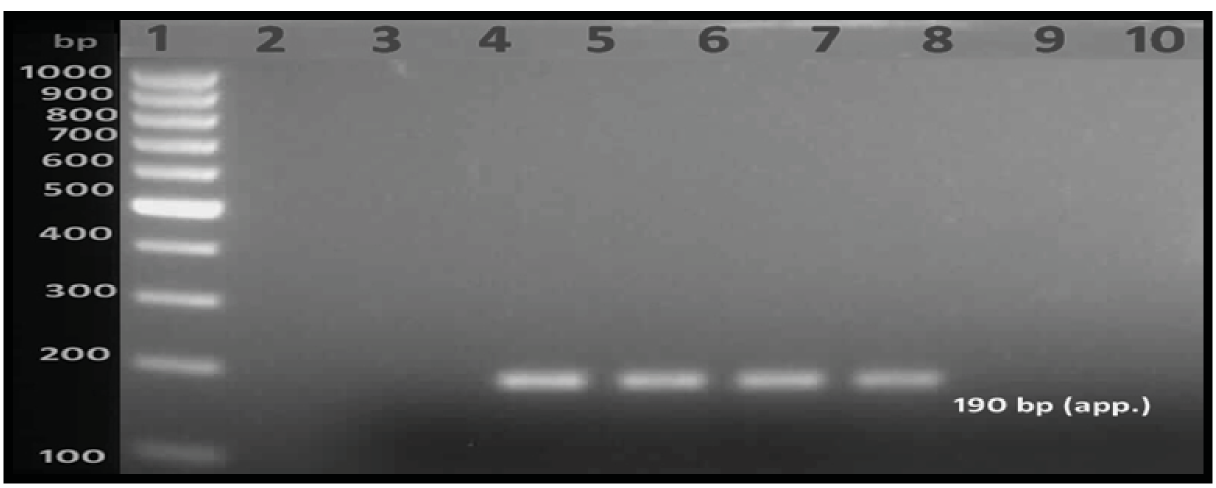

Plate 2. A gel picture of the optimization of $MgCl_2$ concentration for SSR primer Phys 09. Lanes 2–10 are $MgCl_2$ concentration: 2.0 to 4.0 mM respectively and lane 1 is a 100 bp GeneRuler DNA Ladder. The best concentration was determined to be lane 4, 2.5 mM

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, caplillary 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 (Pasiecznik, 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 (Pasiecznik *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 hotpot 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:

$$Y = \alpha + \beta_{1*}Age + \beta_{2*}Gender + \beta_{3*}Income + \beta_{4*}LU + \beta_{5*}Land + \beta_{6*}Distance \qquad (i)$$

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 Bhari[2] to 0.55 and 0.40 Bhari respectively. Likewise, there was a substantial decrease (49%) in average livestock owned by the BZ households.

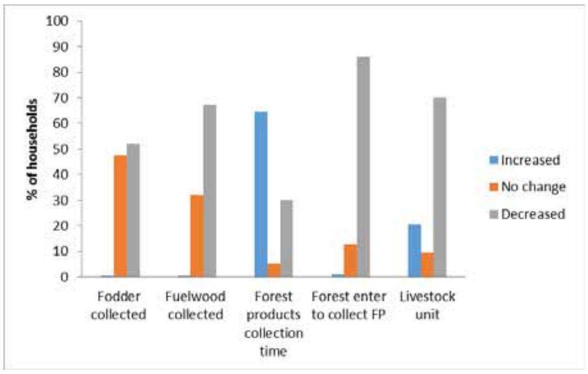
The number of households experiencing changes in household activities compared to five years ago indicates that the colonization of *Mikania* has led to a change in household activities (Figure 1). 86% and 70% of the total sample households reduced the frequency of entering BZCF to collect forest products 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:

i. the collection of forest products was not limited to community forest as they enter the national park illegal though; and

ii. 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 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% espectively.

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 micarantha (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 posses 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 km^2 in core and 750 km^2 in buffer zone, the park is situated in south central lowlands of inner Terai (Figure1). The majority of the park is dominated by forest (sal, riverine and mixed hardwood) 80 %, grassland 12%, exposed surface 5% and water bodies (3%)

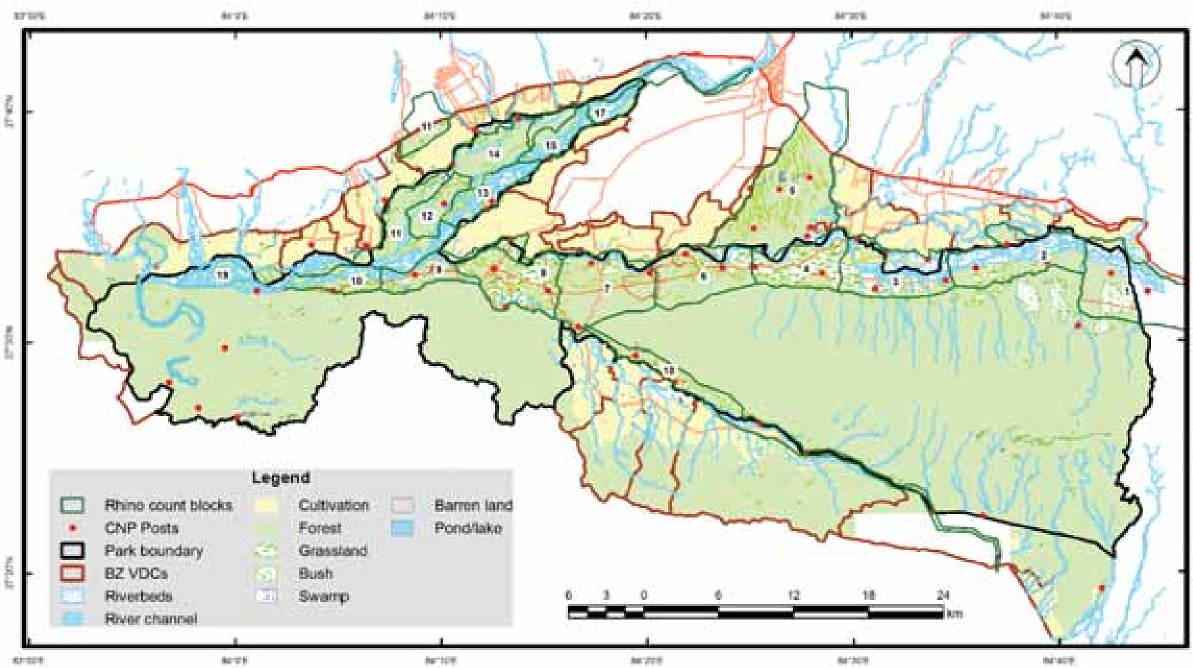

Figure 1. Map of CNP, Buffer zone and rhino count blocks (2011)

(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 into19 blocks (11–75 km^2) 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 km^2 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.

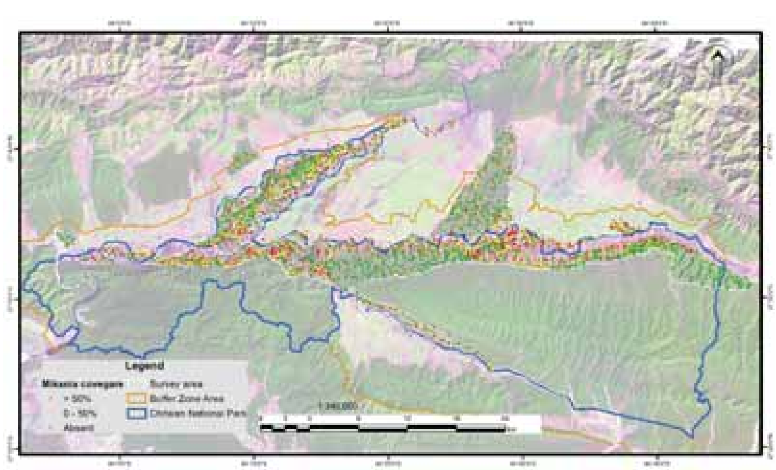

Figure 2. Distribution and level of Mikania invasion in CNP, Nepal (2011)

Table 1. Level of Mikania, Chromolaena and Lantana invasion in CNP, Nepal (2011).

Vegetation type	No of plots	*Mikania*			*Chromolaena*			*Lantana*		
		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.

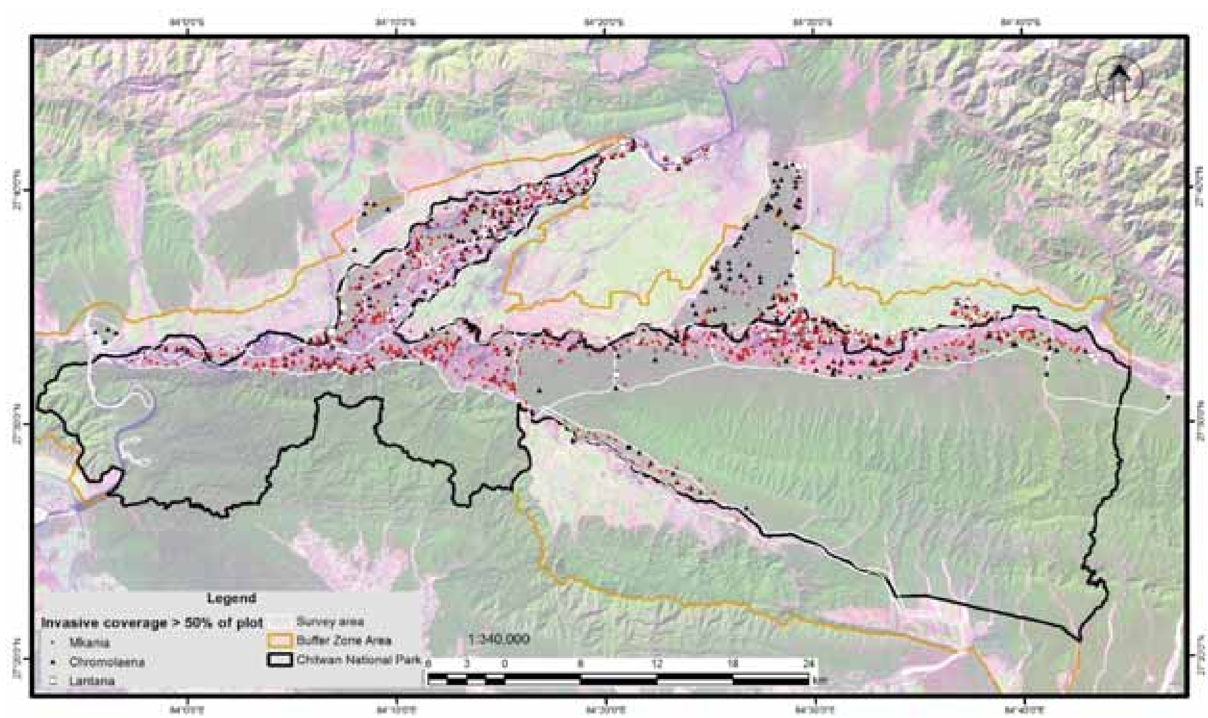

Figure 3. Distribution of high invasion of Mikania, Chromolaena and Lantana in CNP, Nepal (2011).

Table 2. Mikania and other invasives in CNP (2011)

		Mikania			
		0	1	2	Total
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/km^2. Although there is no significant difference ($F_{df(3)}=0.28$, p=o.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.

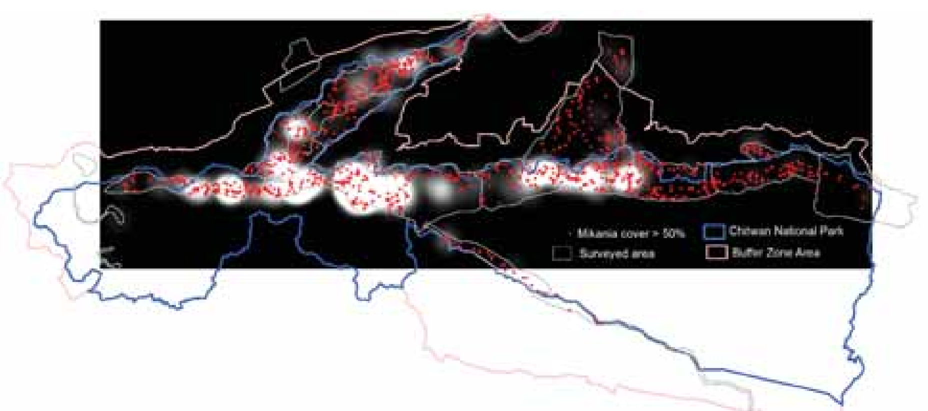

Figure 4. Mikania Invasion and rhino density in CNP (Increasing brightness shows the higher rhino density)

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 Hardwood	4(0.80)	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 *Mikania* 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 etal. 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 hysteropurus*, 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 historophorus*, distribution pattern, landuse 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 severly 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.

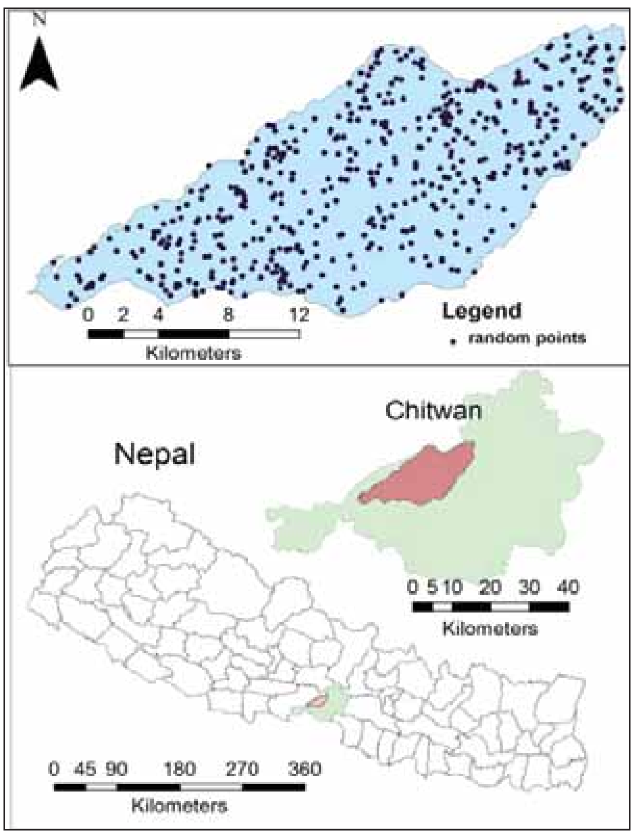

Figure 1. Map showing study area and random points

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 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.

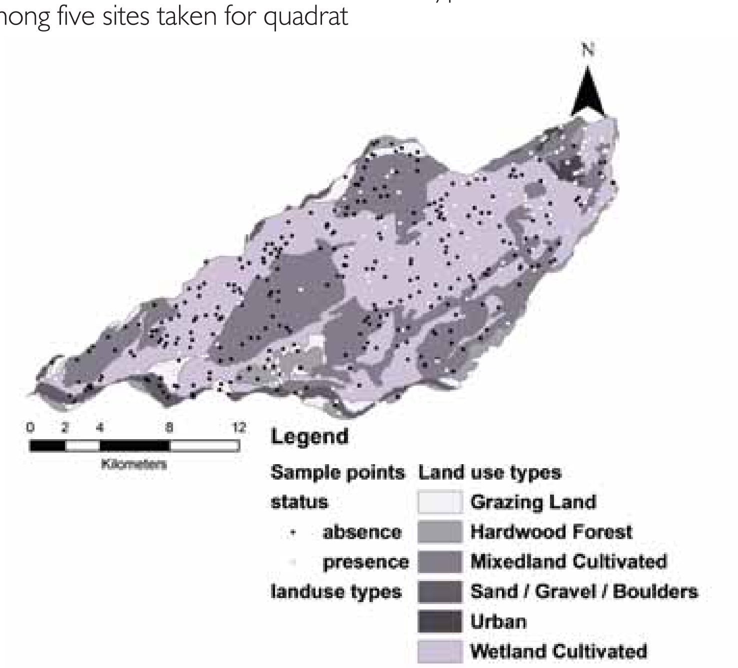

Figure 2: Spatial distribution of *Parthenium hysterophorus* within study area

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/m^2 at high invasion areas. The maximum density of the weed was 126 stem/m^2 at high invasion area of grassland and 81 stem/m^2 at high invasion of tree plantation. The average *P. hysterophorus* for high invasion area of grassland is 53 stem/m^2 and for tree plantation is 34 stem/m^2. 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).

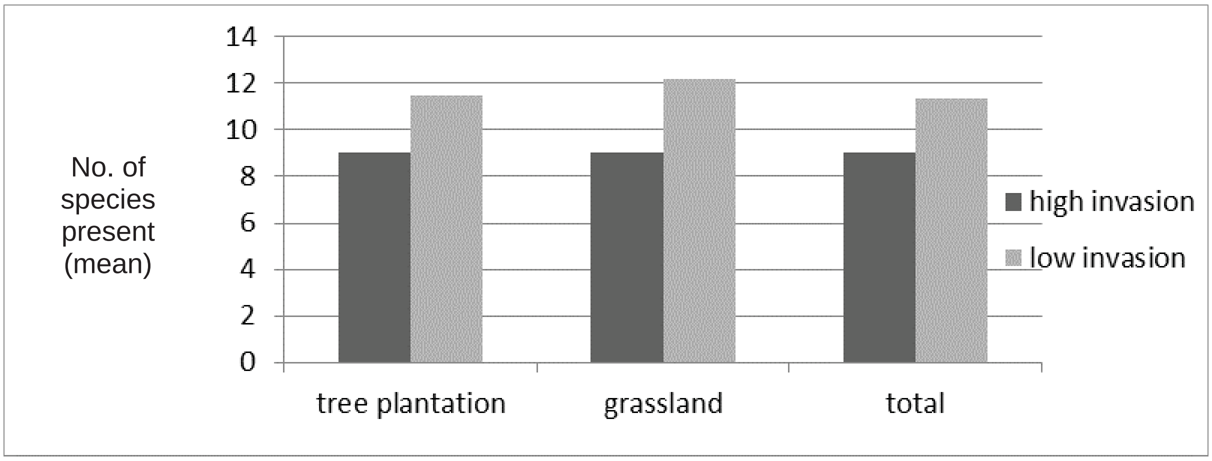

Figure 4. Herbaceous plant species richness at high and low invasion of *Parthenium hysterophorus* on different land use types.

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 (ISj=93% and ISs=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 viscusum*, *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 form 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 P. hysterophorus (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 planation 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, Chyrospogan aciculatus*, *Borreria articularis, B. alata, Scopari adulcis, Linderina Sp.,* and many herbbaceous species were found less after invasion by *P. hysterophoru*s

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 had 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 species[1] (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).

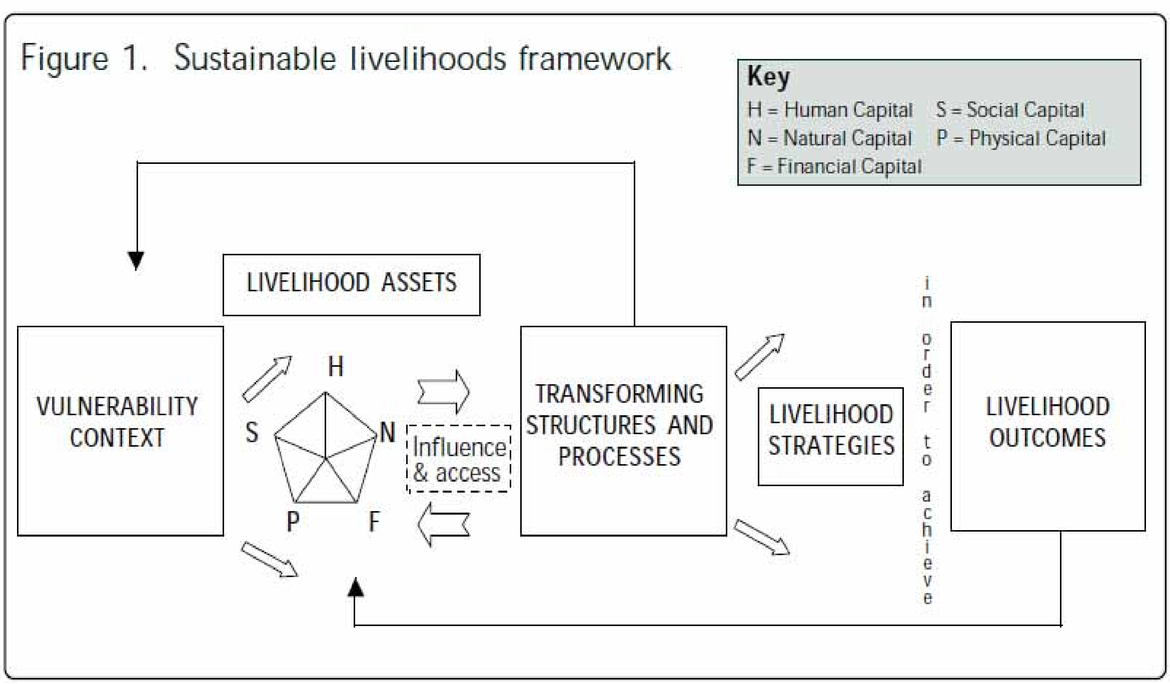

Figure 1. The sustainable rural livelihoods framework (DFID, 1999)

In addition, a systems perspective is useful in understanding linked, dynamic social-ecological systems (SESs) 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).

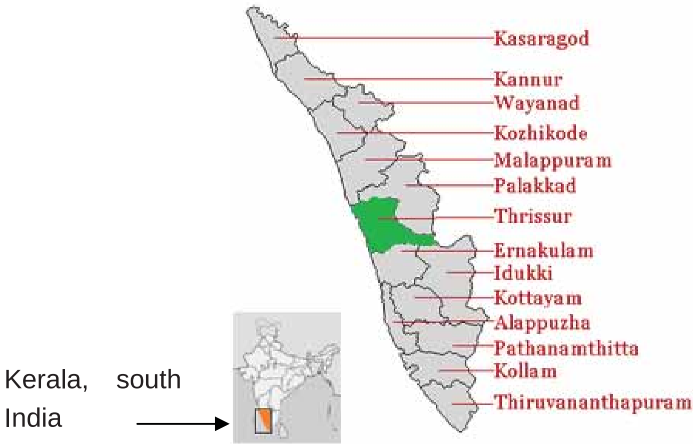

Plate 1. The study site (Puthur) was in Thrissur district in Kerala (Image courtesy of KFRI)

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).

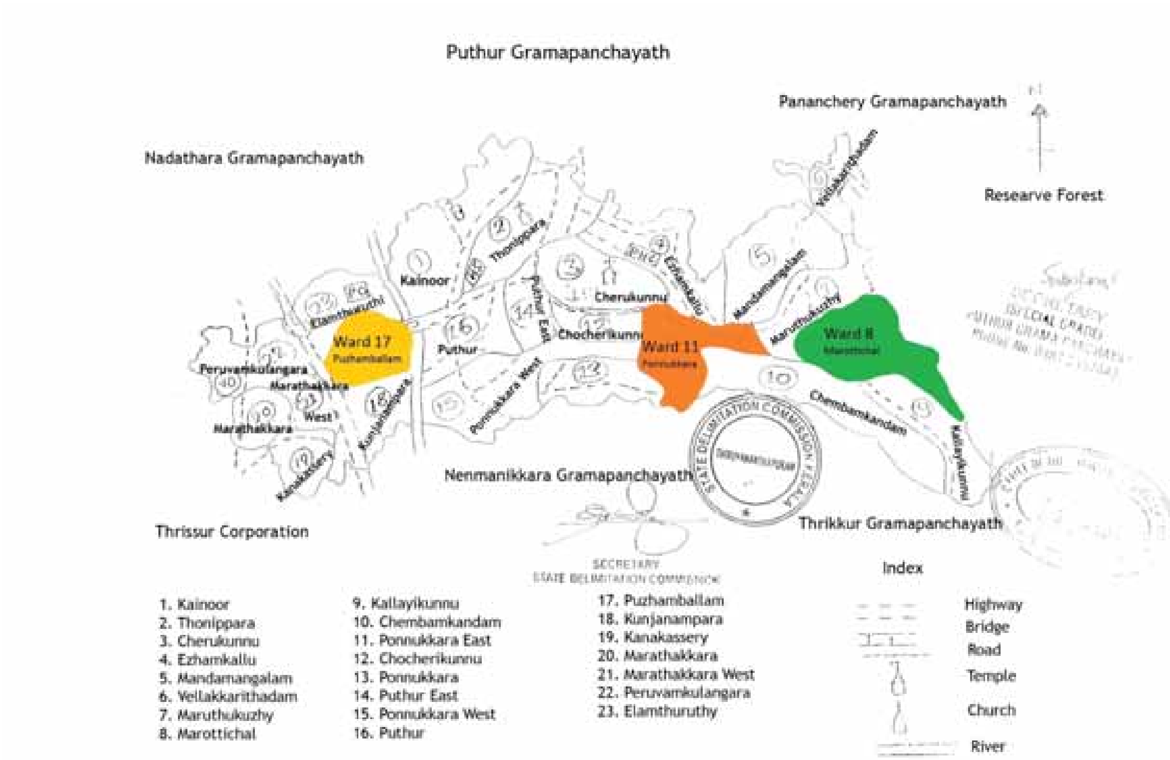

Plate 2. Map of Puthur Gramapanchayath in Thrissur. The wards where interviews took place during the study are highlighted (8 Marottichal, 11 Ponnukkara and 17 Puzhamballam) moving away from the Reserve Forest (map translated from Malalayam to English by Ambaly) (Primary Estimates, 2007).

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° 29' 25.08", +76° 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 km^2 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 Onum[2] 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 previliage 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 steady 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 (Glendinning *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 Kudumbashree[3] 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*).

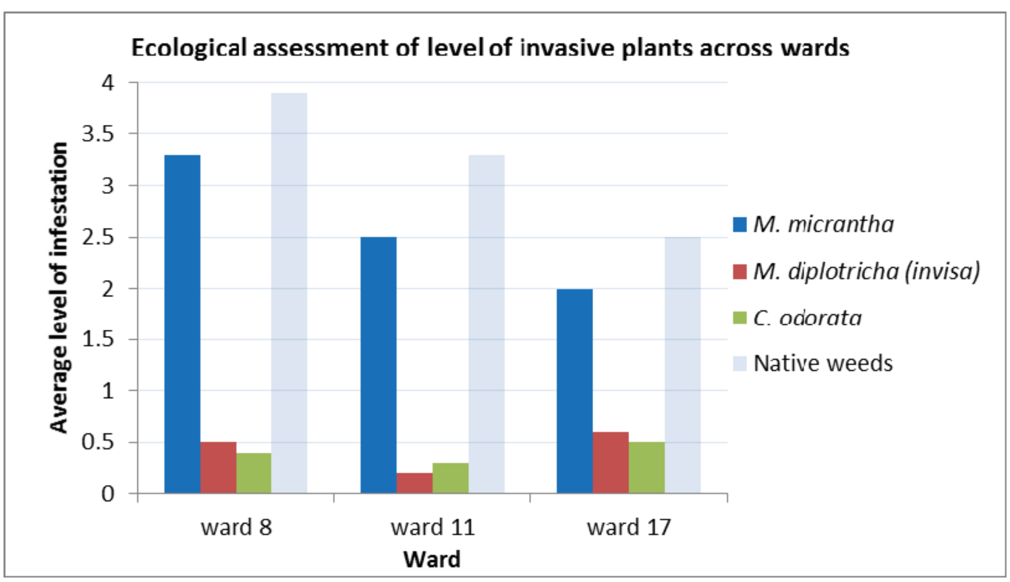

Figure 2. Ecological assessment of level of invasive plants across wards (note: general assessment)

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 communictaion*). 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; Mgidi, 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; Mgidi*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.

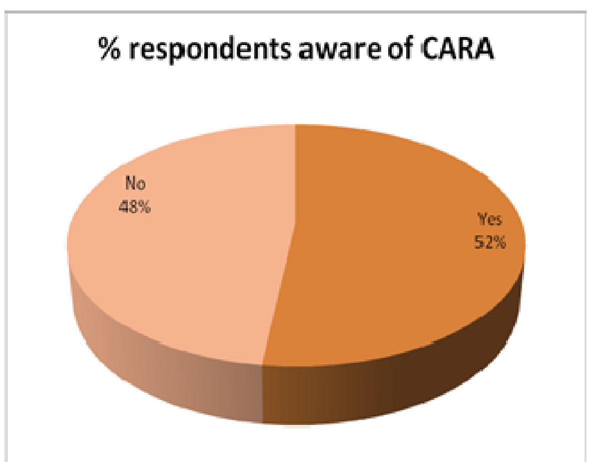

Figure 1. % of respondents aware of the CARA legislation.

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.

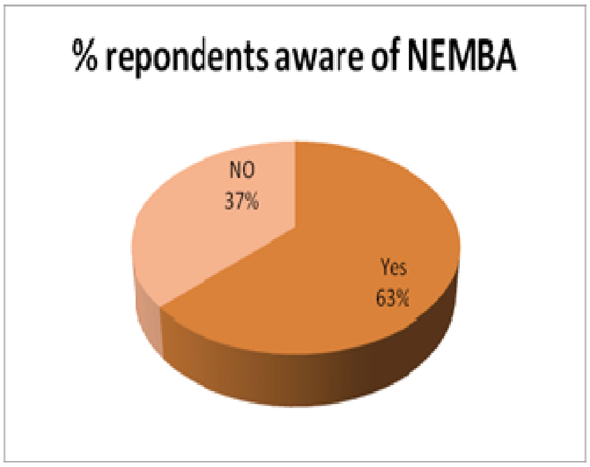

Figure 2. % of respondents aware of the NEMBA legislation.

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.

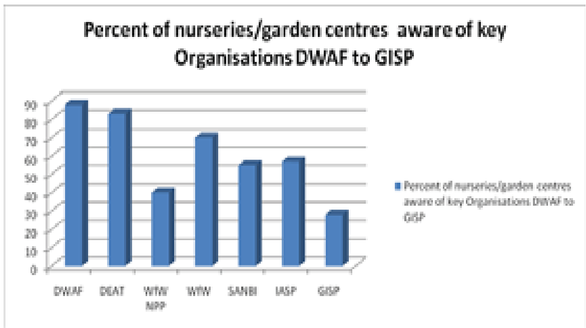

Figure 3. % of nurseries/garden centres aware of key organisations: DWAF to GISP.

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

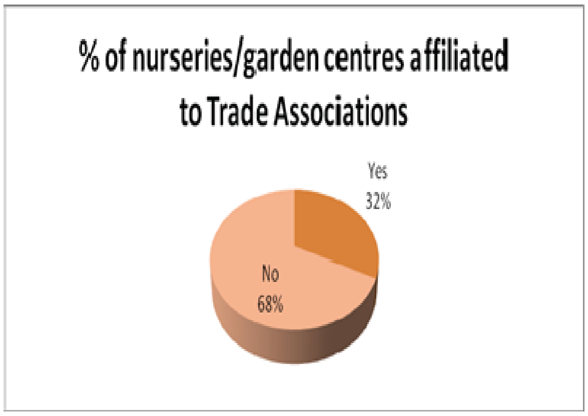

Figure 4. % of nurseries/garden centres affiliated to trade associations

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 X1 – X10, listed in Table 2, against each Dependent Variable Y1 – Y17, 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: ∑ CARA	0–10
Y_2	Stock NEMBA plants	15: ∑ NEMBA	0–11
Y_3	Stock Indigenous Alternative plants	15: ∑ Indigenous plants	0–4
Y_4	Identify/know CARA plants	15: ∑CARA	0–10
Y_5	Identify/know NEMBA plants	15: ∑ NEMBA	0–11
Y_6	Identify/know Indigenous Alternative plants	15: ∑ 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 pin-point 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) stoking 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).

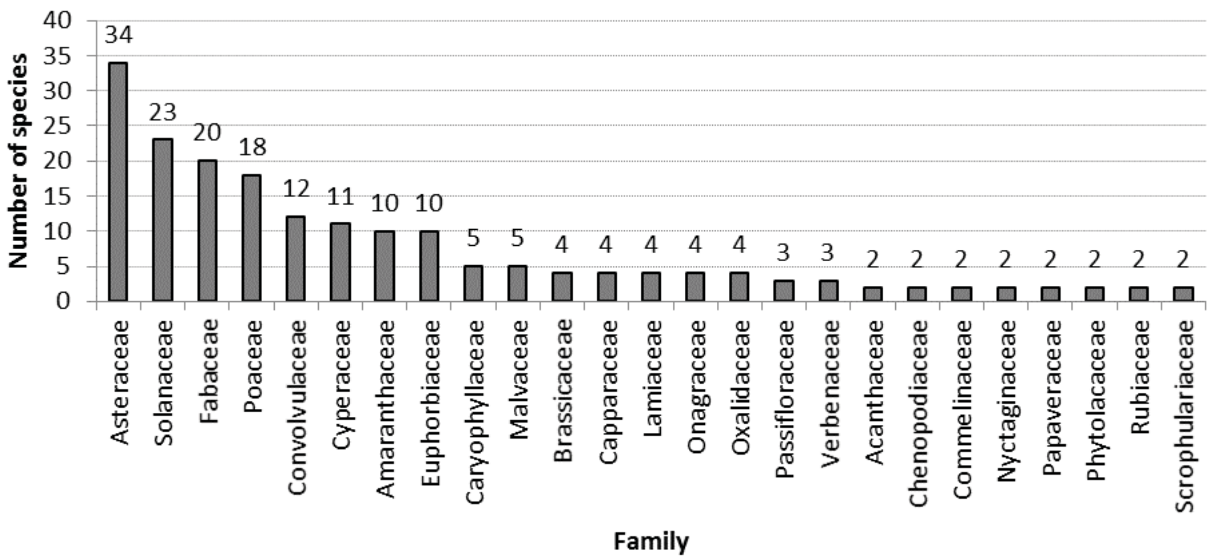

Figure 1. Number of naturalized plant species belonging to different families. Only the families having >1 species are presented. There are 28 families with single naturalized species in Nepal.

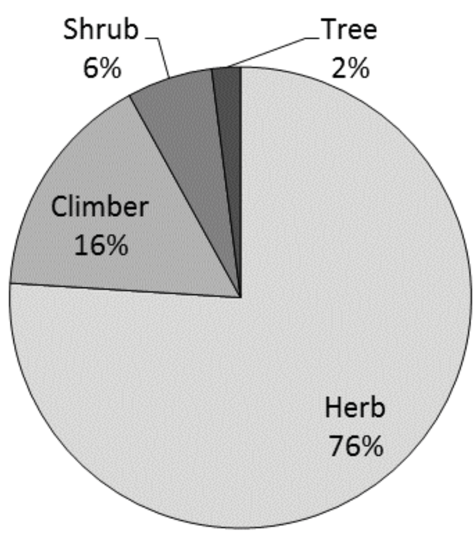

Figure 2. Contribution of different growth forms to the naturalized plant species of Nepal.

Over two dozen plant species including *Ageratina adenophora* (L.) King and Robinson, *Ageratum houstonianum* Mill., *Alternanthera philoxeroides* (Mart.) Griseb., *Chromolaena aodorata* (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, Bidenspilosa* 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 valuated. 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

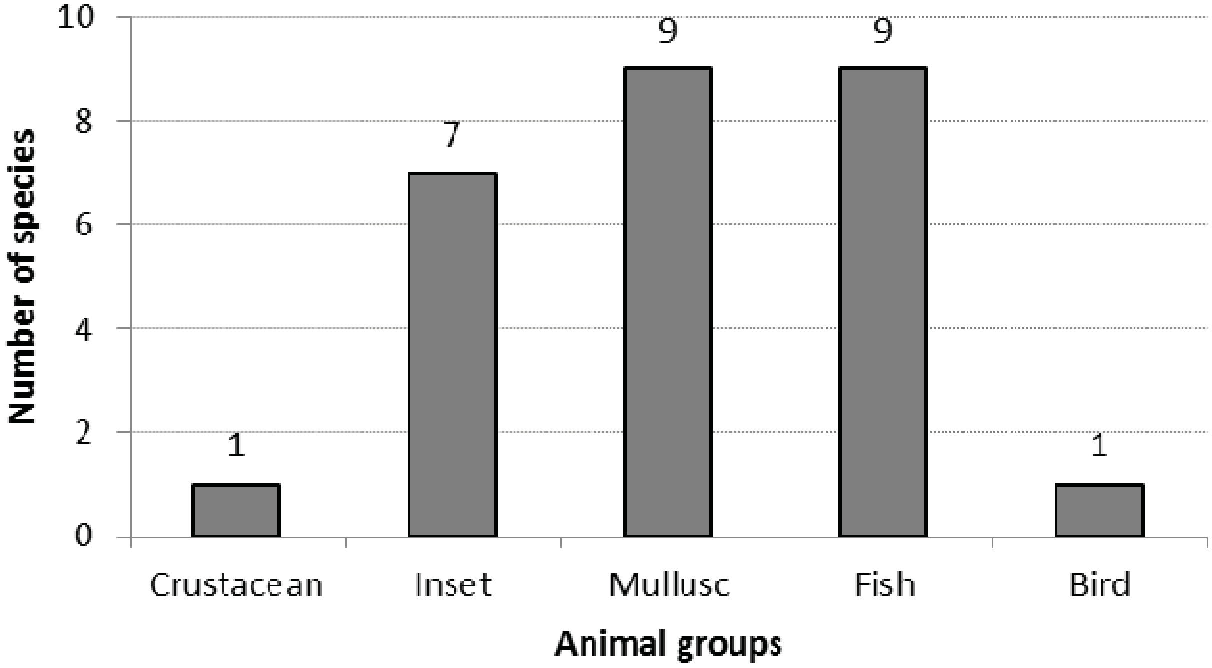

Figure 3. Number of alien species belonging to different groups of animals (Data from Budha, 2013)

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*, Hypopthalmicthys molitrix* Valenciennes*, Ctenopharyngodon idealla* 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/14 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 pasts 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 hasalso 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 guirdneri, S. trutta* and *Oncorhychus 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. sophera* 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 by2020 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 enhancingnational 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 proposed10 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 accidently 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 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 spreadind 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 depened 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 which four fish species were exotic (Pokharel, 1999). Capture fishery of these lakes comprised of both indigenous and exotic fish species (Gurung, 2003). Jalaris, 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 (Figure1) 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 km^2 (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 km^2.

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 km^2. The surface area, maximum depth, and average depth of the lake are 1.35 km^2, 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.

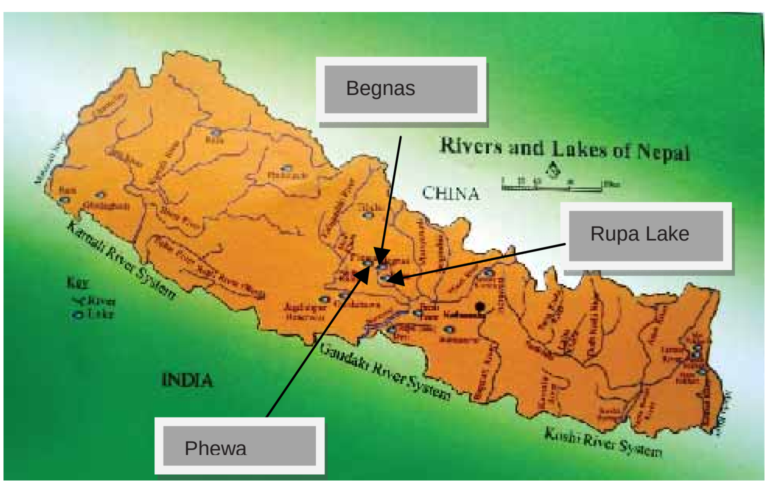
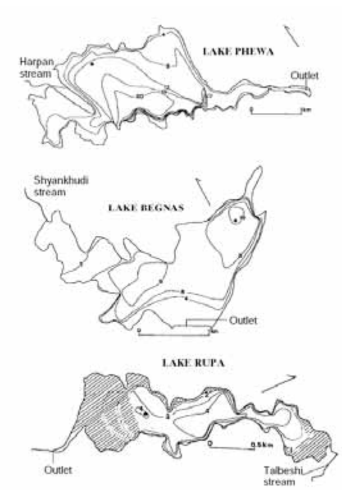


Figure1. Nepal map showing Phewa, Begnas and Rupa Lakes of Pokhara Valley (Source: Shreshtha, 2008)



Bathymetric map of lakes of Pokhara Valley (Rai *etal.*, 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 oliogo-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 m^2. The fish species in the catch of Pokhara valley lakes are presented in Table 2. There were 23 fish species appeared in catch of Pokhra 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	*Tor putitora* (Hamilton)	Sahar	++	++	+
2	*Neolissochilus hexagonolepis* (McClelland)	Katle	+		+
3	*Cirrhinus reba* (Hamilton)	Rewa	+	+	-
4	*Barilius barna* (Hamilton)	Lam Fageta	+	+	-
5	*B. bola* (Hamilton)	Fageta			
6	*B. vagra* (Hamilton)	Fageta			
7	*B. bendelisis* (Hamilton)	Fageta			
8	*Puntius sarana* (Hamilton)	Kande	+	-	+

SN	Scientific name	Local name	% contribution to total catch		
9	*P. sophore* (Hamilton)	Bhitte/Bhitta	++	+++	+
10	*P. titius* (Hamilton)	Bhitte/Bhitta			
11	*P. ticto* (Hamilton)	Bhitte/Bhitta			
12	*Cirrhinus mrigala* (Hamilton)	Naini	+	++	+
13	*Catla catla* (Hamilton)	Bhakur	++	+++	+
14	*Labeo rohita* (Hamilton)	Rohu	+	++	+++
15	*Mastacembelus armatus* (Lacepede)	Chuche Bam	++	++	-
16	*Xenentodon cancila* (Hamilton)	Dhunge Bam			
17	*Clarias batrachus* (L.)	Magur	+	-	-
	Exotic fish species				
18	*Aristichthys nobilis* (Richardson)	Bighead carp	++++	+++	++++
19	*Hypophthalmichthys molitrix* (Valenciennes)	Silver carp	+++	++++	++++
20	*Ctenopharyngodon idella* (Valenciennes)	Grass carp	++	++	++
21	*Cyprinus carpio* (L.)	Common carp	+	++	+++
22	*Clarias gariepinus* (Burchell)	African magur	++	++	+
23	*Oreochromis niloticus* (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.

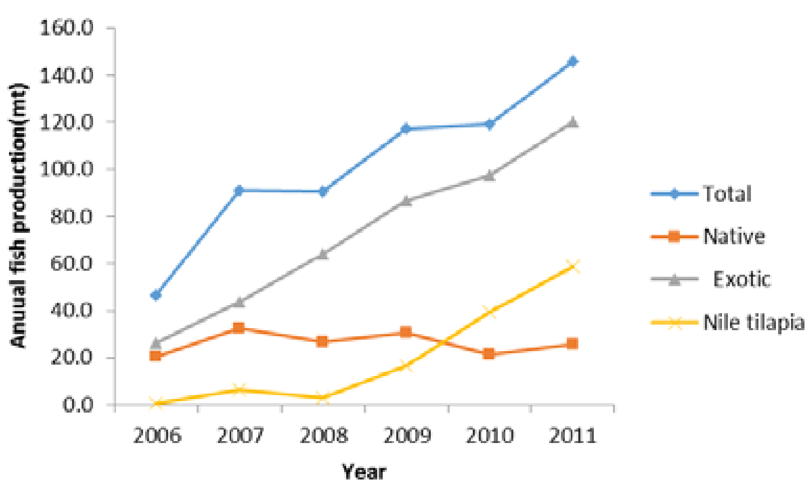


Figure 2. Annual trends of fish catch from three lakes (total of Phewa, Begnas and Rupa) of Pokhara valley

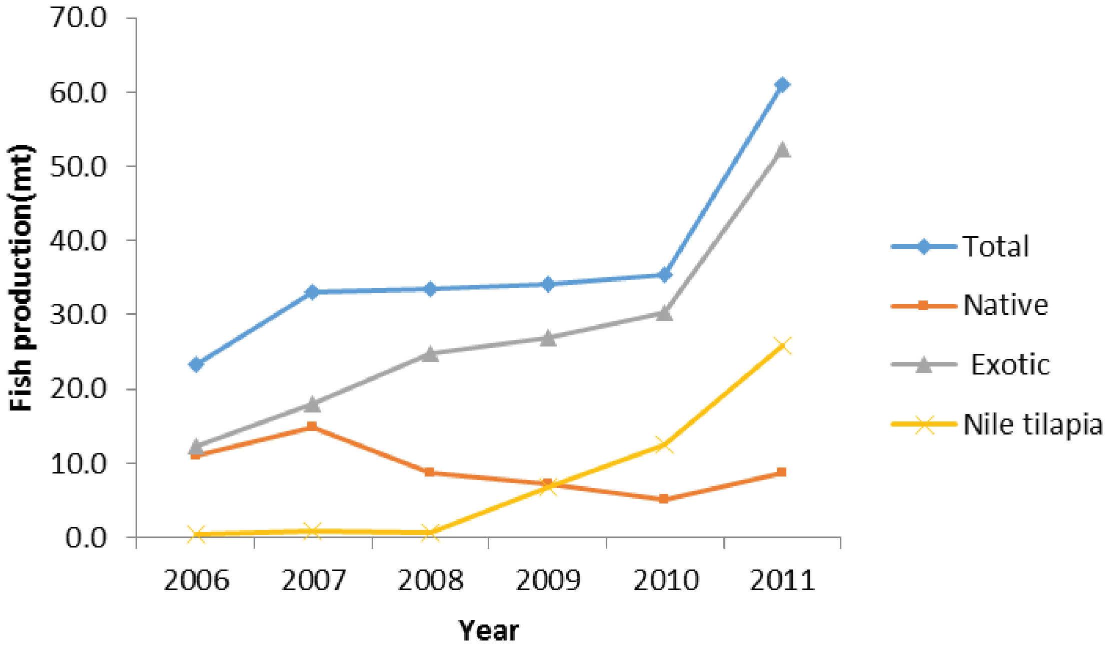


Figure 3. Annual trends of fish catch (mt) from Phewa Lake

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.

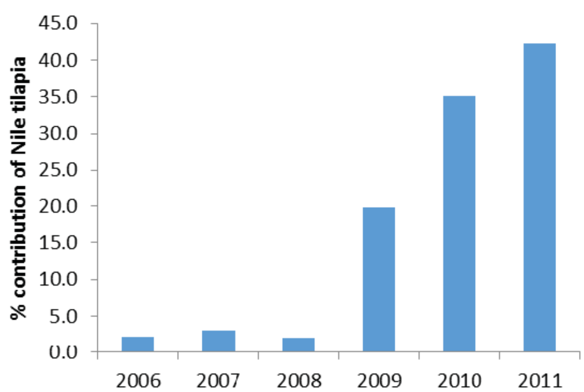


Figure 4. Annual trends of Nile tilapia contribution (%) in total fish catch from Phewa Lake

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 0.11mt 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).

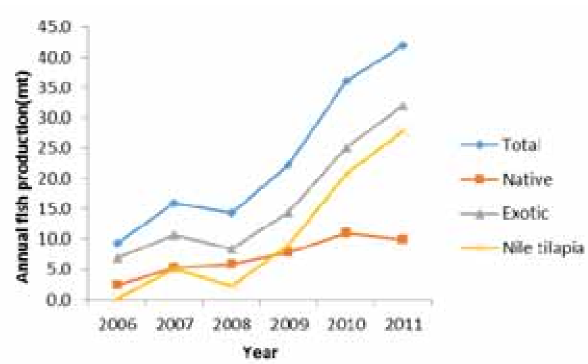


Figure 5. Annual trends of fish yield from capture fishery in Begnas Lake.

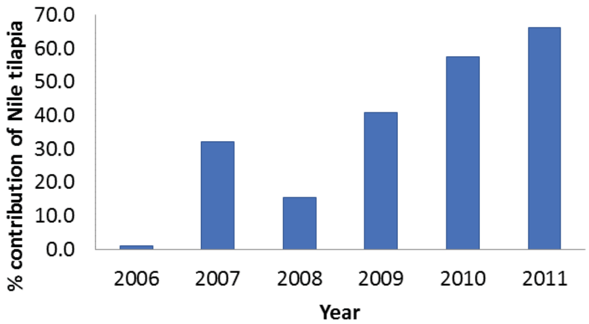


Figure 6. Annual trends of Nile tilapia contribution (%) in total fish catch from Begnas Lake

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 0.01mt 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).

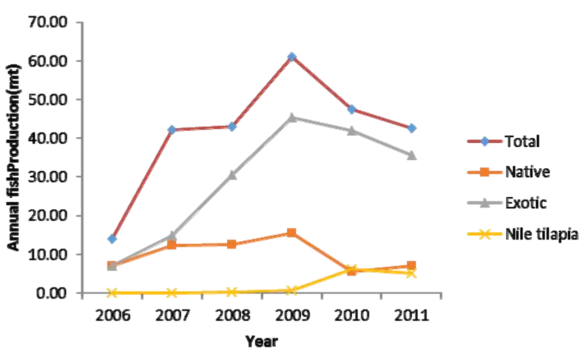


Figure 7. Annual trends of fish catch from Rupa Lake of Pokhara valley

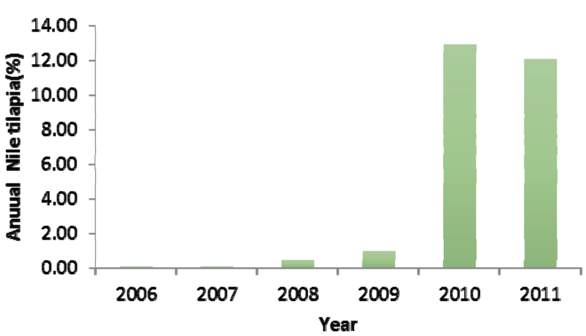


Figure 8. Annual trends of Nile tilapia contribution in total fish catch from Rupa Lake

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 *Orechromis* 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.13.51million 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 (Shreshtha *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 up-rooting is not feasible nor effective (Pasiecznik *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.

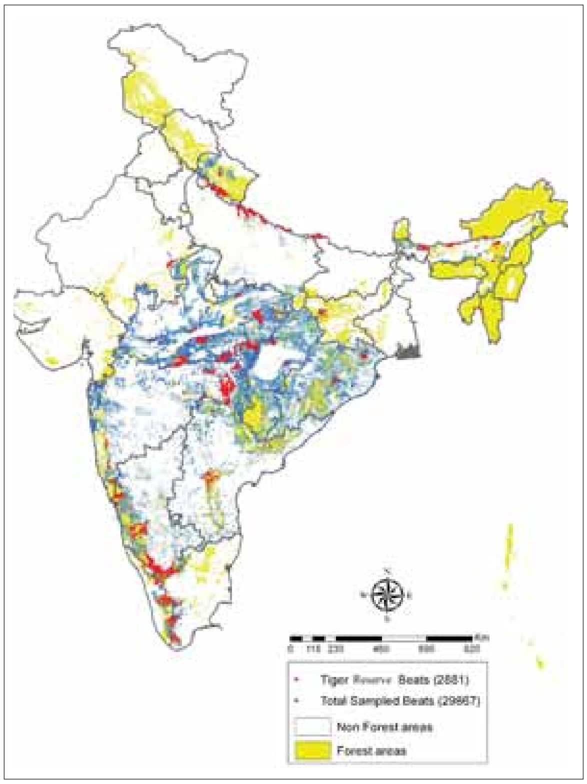

Figure 1. Map depicting the spatial coverage of invasive plants monitoring in India that happens after every 4years. Blue and red locations represent 1 to 3 survey transects.

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 1 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 envelops 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 resent 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 we 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 questioner survey of the involved people followed by ground validation. In case of the current study, forest department is responsible for managing invasive species. The questioner 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 I 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 CO_2 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 28^0 12' and 28^0 18' N, and longitudes between 83^0 45' and 83^0 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 (VDCs[1]) 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).

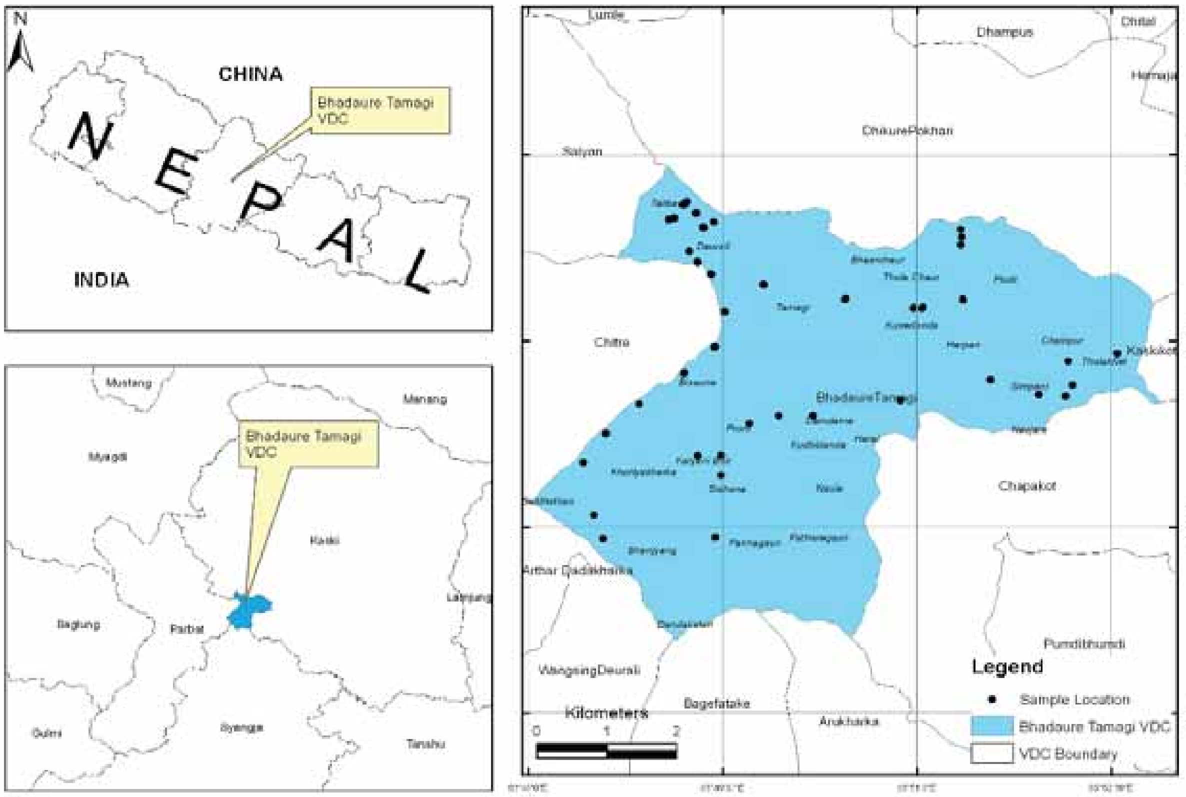


Figure 1. Study Area

Chromolaena odorata, Eichhornia crissepes 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.

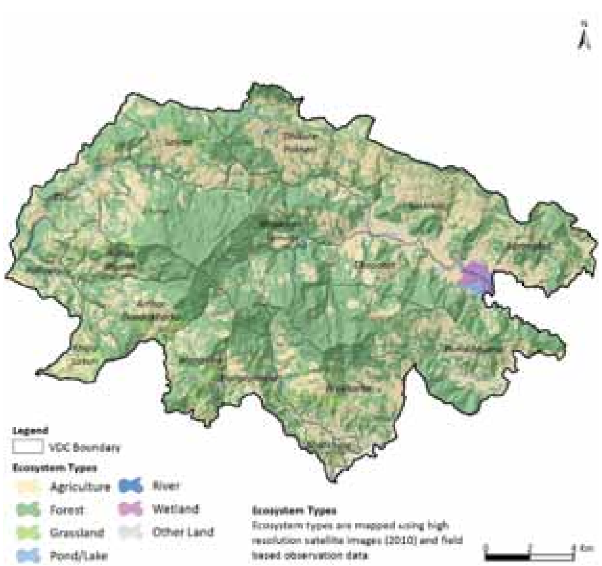


Figure 2. Ecosystem Types

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, Panchase 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.

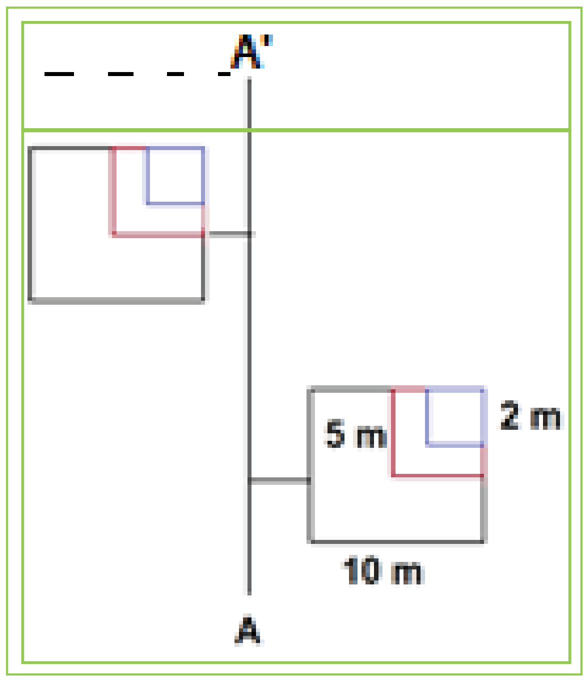


Figure 3. Layout of transect and sample

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 = Relative Frequency (RF) + Relative Density (RD) + 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, 14[2] 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 crissepes*, *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 crissepes, Hedychium gardnerianum, Hiptage benghalensis, Imperata cylindrica, 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	*Ageratina adenophora*	43.39
2	*Ageratum conyzoides*	31.91
3	*Chromolaena odorata*	28.83
4	*Eichhornia crissepes*	21.23
5	*Imperata cylindrical*	19.29
6	*Lantana camara*	17.00
7	*Leucaena leucocephala*	11.34
8	*Parthenium hysterophorus*	10.52
9	*Rubus ellipticus*	8.62

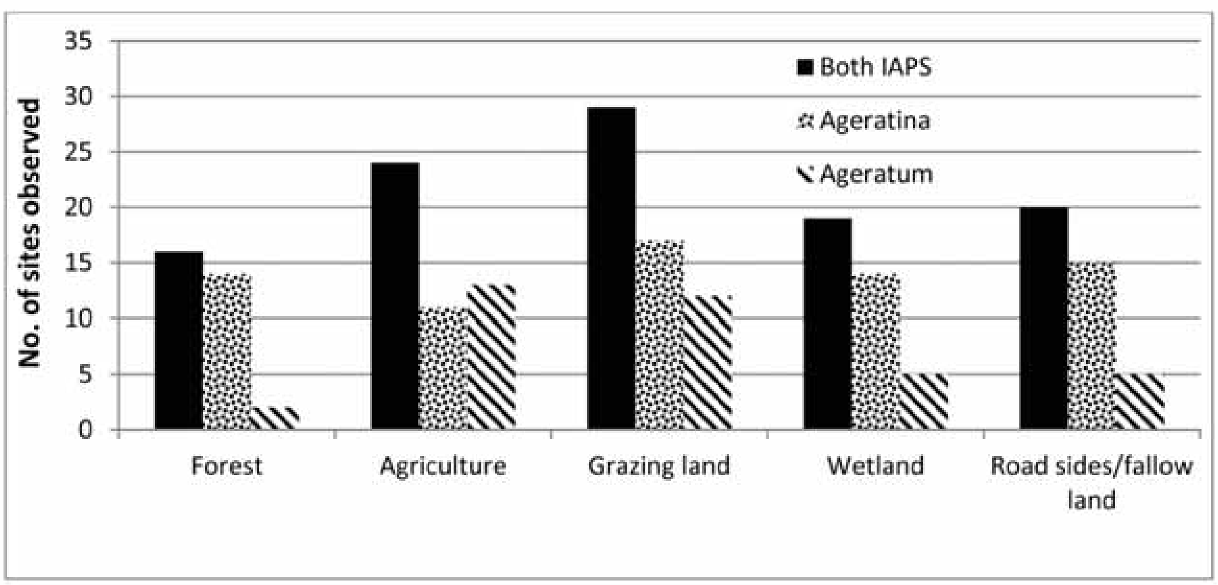
Detail analysis of IVI in the study area showed that *A. adenophora* was found invaded throughout the study site. However, it is mostly available at higher altitude of the study site. The transition lands between agriculture and forests, fallow lands and roadsides above 2,000 m of study site were the 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.



Impact of invasive alien plant species on important ecosystems

Table 2. Factors for invasion in percent (N = 28)

SN	Factors	Respondent (10%)	
		A. conyzoides	*A. adenophora*
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 provids 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 hiders 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.

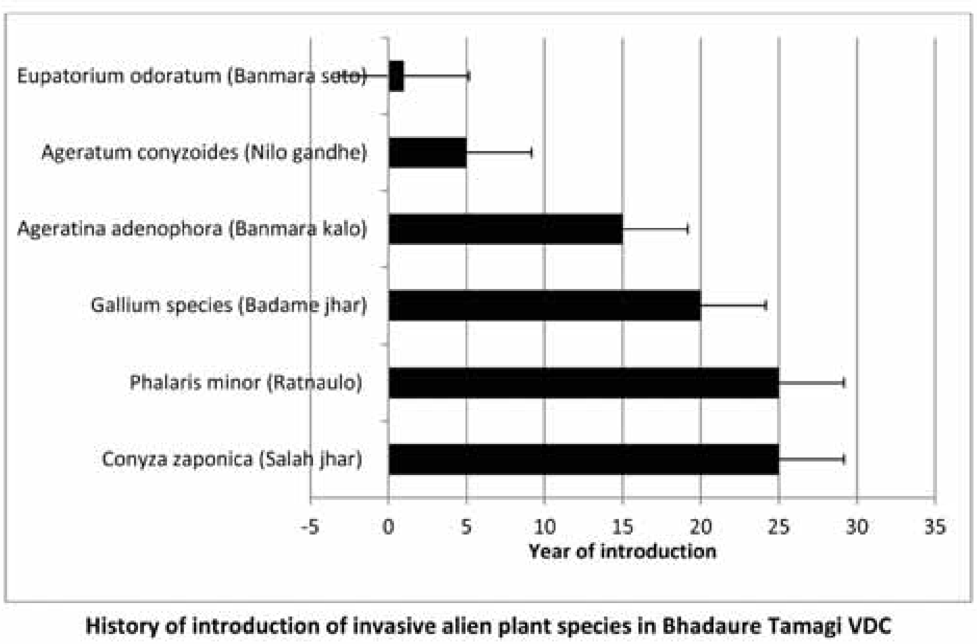


Figure 5. History of introduction of Invasive alien plant species in Bhadaure Tamagi VDC

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 (Tjitrosemito, 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 m^2) 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 lacoor, 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 per cent 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 in 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 threading 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, funguses 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; mono-cotyledons 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 (CO_2) 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 induces 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 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 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, diphyllobothriosis, 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 (Devleesschauwer *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-Briales 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 Measues (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 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 *Mikana 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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Invasive Alien Fauna of Nepal: Current Situation and Future Perspectives

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Abstract

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. The established IAS in non-native range are being a serious global issue. 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. Wide ranges of fauna are already introduced in Nepal including livestock breeds, wild mammals, birds, fish, molluscs, insects and freshwater prawn. This paper includes altogether 69 species of alien fauna of Nepal comprising insects (21 species), freshwater prawn (one species), platyhelminths (one species), fish (16 species), wild mammals (2 species), birds (3 species), and livestock breeds (25 improved breeds). Among reported alien species some species are member of top 100 dangerous invasive species of the world, some are serious pests of crops, vegetables and fruits and some are biocontrol agents such as predators, parasitoids, leaf minors, as well as some commercially exploited species such as silkworm, honey bees, fish and livestock breeds.

Keywords: Alien, invasive species, fish, pests, snail, slug, insect.

INTRODUCTION

Species which are introduced outside their natural distribution range are known as alien. There are several terminologies have been used for alien species such as exotic species, introduced species, non-native species, non-indigenous species and invasive species. But not all alien species are invasive but some of them have been established as invasive, start competing with native species causing a negative impact on local species, ecosystems and habitats. Biological invasions by non-indigenous species (NIS) are widely recognized as a significant component of human-caused global environmental change, often resulting in a significant loss in the economic value, biological diversity and function of invaded ecosystems (Humle, 2003). Invasive alien species (IAS) belong to all major taxonomic groups such as micro-organisms, fungi, plants, invertebrates, fish, amphibians, reptiles, birds and mammals (Fig. 1 and 2) comprising highest number of animal species of "100 world's worst IAS" (Lowe et al., 2000). Mostly all these IAS are introduced by human agencies either accidentally with trading goods or intentionally in the form of commodities such as livestock, pets, nursery stock, and produce from agriculture and forestry (McNeely et al., 2001). Invasive species are the global concern due to economic and biodiversity loss across the world. A study result of six countries (Australia, Brazil, India, South Africa, United Kingdom and United States) alone estimated 120,000 alien species in these countries causing economic loss of $ 314 billion every year (Pimentel et al., 2001).

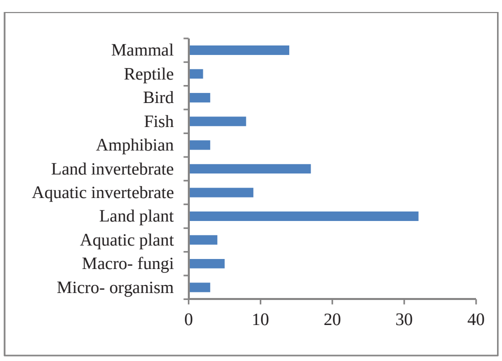

Figure 1.

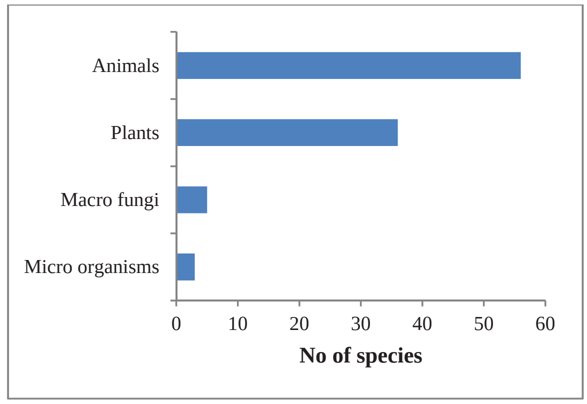

Figure 2.

Figure 1. Major groups of IAS among "100 world's worst invasive alien species" (Lowe et al., 2000). Figure 2. Proportion of animal species among the most dangerous 100 IAS of the world.

In comparison to alien plant species of Nepal, alien fauna are poorly investigated and relatively neglected. Budha (2013) produced the first preliminary documentation on invasive alien fauna of Nepal and provided the first hand information about 27 aliens species including one species of crustacean, seven species of insects, nine species of molluscs, nine species of fish and one species of bird, however many more species need to be explored to produce the complete list of animal alien species. Nevertheless, there is a complete gap of information on the impacts of introduced faunal aliens and their invasive nature in Nepal.

This paper provides a baseline data on the introduced alien and invasive fauna of Nepal and briefly discusses the potential impacts of worst invasive species on native biodiversity and human property.

MATERIALS AND METHODS

The work is primarily based on the best available published information and field observations made by author. All non-native species were collected from journal articles, books and reports. Native ranges of species were verified and year of introduction in Nepal for each species were included wherever data were available. The most dangerous invasive species of world tallied with the list of Nepalese fauna and their impacts are discussed.

RESULTS AND DISCUSSION

Alien and Invasive Animal Species Introduced in Nepal

Alien species in this paper includes livestock breeds, wild mammals and birds, fish, insects, molluscs and helminthes. Invasive species among all known alien animal species have been identified. All alien species are grouped under separate heading as follows;

Introduced Livestock Breeds

Livestock raising is a fundamental component of the farming systems of Nepal which provides draught power for tilling farmland and transporting goods, wool, and meat besides manuring field crops and nourishing the farmer. It has been the second major economic activity substantially contributing to household income through sale of cattle, sheep, goat and sheep for meat and milk products. The emphasis has been given to the improved livestock breeds to increase national production. Table 1 shows the important livestock breeds introduced in Nepal.

Table 1. Improved livestock breeds introduced in Nepal

Livestock	Year of Introduction	Country of origin
Cows		
1. Jersey	1840s	UK
2. Holeistin	1950s	EU
3. Brown Swiss	1950s	Switzerland
4. Haryana	1964	India
5. RD Sindhi	1950s	India
6. Tharparkar	1950s	India
7. SiriBuffalo	1950s	India
Buffalo		
8. Murrha	Unknown	India
Goats		
9. Jamunapari	1920s	India
10. Barberi	1930s	India
11. Shannan	1970s	Israel
12. Bengal black		India
Sheep		
13. Corriedale	1940s	UK
14. Merino	1950s	New Zealand
15. Pollwarth	1950s	New Zealand
16. Rambuillet	1950s	Europe
Pigs		
17. Landrace	1950s	Europe and USA
18. Hampshire	1950s	Europe
19. Yorkshire	1950s	USA
20. Duroc	1950s	
Chicken, Turkey birds		
21. New hamshire	1940s	USA
22. White leghorn	1940s	USA
23. Austrolorp	1970s	Australia
24. Giri Raj		
25. Turkey bird	2001	

Source: Shah (2010)

Wild Mammals and Birds

Alpaca *Vicugna pacos* (Mammalia: Artiodactyla: Camelidae)*:* Five alpacas, native to south America (Andes of southern Peru, northern Bolivia and Chile) were first brought by air cargo of Lufthansa jet in 1997 (Subedi, 2000). The commercial farming of alpaca has been started for high quality wool in Godavari, Lalitpur district.

Russian Wild Boar *Sus scrofa scrofa* (Mammalia: Artiodactyle: Suidae): There are 20 subspecies of wild boar divided into four major subspecies groups based on their relative lengths and shapes of the lacrimal bones these are: Western race (*scrofa* group), Indian race (*crystatus* group), Eastern race (*leucomystax* group) and Sundaic race (*vittatus* group). The native wild boar of Nepal belongs to *cristatus* group but the introduced wild boar belongs to *scrofa* group. The exact date of its introduction in Nepal is not yet properly documented. The available report indicates that it was released in Shivapuri National Park in 1980s (HMG/N, 1995). It is believed that the late King Mahendra Bir Bikram Shah brought this species as a gift from Russia and released in Shivapuri National Park which is different with native wild boar by brown colour, but the native species is black (Chalise, 2013). Unless tracing out the official records or evidences, this wild boar was probably reared in the Royal palace before the King's death in 1972 and released in Shivapuri later. Chalise (2013) also pointed out that the introduced species have been spread in hills from east to west, however, it is still matter of investigation whether the introduced species is restricted within Shivapuri area or spread to other parts of the country. This is the most problematic wild animal in Shivapuri National Park (=Nagarjun-Shivapuri National Park) responsible of human wildlife conflict.

Birds

Ostrich *Stuthio camelus* (Aves: Struthioniformes: Struthionidae): The ostrich is the largest and flightless bird native to Africa. It was introduced from Australia in Nepal in 2009 (www.**ostrichnepal**.com). The commercial farming of Ostrich has been started in Gangoliya, Rupandehi for its egg, meat, feathers and leather. The farming is now extended to Dang district.

Emu *Dromaius novaehollandiae* (Aves: Struthioniformes: Dromaiidae): The Emu, soft feathered and flightless bird which is second largest extant bird in the world. It is native to Australia. It has been recently introduced in Nepal for commercial farming.

Budgerigar *Melopsittacus* sp. (Psittaciformes: Psittaculidae)- Budgerigars are common pet parakeets, which have been illegally traded in Kathmandu. These birds were seen in home garden in Kathmandu in 1992 but there are no subsequent reports in Nature (per. commun. Baral).

Fish

The exact number of exotic fish species in Nepal varies according to different authors ranging from 8 to 11 (Shrestha, 1994, 2013; Sharma, 2008), however, the list of the most of the aquarium species have not yet been updated. Based on the database available in web site of Fishbase (www.fishbase.org), there are altogether 238 species of fish have been reported from Nepal including 16 introduced species, 4 endemic species, 178 native species and doubtful occurrence of 38 species. Some of the introduced fishes viz. *Clarias batrachus, Gambusia affinis* erroneously considered as native by some authors (Shrestha, 2013; Sharma 2008). The list of exotic fish species of Nepal are included in Table 2.

Table 2. Exotic fish species of Nepal

Order: Family: Zoological name	Common name	Origin	Introduced year
ORDER: ANGUILIFORMES, Family: Clariidae			
1. *Clarias batrachus*	Philippine Catfish	Indonesia	Unknown
2. *Clarias gariepinus*	African Catfish	Africa	1996-97
ORDER: CYPRINIFORMES, Family: Cyprinidae			
3. *Barbonymus gonionotus*	Silver Barb	SE-Asia	Unknown
4. *Ctenopharyngodon idella*	Chinese Grass Carp	China	1965/66
5. *Cyprinus carpio*	Common Carp	E-Asia	1979
6. *Cyclocheilichthys apogon*	Beardless Barb	Myanmar to Indonesia	Unknown
7. *Hypophthalmys molitrix*	Silver Carp	China	1967/68
8. *Hypophthalmys nobilis*	Big-head Carp	China	1971
9. *Carassius auratus*	Gold Fish	E-Asia	Unknown
10. *Carassius carassius*	Crucian Carp	Europe	Unknown
ORDER: CYPRIONODONTIFORMES, Family: Poecilidae			
11. *Gambusia affinis*	Mosquito Fish	N America	1994
ORDER: PERCIFORMES, Family: Cichlidae			
12. *Oreochromis mossambicus*	Mozambique Tilapia	Africa	1985
13. *Oreochromis niloticus*	Nile Tilapia	Africa	1985
ORDER: SALMONIFORMES: Family; Salmonidae			
14. *Onychorynchus mykiss*	Rainbow Trout	N America	1971, 1988
15. *Onychorynchus rhodurus*	The Biwa Trout	Japan	1975
16. *Salmo trutta*	Brown Trout	Europe	1969

Source: Shrestha (1994, 2013); Gurung et al. (1994), Rai et al. (2003, 2005), Sharma (2008), Bista et al. (2011), www.fishbase.org (Accessed 7 May 2014)

Insects, Non-insect Arthropods and Molluscs

Exotic species of insects and non-insect invertebrates are the most neglected groups and the information on how many species of alien and invasive species occur in Nepal are not yet documented properly. Many species have been established as pests causing serious problems in agriculture *viz*. The Potato Tuber Moth (PTM) *Phthorimaea operculella,* The San José Scale *Quadraspidiotus perniciosus* (=*Diaspidiotus perniciosus),* The *Leucaena* Psyllid *Heteropsylla cubana* and The African Giant Land Snail *Lissachatina fulica.* The list of introduced species of arthropods and molluscs are given in table 3 and 4.

Table 3. List of Alien and invasive species of Arthropods in Nepal

Order/Family/Zoological Name	Common Name	Introduced in Nepal (Yr)
CLASS: CRUSTACEA, ORDER: DECAPODA, Family: Palaemonidae – Freshwater Prawn		
1. *Macrobrachium rosenbergii*	Giant Freshwater Prawn≠	1986, 1999
CLASS: INSECTA: ORDER: DIPTERA: Family: Agromyzidae - Leaf minor		
2. *Liriomyza huidobrensis*	S-American Leaf Minor**	Unknown
Family: Tephritidae - Fruit flies, gall fly		
3. *Dacus (Didacus) ciliatus*	Ethiopean Melon Fly**	1978
4. *Carpomya vesuviana*	Fruit Fly**	Unknown
5. *Carpomya pardalinia*	Baluchistan Melon Fly**	Unknown
6. *Bactrocera (Paratridacus) diversa*	Guava Fruit Fly **	Unknown
7. *Bactrocera (Daculus) oleae*	Olive Fruit Fly**	Unknown
8. *Bactrocera (Zeugodacus) caudate*	Fruit Fly**	Reported in 1976
9. *Procecidochares utilis*	Gall Fly*	1963 from New Zealand
ORDER: HOMOPTERA, Family: Aphididae – Aphids		
10. *Ceratovacuna lanigera*	Sugarcane Wooly Aphid (SWA)**	Unknown
11. *Eriosoma lanigerum*	Wooly Apple Aphid (WAA)**	1962
Family: Diaspididae - Scale insect		
12. *Quadraspidiotus pernicious*	San Jose Scale**	1962 from India
Family: Margarodidae - Cushion scale insect		
13. *Icerya purchase*	Cottony Cushion Scale**	Unknown
Family: Psyllidae - Psyllids		
14. *Heteropsylla cubana*	Ipil-ipil (*Leucaena*) Psyllid**	1987
ORDER: COLEOPTERA, Family: Chrysomelidae		
15. *Zygogramma bicolorata*	*Parthenium* Defoliator*	
ORDER: HYMENOPTERA, Family Braconidae – Parasitoids		
16. *Apanteles subandinus*	PTM Parasitoid*	2009-10
17. *Orgilus Lepidus*	PTM Parasitoid*	2009-10
Family: Encyrtidae		
18. *Copidosoma koehleri*	PTM Parasitoid*	2009-10
Family: Apidae		
19. *Apis mellifera*	European honey bee≠	
ORDER: LEPIDOPTERA, Family: Bombycidae		
20. *Bombyx mori*	The silworm≠	
Family: Gelechiidae		
21. *Phthorimaea operculella*	PTM	1966 from India

Source: Kapoor & Malla (1978, 1979), Joshi (2004); Kapoor (2005), Sharma and Subba (2005), CABI (2009), FAO (2009), Shrestha (2011), Budha (2013). Note: * Biocontrol agents, ** pests, ≠ Commercially exploited species

There are nine species of alien molluscs reported from Nepal, however origin of *Gulella bicolor* is still doubtful. African Giant Land Snail *Lissachatina fulica* is well established in almost all Tarai districts and some mid hill districts of Nepal (Budha and Naggs, 2008) which is becoming a serious pest of vegetables. The presence of another serious pest of rice *Pomacea canaliculata* is not yet confirmed however this species is already established in India, China, Sri Lanka and SE Asian countries and shape and size is similar with native species *Pila globosa* but the further work is needed to confirm the status of introduced species.

Table 4. List of alien and invasive species of molluscs in Nepal

Order/Family/Zoological Name	Common Name	Origin	Introduced in Nepal (Yr)
CLASS: GASTROPODA, ORDER: STYLOMMATOPHORA- Terrestrial snails and slugs			
Family: Achatinidae			
1. *Lissachanina fulica*	African Giant Land Snail		1930s-40s
Family: Streptaxidae			
2. *Gulella bicolor*	Two-toned gulella		Unkown
Family: Agriolimacidae			
3. *Deroceras leave*	The Marsh Slug		Unknown
Order: Systelommatophora, Family : Veronicelidae			
4. *Laevicaulis alte*	The Veronicellid Slug		Unknown
Family: Ampullariidae			
5. *Pomacea canaliculata*	The Golden Apple Snail		Not confirmed
Order:			
6. *Filopaludina sumatrensis*			Unknown
7. *Pseudosuccinea columella*			Unknown
8. *Planorbarious corneous*			Unknown
Family: Viviparidae			
9. *Viviparus* sp.			Unknown

Source: Budha and Naggs (2008), Irikov and Beckev (2011)

Helminth: Terrestrial flat worm *Platydemus manokwari* is reported from Langtang National Park and Nagarjun-Shivapuri National Park. Further analysis of this species is needed.

Commercialized Alien Fauna

The Silkworm *Bombyx mori:* The silkworm is native to China which has been introduced throughout the world for the commercial production of silk. It is now entirely domesticated and not known in the wild state. Among the commercialized insects, subspecies of European honey bee *Apis mellifera ligustica* introduced in 1990 and later another sub species *carnica* was introduced but not successful. Similarly *Bombyx mori* was introduced 1911, 40, 50s in Nepal but the commercial farming started only after 1967.

The European Honey Bee *Apis mellifera:* It is native to Europe. This European species has been introduced in Hindukush- Himalayan region for getting high yields of honey. Introduction of *Apis mellifera* in Asia have encountered a number of problems such as the inter-species transmission of bee pests and diseases (Ahmad et al., 2004). Robbing behaviour is the interspecific relations between introduced *A. mellifera* and native *Apis cerana* which displace the later one.

Fish species: Fish is the major source of protein for fisher communities depending on capture fishery for livelihood. Fisheries sector contributed over 0.94 % in national GDP and 2.72 % in AGDP with a growth rate of 6.3% (Mishra and Upadhyaya, 2011). Therefore, fisheries and aquaculture is a priority sector of government of Nepal. To boost up the fish production in Nepal many introduced species *viz*. Rainbow trout, Carps, tilapia, catfish have been commercially exploited in different parts in Nepal in ponds, natural lakes, reservoirs and cold water river streams.

The Most Dangerous Invasive Fauna Introduced in Nepal

The African Giant Land Snail *Lissachatina fulica*

This species is also known as *Achatina fulica.* It is a member among 100 of the world's worst invasive alien species. It is native to East Africa but introduced throughout the world. A single pair of this snail was released in Culcutta by a British malacologist William Henry Benson in 1847 (Naggs, 1997). Probably the existing populations of this species in S and SE Asia belong to the single pair which has spread by the end of 1930s throughout South and South East Asian countries to Australia (Raut and Barker, 2002). Although the exact date of its arrival in Nepal is not known, it was likely entered to Nepal during 1930s-1940s in eastern Nepal (Budha and Naggs, 2008; Raut, 1999). Now, it has already been established in all districts of Tarai region including hill districts such as Kaski, Parbat, Baglung, Gulmi, Syangjha, Palpa, Surkhet, Chitwan, Dhading, Myagdi and Dang. It is a serious

pest of crops, vegetables and fruits in most of the established areas. The main cause of its dispersal in Nepal is due to human agency. The rate of spread is very rapid and some people, regarding it as a Chank shell, an important Hindu religious symbol of worship, unwittingly carry it to their homes. Specimens subsequently released into traditional home gardens rapidly become major pests, feeding on garden produce (Budha and Naggs, 2008).

The Golden Apple Snail *Pomacea canaliculata*

This is a freshwater mollusc native to South America but has been spread widely through the aquarium trade and as food value (Watanabe et al., 2000; Mordan et al., 2003). It is already spread in India, Bangladesh, Pakistan, Vietnam, Thailand and Australia (Joshi, 2005). It is a serious pest of paddies where it eats the shoots of rice seedlings. This species has not yet been reported from Nepal. Probably, it has been already introduced in Nepal and has been considered as the native species *Pila globosa* due to similar colour pattern and same shell size (Budha, 2013). It can be distinguished from *P. globosa* due to golden-brown colour, thin, horny operculum and characteristic bright pink egg mass.

The Mosquito Fish

This is small larvivorous fish native to southern parts of Illinois and Indiana, throughout the Mississippi River and its tributary waters, to as far south as the Gulf Coast in the northeastern parts of Mexico (Krumholz, 1944). It has been introduced in several countries in the world to control mosquito larvae. Although the exact date of the introduction in Nepal is not known, it was first reported by Shrestha (1994) in Bagmati river, Kathmandu. But there are no subsequent reports of this species in other part of Nepal. The existence of this species in Nepal is doubtful. The mosquito fish is a small, harmless-looking fish native to the fresh waters of the eastern and southern United States. It has become a pest in many waterways around the world following initial introductions early last century as a biological control of mosquito. In general, it is considered to be no more effective than native predators of mosquitoes. The highly predatory mosquito fish eats the eggs of economically desirable fish and preys on and endangers rare indigenous fish and invertebrate species.

Tilapia

Out of about 70 known species of Tilapia (all native to Africa), 10 species have been used for aquaculture (ADB, 2005). Two species of Tilapia in culture practices in Nepal are *O. mossambicus and O. niloticus.* The previous one is listed among the worst invasive species of the world. In Nepal it has also released in large natural lakes such as Phewa, Begnas, Rupa lakes of Pokhara valley, Indrasarobar and other parts.

Cat fish

Clarias batrachus, a air breathing catfish, native to SE Asia (Indonesia), is another member of the world's worst invasive species. It is introduced in several part of the world including Nepal. Another catfish is *C. garipenius,* which is native to Africa is also commercialized in Nepal. It has been reported in the natural river system in eastern Nepal, tributaries of Tamor river (Sharma, 1999).

Rainbow and Brown trout: Rainbow trout is a coldwater carnivorous fish that feed upon aquatic and terrestrial invertebrates, eggs and larvae of native fishes and other fish fry. It is native to Pacific coast of North America and the Kamchatka Peninsula. It has been introduced to 87 countries worldwide (Welcomme, 1992) as commercial table and game fish. In Nepal, it is highly prioritized species for commercial purpose but it is also listed in the worst invasive species of the world (Lowe

et al., 2000). Both of above trout, Rainbow and Brown have negative impacts on local biodiversity in the established areas (Kitano, 2004). These two species have been successfully established in rivers and streams in Japan and Himachal Pradesh, NW India (Kitano, 2004, http://hpfisheries.gov.in). They are reportedly forced the native fish species to shift their foraging habitats in picking benthic insects from the streambed and the biomass and responsible in reducing prey species by 75 % (Fausch et al., 1997; Nakano et al., 1999).

Terrestrial Flatworm *Platydemus manokwari*

The terrestrial flat worm *P. manokwari* is listed as the 100 most dangerous invasive species in the world feeding upon native snails and earthworms in introduced areas. Terrestrial molluscs are the principal prey in the field (Justine et al., 2014). It was confined to the Indo-Pacific region within the bounds of the Ogasawara Islands, Japan in the north; near Mackay in Queensland, Australia to the south; French Polynesia to the east; with the most westerly extent of the flatworm in the Maldives

(Justine et al., 2014). It has been accidentally introduced, probably together with plants and soil, to various islands in the Pacific region including Australia, Guam, Palau, Hawaii, Federated States of Micronesia, French Polynesia, and Samoa. It prefers wet and humid conditions. The possible threshold temperature for the establishment of *P. manokwari* is 10°C (Sugiura, 2009). It is recently reported from the national parks of Nepal in Langtang National Park and Nagarjun-Shivapuri National Park. It is still not known how it is introduced in these areas. Unless the further investigation on molecular taxonomic studies to confirm its status, it is provisionally identified as *P. manokwari* based on the morphological characters.

Impacts of Invasive Species

Every alien species that becomes established alters the composition of native biological communities in some way. The ecological impact of the loss of biodiversity due to IAS depends to a large extent on the link between native species (McNeely et al., 2001). Although impact analyses of invasive species have not yet been carefully studied in Nepal, some reports clearly indicate that invasive species play destructive role in natural ecosystem and human economy. It was reported that 42 percent reduction of the native fishes in Begnash lake, Pokhara after the introduction of Bighead Carp, Silver Carp and Grass Carp (Swar and Gurung, 1988). More than seven species have been vanished from Indrasarobar (Swar, 1992) and only two native fish species *Neolissocheilus hexagonolepis* and *Nazirator chelynoides* are left (Saud and Shrestha, 2007). Invasion of this fish in Yamuna river eat detritus, filamentous and cellular algae, zooplankton, fish, insects. It is spread to Godavari, Krishna, Cauveri, Yamuna and Ganga river in India (Ganie et al., 2013). In high altitude mountains the rainbow trout farming is considered one of the successful technologies in Nepal (Gurung, 2008) without noticing of its voracious nature of predation on natural aquatic fauna if released into natural water bodies. Local breeds such as Achhame, Lulu cows are in threat and most of the hill cows in eastern part of Nepal have been replaced by Siri breeds.

The insect pest species are major problems in agricultural productivity by reducing significant loss of yield for example the PTM is an introduced species which causes 30-85% losses of stored potato and the standing crop (Joshi, 1989; Lal, 1998; Chandla and Verma, 1998; Chandel and Chandla, 2005), often reached to 100% during heavy infestation if control measures are not applied (Das, 1992; NPRP, 2004/05; SSMP, 2008). *Liriomyza huidobrensis* is a serious pest for the floriculture industry where leaf-miner damage directly affects the marketable portion or in vegetable crops where the leaves are sold as the edible part, i.e. spinach, beet greens, Asian greens, lettuce and leeks.

Conclusion

Altogether 68 species of alien species have been reported in this paper including 20 species of insects including commercial insects, pests and biocontrol agents (predator, parasitoid, defoliator, gall insect), one freshwater prawn, one species of platyhelminths, 16 species of fish, 2 species of wild mammals, 3 species of birds, and 25 species of livestock breeds. Out of all reported alien species 8 species are the most dangerous species of the world listed in the top 100 invasive species of the world among which existence of Mosquito fish *Gambusia affinis* and its distribution in Nepal is yet to be verified. Likewise doubtful presence of another species the Golden Apple Snail *Pomacea canaliculata* is yet to be proved taxonomically.

In comparison to the invasive plant species, their distribution pattern, impact studies have been comparatively better studied than animal species. Some of the invasive species causes serious loss of crop yield such as *Lissachatina fulica, Phthorimaea operculella* and *Liriomyza huidobrensis,* impact assessments of most of invasive species in Nepal are still to be performed. Documentation of all alien and invasive animal species, their distribution mapping, impacts studies are urgently required to overcome the negative ecological impacts and economic as well as biodiversity loss of the country.

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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 (*Cymsopogon* 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 plant 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. 1.

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 climactically 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 beelte 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 1m × 1m 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/m^2. 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/m^2 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 accidently 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 km^2 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;* $R^2 = 0.68$, $p < 0.0001$) and percentage cover of native forage plants (% Native cover = 79.80 (±1.7) - 0.87 (±0.1) * % *Mikania* cover; $R^2 = 0.89$, $p < 0.0001$) 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 ($\chi^2_{(6\ df)} = 115.27$, $P < 0.0001$) was 10–20% > 20–30% > 1–10% > 0%

> 40–50% > above 50%. ii) The cool dry season preference ($\chi^2_{(6\ df)} = 64.55$, $P < 0.0001$) was 10–20% > 20–30% > 30–40% > 1–10% > 0% > above 50% > 40–50%. iii) The hot dry season preference ($\chi^2_{(6\ df)} = 67.39$, $P < 0.0001$) was 10–20% > 1–10% > 20–30% > 0% > 30–40% > above 50%. iv) The order of preference for the monsoon season was same ($\chi^2_{(6\ df)} = 75.56$, $P < 0.0001$) 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. hysterophrus* extract on seed germination. The alien weed species appeared to be more tolerant to allelopathic effects of *P. hysterophorus* than native plant species.

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 (≥ 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 m^2 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 *Anzar A. Khuro, Zafar A. Reshi, Irfan Rashid, Akhtar H. Malik, G. H. Dar*
	2. Invasive plant problems and need for risk assessment in India *Mool Chand Singh, N. T. Yaduraju, Madhu B Priyadarshi, K. C. Bansal*
	3. Invasive plant threats to forests in the humid tropics: a case study from Kerala State, India *K. V. Sankaran, T. V. Sajeev, T.A. Suresh*
	4. Monitoring and control of invasive species in the grassland ecosystem of Manas World Heritage Site, India *Bibhuti P. Lahkar, Anukul Nath, Sonali Ghosh*
	5. Invasive alien species: threats and challenges for biodiversity conservation - A case study from Annapurna Conservation Area, Nepal *Neeru Thapa, Menuka Maharjan*
	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 *Steve Adkins, Sangita Shrestha, Asad Shabbir, Bharat B. Shrestha*
	2. The current and potential geographic distribution of invasive Parthenium weed in South Asia *Asad Shabbir, Myron P. Zalucki, Kunjitapatham Dhileepan, Bharat B. Shrestha, Steve W. Adkins*

	3. Distribution, spread and status of Parthenium weed and its biological control agent in Nepal *Bharat B. Shrestha, Kusum Pokhrel, Nirmala Paudel, Sushmita Paudel, Asad Shabbir, Steve Adkins*
	4. Genetic diversity assessment of the alien invasive weed *Parthenium hysterophorus* L. in Nepal *Sangita Shrestha, Smita Shrestha, Jagat K. C. Shrestha, Bharat B. Shrestha, Steve W. Adkins*
	5. Plant species composition and soil seed bank in *Parthenium hysterophorus* invaded grassland of Hetaunda, Central Nepal *Jyoti Khatri-Chettri, Ambika Paudel, Bharat B. Shrestha*
	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 *Mikania micrantha* on greater one-horned rhinoceros conservation in Chitwan National Park, Nepal *Naresh Subedi, Shant R. Jnawali, Babu R. Lamichhane, Rajan Amin, Y. V. Jhala*
	2. Invasive plants and rural livelihoods: an assessment of the effects of the invasion of *Mikania micrantha* in rural livelihoods in Nepal *Rajesh K. Rai, Helen Scarborough*
	3. Status of *Mikania micrantha* invasion in the rhino habitat of Chitwan National Park, Nepal *Babu R. Lamichhane, Naresh Subedi, Nawa Raj Chapagain, Maheshwar Dhakal, Chiranjibi P. Pokheral, Sean T. Murphy, Rajan Amin*
	4. Antimicrobial activities and phytochemical screening of leaf extract of *Mikania micrantha* *Anita Sahu, A. Devkota*
16:00–16:20	***Tea Break***
	5. Germination response of fallow-land plant species of central Nepal to allelopathic effect of *Parthenium hysterophorus* L. *Ambika Paudel, Jyoti Khatri-Chettri, Bharat Babu Shrestha*
	6. Vulnerability assessment of different land use types to invasion by *Parthenium hyetsrophorus* L. in western Chitwan, Nepal *K. Bhusal, M. P. Devkota, B. B. Shrestha*
	7. Changes in cropping patterns, resilience and invasive plant species in social-ecological systems: A study of the home gardens of Kerala, India *Kate L. Jones*
	8. An investigation into the compliance of selected nurseries and garden centres within Kwazulu-Natal Wthekwini and Umsunduzi geographical regions, South Africa *Astrid Beverley Badenhorst*
	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 *Mohan Siwakoti, Bharat Babu Shrestha*
	2. Invasive alien fauna of Nepal: problems and future perspectives *Prem B. Budha*
	3. Impact if invasive alien fish, Nile Tilapia (*Oreochromis niloticus*) on native fish catches of sub-tropical lakes (Phewa, Begnas and Rupa) of Pokhara Valley, Nepal *Md. Akbal Husen*
	4. An integrated framework for monitoring plant invasion in tropical India *Ninad, Mungi, Qamar Qureshi Yadvendradev Jhala*
	Discussion, Question/Answer
	Mikania Movie by Dr. K. Sankaran (15 minutes)
11:00–11:15	***Tea Break***
Second Session **11:15–13:10**	**Session Chair:** Mr. Ganga Jang Thapa **Co-Chair:** Ms. Keshari Rajkarnikar **Panelists:** Dr. Anzar Khuro, Dr. Dean Current
	1. Environmental bad to good: exploitation of *Mikania micrantha* for compost *Rajan Subedi, Rajesh K. Rai*
	2. The biology and management of Mikania: An impact assessment on crop production systems in Viti Levu, Fiji *Apai Macanawai, Michael Day, Tessie Tumaneng-Diete, Steve Adkins*
	3. Factors affecting alien species invasion and their impacts on different ecosystem in Panchase Area Nepal *Sony Baral, Anu Adhikari, Rajendra Khanal*
	4. From weeds to wealth: a case study from the wetland project, Nepal *Shalu Adhikari, V. N. Jha*
	5. Invasive alien species management through utilization for application in domesticated livestock species raising *Krishna Kaphle, Chiranjibi Pd. Pokheral*
	Discussion, Question/Answer
	Implementing management of invasive alien species – learning from global experiences with invasive plants to optimize the way forward *Sean T. Murphy, Naresh Subedi*
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 achieveable 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
174	Tina Baidar	Kathmandu University
175	Tirtha Lama	NTNC - BCC
176	Uttal Mainali	NTNC - MCAP
177	Yam Bahadur Khanal	DFO Bharatpur Chitwan

Annex V

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