Journal of Environmental Management 229 (2019) 38–47

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Community perception and prioritization of invasive alien plants in Chitwan-Annapurna Landscape, Nepal

Bharat Babu Shrestha[a,*], Uttam Babu Shrestha[b], Krishna Prasad Sharma[a], Resham Bahadur Thapa-Parajuli[c,d], Anjana Devkota[a], Mohan Siwakoti[a]

[a] Central Department of Botany, Tribhuvan University, Kirtipur, Kathmandu, Nepal
[b] Institute for Agriculture and the Environment, University of Southern Queensland, Toowoomba, QLD, 4350 Australia
[c] Central Department of Economics, Tribhuvan University, Kirtipur, Kathmandu, Nepal
[d] Hull University Business School, University of Hull, HU6 7RX, Hull, UK

ARTICLE INFO

Keywords:
Focus group discussion
Community forestry
Invasive species management
Species prioritization
Ecosystem services
Stakeholder engagement

ABSTRACT

The management of invasive species is a complex, yet an essential component of biodiversity conservation and environmental management for sustainable futures. Despite a well-established linkage between biological invasions and human activities, the social dimension of invasive species management is less explored as compared to the ecological aspects. In recent years, the active participation of local communities, such as assessing levels of awareness and the selection of targeted species prioritized by communities, has been considered as a crucial element for managing invasive species. We conducted 32 focus group discussions (FGDs) including 218 participants in Chitwan-Annapurna Landscape (ChAL) of central Nepal, to assess knowledge and perceptions of agrarian and forest-dependent communities about invasive alien plants (IAPs), document the efforts of the community management of IAPs and prioritize IAPs for management. In the prioritization exercise, participants of each FGD were asked to rank three IAPs using scoring methods and to express their experience about the effects of the selected IAPs on humans and the environment. We found that communities had a living memory of the arrival of some of the IAPs in their locality without knowing the exotic nature of IAPs. Biodiversity loss, livestock poisoning, reduced agricultural production and forage supply, and negative impact on forest regeneration were reported as major negative impacts of IAPs. Communities also reportedly utilized IAPs for medicinal purposes, making compost by using biomass, and controlling floods and landslides. None of the government and non-governmental organizations working in the sectors of biodiversity conservation and environmental management has informed local forest-dependent agrarian communities about the consequences of biological invasions and management of IAPs. However, local communities had already started controlling the spread of some IAPs through manual uprooting. They were able to spot, identify and prioritize IAPs for management and some of the prioritized species were among the world's worst invasive species. *Ageratum houstonianum* was the top-ranked worst invasive species in agroecosystems while *Chromolaena odorata* and *Ageratina adenophora* were the top-ranked worst species in natural ecosystems. Our findings will be useful for guiding community education programs as well as the management of IAPs through formal policy and management plans, such as Nepal's National Biodiversity Strategy and Action Plan.

1. Introduction

Biological invasions are continuously increasing in their spatial extent with a greater severity of impacts on the environment, agriculture, and livelihoods (Pejchar and Mooney, 2009; Simberloff et al., 2013; Paini et al., 2016). Despite several efforts to manage biological invasions, the number of alien species has been ever increasing across all taxonomic groups and geographic regions of the world (Seebens et al., 2017). Overall progress in achieving the targets of the Convention on Biological Diversity related to biological invasions (Aichi biodiversity target 9) is not satisfactory (CBD, 2014). Furthermore, the biological invasions are likely to be exacerbated by climate change (Bellard et al., 2013; Tittensor et al., 2014; IUCN, 2017) and further international trade (Levine and D'antonio, 2003). Therefore, the management of invasive alien species, which is an essential component of biodiversity conservation and environmental management, has become

* Corresponding author.
E-mail addresses: shresthabb@gmail.com, bb.shrestha@cdbtu.edu.np (B.B. Shrestha).

https://doi.org/10.1016/j.jenvman.2018.06.034
Received 28 November 2017; Received in revised form 7 June 2018; Accepted 12 June 2018
Available online 19 July 2018
0301-4797/

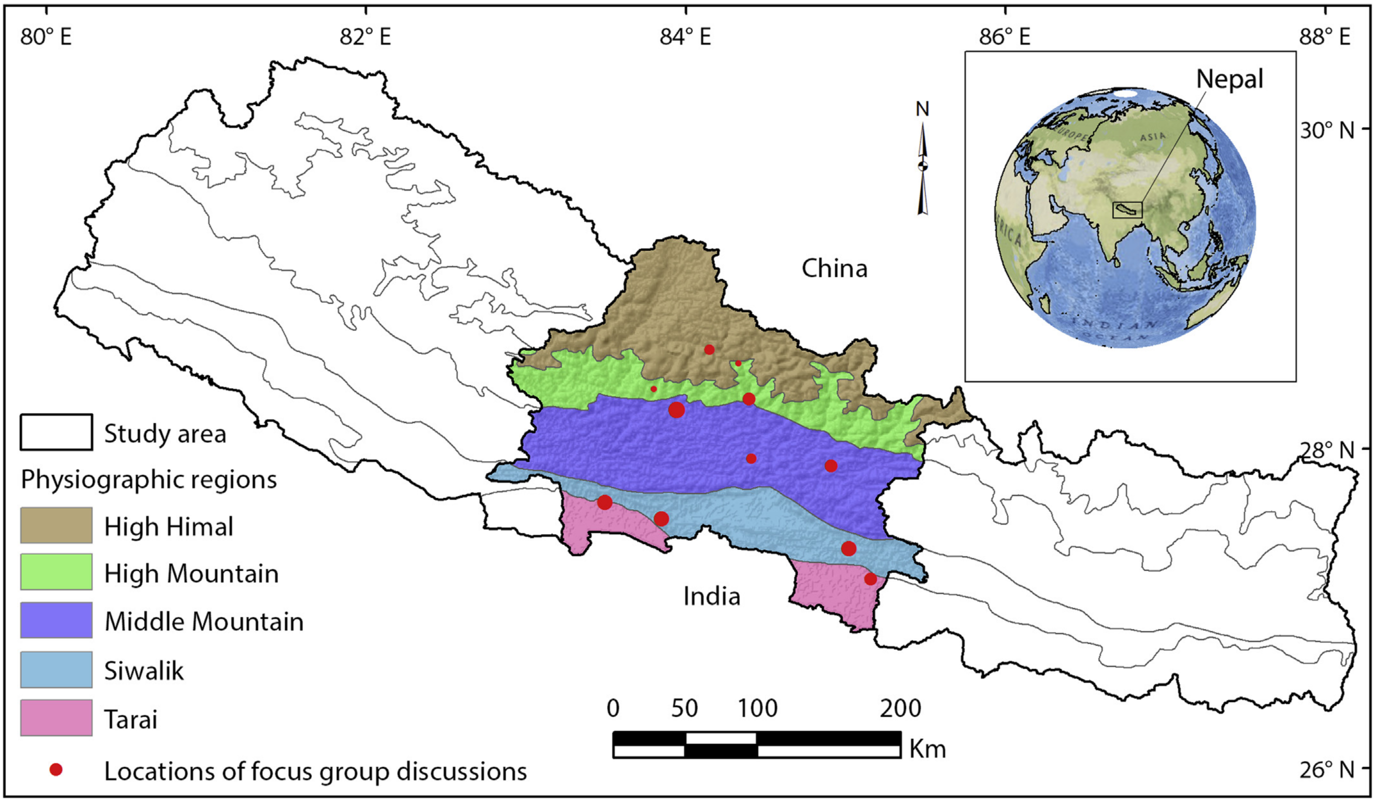

Fig. 1. Locations of focus group discussions (FGDs) in Chitwan-Annapurna Landscape and the adjoining three Tarai districts of Nepal. The relative size of dots indicates the number of FGDs ranging from 1 to 5 carried out in each location.

a major challenge globally.

Due to the inherent linkage between biological invasions and human activities, invasive species have become an important footprint and a part of social and economic processes linked to global environmental change (Vitousek et al., 1997). This implies that the social components of biological invasions need to be well articulated in management planning. Research on biological invasions has, however, traditionally focused on ecological and environmental aspects with a little consideration for social dimensions (García-Llorente et al., 2008). However, the inclusion of a strong social component together with environmental and economic dimensions surrounding invasive species management is needed (Larson et al., 2011). Realizing this gap has led to a recent increase in research on these topics (e.g., Marshall et al., 2011; Vaz et al., 2017; Shackleton et al. a, this issue) and this is one of the motivations behind this study as well.

From a sociological perspective, management of invasive species and environmental issues often requires a multi-stakeholder approach that includes a better understanding of the human dimensions (García-Llorente et al., 2008; Reed, 2008; Shackleton et al. b, this issue). Perceptions of invasive species, levels of awareness, and priority species for management often vary among different stakeholders. Engaging all stakeholders in invasive species management from inception to implementation of a project not only helps to make the management more effective but can also reduce conflict of interests among stakeholders, if they exist (Novoa et al., 2018) and can help build trust (Wald et al. this issue). In peri-urban and rural settings, one of the key stakeholder groups involved in the management of invasive species is agrarian and forest-dependent local communities. In Nepal, these forest-dependent communities have been instrumental for successful participatory biodiversity conservation and forest management programs (Acharya, 2002). This indicates a high potential for involving local communities in the management of invasive species, which have become increasingly problematic in many landscapes of the country (Murphy et al., 2013; MFSC, 2014; Shrestha et al., 2015; Shrestha et al., 2018a). Participation of local communities in invasive species management often depends on levels of community awareness, their perceptions of the problem, species of their priority, best practices to control the targeted species for management, and the incentives of management intervention for communities (García-Llorente et al., 2008; Shackleton and Shackleton, 2016, 2017). These social dimensions of biological invasions, including community involvement in invasive species management have not fully explored, in Nepal. A few studies related to social aspects of biological invasions conducted previously were focused either on very few species or confined to a single location (e.g., Rai et al., 2012; Rai and Scarborough, 2015; Baral et al., 2017). Given the physiographic, climatic and socio-cultural diversity of Nepal, findings of these localized studies could not provide sufficient evidence required to formulate and guide a national level policy and plans to manage invasive species.

To address knowledge gaps in social dimensions of invasive species management and ensure community involvement in management and planning, we conducted 32 focus group discussions (FGDs) in Chitwan-Annapurna Landscape (ChAL) of central Nepal that comprises all physiographic regions and climate zones of Nepal. This study aims to 1) assess the level of awareness of the local communities about biological invasions, 2) document local perceptions of the harmful and beneficial effects of invasive alien plants (IAPs), 3) examine local management efforts and practices, and 4) identify priority species for management based on local community prioritization. Management interventions focusing on those species which are given a high priority by local communities could help increase community participation and the cost-effectiveness of management (Boudjelas, 2009). The results of this research will be useful to guide community education programs as well as the management of IAPs through formal policy and planning - such as Nepal's National Biodiversity Strategy and Action 2014–2020 (MFSC, 2014).

2. Methods

2.1. Study area

The study was undertaken in Chitwan-Annapurna Landscape (ChAL), which lies in central Nepal and covers 19 out of the country's 75 districts. Four (Siwalik, Middle Mountain, High Mountain and High Himal) out of the five physiographic regions of Nepal are represented in the studied landscape. To represent the remaining physiographic region, the Tarai, we included additional three districts (Rupandehi, Bara and Parsa) in the ChAL area (Fig. 1). Tarai and Siwalik represent southern lowland and relatively plain area of the country with tropical to subtropical climate. Middle Mountain is a hilly region with subtropical to temperate climate. High Mountain and High Himal represents the northern part of the country with rugged topography, deep gorges, glaciers, and snow-capped mountain peaks. The present study area included altogether 22 districts of Nepal with an area of 39,743 square kilometers. The ChAL is an ecologically unique (confluence of eastern and central Himalaya) and socio-culturally diverse region with high potential and needs for conservation. This region has a higher number of naturalized plant species than those found in eastern and western Nepal (Bhattarai et al., 2014). It encompasses a vast elevation gradient (from < 100 to > 8000 m above sea level) with a climate ranging from tropical (Tarai), subtropical, temperate, subalpine to alpine (High Himal) including *trans*-Himalayan cold and dry climate similar to Tibet. The study area comprises two conservation areas (Annapurna and Manaslu), two national parks (Chitwan, also a World Natural Heritage Site, and Parsa), one hunting reserve (Dhorpatan), two Ramsar sites (Beeshazari and Pokhara lake systems) and three protected forests (Barandhabhar forest of Chitwan district, Panchase forest extending in Kaski, Syanja and Parbat districts, and Madani forest of Gulmi district). Annapurna Conservation Area and Chitwan National Park are the two most visited protected areas of Nepal by foreign visitors that attracted 83,419 and 87,391 tourists in the fiscal year 2015/2016 respectively (MCTCA, 2016). This area also has the major highways (e.g., Prithivi, Mahendra), big cities such as Pokhara, Narayanghat, and major entry ports in Nepal-India border (e.g., Birgunj and Bhairahawa) of the country. Agriculture and tourism are the primary livelihood activities for the inhabitants of this region and small enterprises based on forestry and agriculture have also emerged recently contributing to the region's economic development (MFSC, 2015).

Varied natural environments and high anthropogenic activities including trade, travel and tourism make the region vulnerable to biological invasions. Several invasive species already reported in the region are causing adverse impacts on both biodiversity and human life. *Mikania micrantha* has invaded major parts of Chitwan National Park located in the lowland areas of Tarai and Siwalik regions causing degradation of habitats for the endangered one-horn rhino (Murphy et al., 2013) while a rapid expansion of *Eichhornia crassipes* has become a problem in both Ramsar sites of the region. Similarly, *Parthenium hysterophorus* is expanding rapidly in residential areas with negative impacts on forage supply as well as on the health of humans and livestock (Shrestha et al., 2015). IAPs are not only a problem in the low land areas, but also reportedly an environmental challenge in the mountain regions of this landscape (e.g., Thapa and Maharjan, 2014; Baral et al., 2017). In addition, an invasive alien fish *Oreochromis niloticus* (Nile Tilapia) has become the most dominant fish in three major lakes (Phewa, Begnas and Rupa) of the Pokhara valley (Husen, 2014).

2.2. Focus group discussions

Among various research tools used in social sciences, we used focus group discussions (FGDs) to understand local's perceptions of the impacts of IAPs and document community's effort, if any, to help prioritize the management of IAPs in Nepal. FGDs are generally carried out in groups of five to ten people with similar backgrounds or experience, focusing on a limited number of issues to reveal the range of their perspectives (Taylor et al., 2016). We conduced 32 FGDs in different physiographic regions (Tarai: 7, Siwalik: 8 (lowland), Middle Mountain: 13, High Mountain: 2, and High Himal: 2). This led to the participation of 218 people (52% male and 48% female) with the mean age of 46 ± 11 years (range: 20–75). The mean number of participants in each FGD was 7 ± 1.5 (range: 4 to 12). The participants were either executives or general members of the Community Forest Users' Groups (CFUGs). In the High Mountain and High Himal regions, there were no CFUGs. Therefore, the FGDs were organized among the local farmers resided in the Annapurna Conservation Area. The CFUG is a grassroots level community institution constituting a group of forest users legally authorized by the District Forest Office for the management of a specified forest area, which is commonly referred as Community Forest (CF) under the community forestry program (Acharya, 2002). Management and other activities in the CF are guided by a forest management plan prepared by individual CF and approved by the District Forest Office. The CFUGs in Nepal have the biggest network of community-based organizations of the country involved in forest management (Federation of Community Forestry Users, Nepal; http://fecofun.org.np). The community forestry program of Nepal is considered as one of the most successful participatory natural resources management programs in the world (Shrestha et al., 2010). About 35% of Nepal's population has been participating in this program managing more than 1.8 million hectors of the forest area (http://dof.gov.np/dof_community_forest_division/community_forestry_dof; accessed on 17 November 2017). Therefore, the CFUGs are the major stakeholders at the local level for forest management and biodiversity conservation in Nepal.

The FGDs, which were conducted in Nepali language, participants were first informed of the meaning of invasive species and their potential impacts on the environment and livelihoods. This was followed by the distribution of the color photographs of 25 IAPs (Shrestha, 2016; Supplementary Table 1) for identification. The major issues discussed during the FGDs were: 1) overall knowledge about IAPs and the number and names of IAPs found in agro- and natural ecosystems, 2) the negative impacts of these identified IAPs, 3) uses and benefits of IAPs, 4) the management efforts carried out by local communities to control IAPs, 5) prioritization of the top three problematic IAPs in agro- and natural ecosystems based on impacts and management need, and 6) willingness of communities to participate voluntarily in the management of IAPs. During the prioritization exercise of the three problematic species, the participants were asked to rank the most problematic IAPs in decreasing order of the negative impacts and management needs. After the completion of each FGD, we surveyed and examined the nearby ecosystems with some of the participants to verify the presence of IAPs and other related information reported by the participants.

2.3. Data analysis

Most of the data except the IAPs prioritization obtained from the FGD were descriptive. IAPs prioritization data from 32 FGDs were grouped into three groups based on the five physiographic regions. Due to similar climatic conditions and the presence of the same IAPs, the focus groups of Tarai and Siwalik were clustered into a single group; a similar clustering was done for the focus groups of the High Mountain and High Himal (resulting in three groups: a) Terai and Siwalik, b) Middle Mountain, and c) High Mountain and High Himal). Species ranked first, second and third in each FGD were given scores of three, two and one respectively, and they were used to derive a percentage score to prevent data skewness. Scores of each IAPs were summed up separately in three groups to obtain a total score of each species present in three clusters. Based on the total number of FGDs in each group, a maximum possible score for a species was calculated which was used to derive score percentage of each species. The species with the highest score percentage was considered as the most problematic in the given region.

3. Results

3.1. Community knowledge and awareness of invasive alien plants

Participants of all FGDs did not know the meaning of "invasive alien plants" even when the Nepali translation of the phrase (*Meechaha baihya banaspati*) was used in the discussion. Although people in the FGDs could identify the photographs of the IAPs, they were unaware of the exotic nature of IAPs. However, some participants had a living memory of the arrival of some of the IAPs in their localities. For example, the FGD participants from the Binayi CFUG of Dumkibas, Nawalparasi district noticed the spread of *Mikania micrantha* along roadsides. They also recalled its first appearance in their forest about 5–6 years ago. These participants further remarked that *Spermacoce alata* came with the seeds of forage plants distributed to the farmers by the Department of Livestock Service, Government of Nepal. Although most of the participants of the FGDs had been experiencing a range of negative impacts from the IAPs, they had not been formally informed about the consequences of biological invasions in relation to biodiversity and agriculture production by any government and non-governmental agencies.

3.2. Costs and ecosystem disservices for humans and the environment

The IAPs had several socio-economic impacts and provided ecosystem disservices in the study area. Out of 25 IAPs found in Nepal, 15 species were reported to have some negative impacts on human welfare and the environment. The reported negative impacts of IAPs during the FGDs can be grouped into four broad categories: impacts on agriculture production, livestock poisoning, reduced forage supply, and loss of biodiversity and prevention of forest regeneration (Table 1). The number of FGDs, which reported these four types of impacts, were nearly equal (15–19). In total nine IAPs were attributed to the reduced forage supply in natural ecosystems such as grassland and forest (both free grazing and forage collection for stall feeding) whereas a lower number of IAPs (four species) were reported as causing livestock poisoning. The participants said that the species with forage value had been smothered by rapidly expanding IAPs. Slightly more than half (53%) of the FGDs reported poisoning effects of *Ageratum houstonianum* on livestock that included stomach swelling, dysentery and a loss of appetite. The death of livestock due to the feeding on this weed was reported in an FGD conducted in Bara district of the Tarai region. According to the participants, the livestock preferred *A. houstonianum* less than the congener *A. conyzoides*, also an IAP. However, free grazing animals fed on *A. houstonianum* when other forage was unavailable. Participants also noted that while collecting forage, separating *A. houstonianum* from the forage collected from the invaded areas was cumbersome if not impossible. When such forage with high amounts of *A. houstonianum* was supplied to stall feeding livestock, animals suffered from health problems. The participants also reported that flowers had more toxic effects than vegetative parts of this plant.

Four IAPs were mentioned to have impacts on biodiversity (Table 1). The most frequently reported (50% of the total focus group) impact was the reduction of biodiversity and prevention of forest regeneration due to *Chromolaena odorata*, particularly in Tarai, Siwalik and Middle Mountain regions. According to the participants, *C. odorata* and other IAPs (*Ageratina adenophora*, *Lantana camara* and *Mikania micrantha*) had similar impacts; they formed impenetrable and monodominant stands smothering other vegetation and preventing native tree seedling establishment. This situation had not only reduced forest regeneration but also minimized the supply of forage to wild and domestic animals. The participants also reported that five species of IAPs in agroecosystems resulted in increased labor input for weeding and those IAPs also competed for nutrients with crops thereby reducing the crop yield.

3.3. Benefits and ecosystem services provided by invasive alien plants

Although harmful impacts of IAPs were reported more prominently by the participants of the FGDs, ten species of IAPs found in the study area had reportedly provided beneficial provisioning and regulating services to the local communities (Table 2). *C. odorata, L. camara* and *A. adenophora* were reported as the sources of biomass for compost, charcoal and bio-briquette. These species were used and sometimes preferred where they were found abundantly and could be collected easily. *Ageratum conyzoides, Bidens pilosa*, *Galinsoga quadriradiata* and *Mimosa pudica* were also used as forage for livestock and these IAPs

Table 1
Community perceptions of the impacts of invasive alien plants.

Perceived impacts	Number (percentage) of FGD reporting the impacts (N = 32)	Species considered responsible for the impacts (Number of FGDs)[a]
Increased labor input and reduced production in agriculture	15 (47%)	*Ageratum houstonianum* (6) *Oxalis latifolia* (4) *Pistia stratiotes* (4) *Argemone mexicana* (1) *Galinsoga quadriradiata* (1)
Poisoned livestock	19 (59%)	*Ageratum houstonianum* (17) *Parthenium hysterophorus* (2) *Ipomoea carnea* ssp. *fistulosa* (1) *Lantana camara* (1)
Reduced forage production and increased time for forage collection from the wild (natural ecosystems)	17 (53%)	*Ageratina adenophora* (6) *Spermacoce alata* (6) *Ageratum houstonianum* (4) *Chromolaena odorata* (4) *Bidens pilosa* (3) *Parthenium hysterophorus* (3) *Lantana camara* (2) *Mimosa pudica* (2) *Mikania micrantha* (1)
Competitively displaced native species and reduced biodiversity and forest regeneration	19 (59%)	*Chromolaena odorata* (16) *Ageratina adenophora* (4) *Lantana camara* (3) *Mikania micrantha* (3)

[a] Values in parentheses indicates the number of focus group discussion (FGD) reporting the species responsible for the particular impact.

Table 2
Community perceptions of the ecosystem services provided by the invasive alien plants in the study area.

Ecosystem services		Number (percentage) of FGDs reporting the services (N = 32)	Invasive alien plants (Number of FGD)[a]
Provisioning services	Biomass for composting	5 (16%)	*Chromolaena odorata* (5)
			Ageratina adenophora (3)
	Biomass for bio-briquette	1 (3%)	*Chromolaena odorata* (1)
	Biomass for charcoal	1 (3%)	*Chromolaena odorata* (1)
			Lantana camara (1)
	Forage for livestock	6 (19%)	*Ageratum conyzoides* (3)
			Bidens pilosa (3)
			Mimosa pudica (2)
			Galinsoga quadriradiata (1)
			Spermacoce alata (1)
	Medicinal use	4 (13%)	*Ageratum conyzoides* (2)
			Amaranthus spinosus (2)
			Chromolaena odorata (2)
			Ageratina adenophora (1)
	Culinary use	1 (3%)	*Amaranthus spinosus* (1)
Regulating services	Flood control	1 (3%)	*Ipomoea carnea* ssp. *fistulosa* (1)
	Landslide stabilization	3 (9%)	*Ageratina adenophora* (2)
			Ipomoea carnea ssp. *fistulosa* (1)

[a] Values in parentheses indicate the number of focus group discussion (FGD) reporting the uses of particular species.

were not considered as harmful as other agriculture weeds with no fodder value such as *Parthenium hysterophorus* and *A. houstonianum*. Participants also reported medicinal and culinary uses of some IAPs. The paste of fresh leaves of *C. odorata, A. adenophora* and *A. conyzoides* was used to treat cuts and wounds. The root of *Amaranthus spinosus* was used to treat urinary tract obstruction by local villages while the tender shoot of this species was consumed as a vegetable. Regulating services of some of the IAPs reported by the participants were: control of floods by *Ipomoea carnea* ssp. *fistulosa*, and stabilization of landslides by *A. adenophora* and *I. carnea* ssp. *fistulosa*. Five species – *A. houstonianum, Argemone mexicana, Oxalis latifolia, P. hysterophorus* and *Pistia stratiotes* did not have any reported benefits.

3.4. Management efforts

No specific plans for the management of IAPs were reported in all 32 FGDs. It also meant that none of the CFUGs had IAPs management activities included in their Forest Management Plan that is an approved protocol by the District Forest Office to guide management activities in the community forests. However, communities have responded arbitrarily to the arrival and rapid spread of some IAPs by manually uprooting them and by using their biomass - rarely with the use of herbicides (Table 3). Half of the FGD participants reported that they did not put any effort towards the management of IAPs. Manual uprooting by hands was mostly done in agroecosystems as an effort to reduce the cover of IAPs but the respondents did mention that this had no significant impact on controlling the spread of IAPs elsewhere. Inadvertent use of IAPs to produce compost, charcoal and bio-briquette might have helped to reduce the spread and abundance of some IAPs. However, the biomass of IAPs was used not as a part of any planned IAPs management, but was rather used for convenience as IAPs were available abundantly. The participants of three FGDs conducted in Makawanpur, two in Bara, and one in Kaski districts expressed strong willingness to initiate commercial productions of charcoal and bio-briquettes from the biomass of IAPs if they were provided training and technical support.

The participants of an FGD in Rupandehi district of the Tarai region reported the use of herbicide for the control of *I. carnea* ssp. *fistulosa* about 10 years back when the species was rapidly spreading. That had led to control of the species and it was not considered problematic at the time of this study.

3.5. Species prioritization

Out of 25 IAPs reported from Nepal (Shrestha, 2016), 16 and 12 species were reported as problematic in agro- and natural ecosystems respectively (Figs. 2 and 3). In both ecosystems, the number of IAPs reported as problematic by the participants of the FGDs decreased from low land Tarai and Siwalik in the south to High Mountains and High Himal in the north. With the highest score, *A. houstonianum* was reported as the most problematic agriculture weed by 22 FGDs in Tarai, Siwalik and Middle Mountain regions (Supplementary Fig. 1). This weed has mainly invaded non-irrigated agroecosystems and was common both in summer (e.g., maize) and winter crops (e.g., black gram, finger millet, mustard). In irrigated paddy fields, it was found in bund and terraces. In Tarai and Siwalik, the next two problematic IAPs were *P. stratiotes* (in irrigated paddy fields) and *P. hysterophorus* (in summer crops such as maize). In Middle Mountains, *O. latifolia* was reported as the second most problematic IAPs for agriculture that has invaded both summer (e.g. maize) and winter crops (e.g. vegetables

Table 3
Various activities reported during focus group discussion for the management of IAPs.

Management activities		Number (percentage) of FGDs (N = 32)	Target species (Number of FGDs)[a]
Manual uprooting		12 (37.5%)	*Ageratum houstonianum* (5), *Chromolaena odorata* (3), *Galinsoga quadriradiata* (2), *Ageratina adenophora* (3), *Bidens pilosa* (1)
Biomass utilization	Composting	5 (15.6%)	*Chromolaena odorata* (5), *Ageratina adenophora* (3)
	Charcoal preparation	1 (3.1%)	*Chromolaena odorata* (1)
			Lantana camara (1)
	Bio-briquette production	1 (3.1%)	*Chromolaena odorata*
Use of herbicide (10 years back)		1 (3.1%)	*Ipomoea carnea* ssp. *fistulosa*
No effort		16 (50%)	Not applicable

[a] Values in parentheses indicate the number of focus group discussion (FGD) reporting the activities for the management of the particular species.

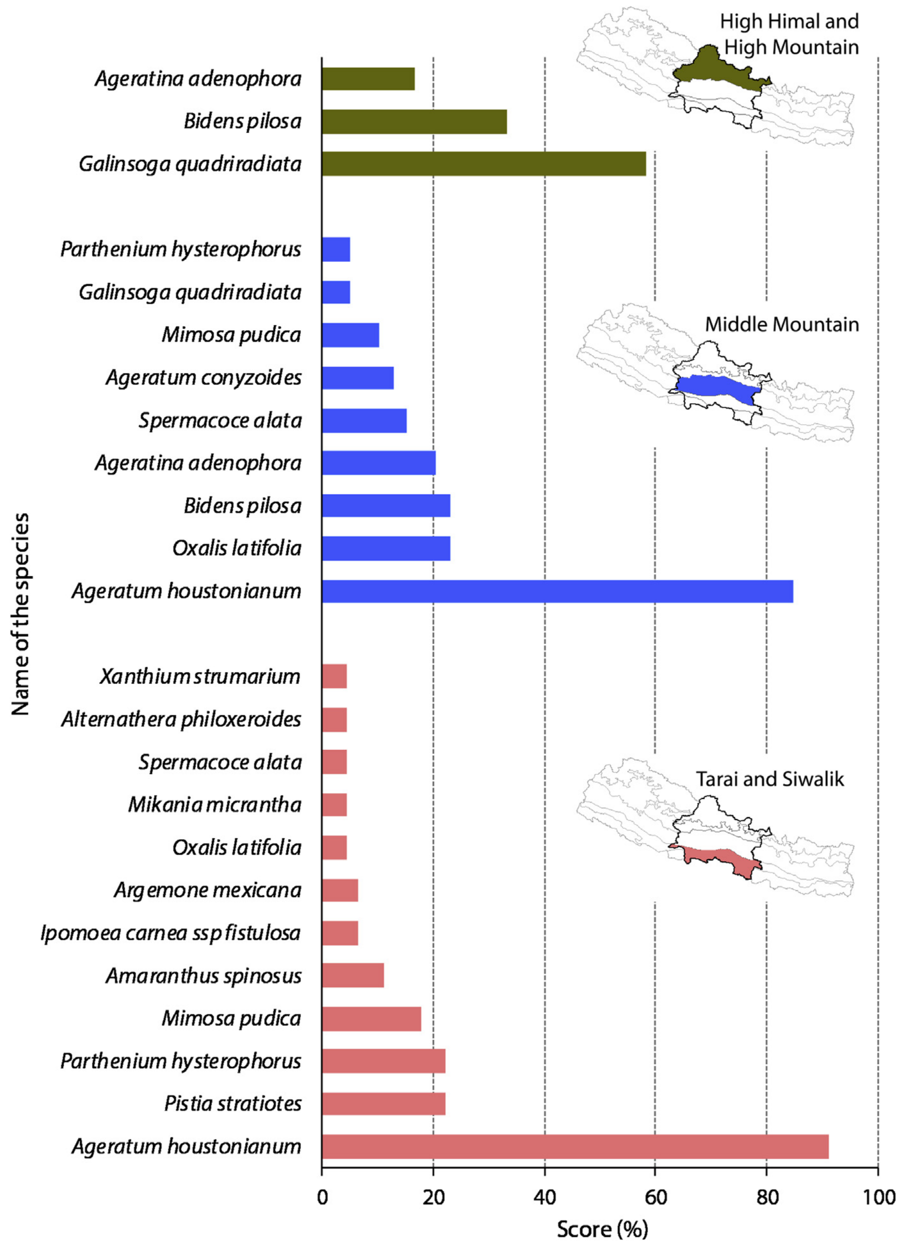

Fig. 2. Score percentage of invasive alien plants of agroecosystems based on the prioritization by participants of the focus group discussions across physiographic regions.

such as pea, radish). In High Mountains and High Himal, only three IAPs were reported as problematic with the maximum score for *G. quadriradiata*.

In natural ecosystems of Tarai and Siwalik regions, *C. odorata* was ranked the most problematic weed followed by *M. micrantha* and *L. camara* (Fig. 3). These three shrub species were found co-occurring in many localities. These species had mainly invaded open-canopy forests, shrublands, grasslands, and areas near road side corridors. In addition, *M. micrantha* was also found to be dominant in wetlands such as lake shores, spring banks and riverine *Dalbergia sissoo* forests. In Middle Mountains, *A. adenophora* was reported as the most problematic IAPs followed by *C. odorata* and *L. camara*. *Ageratina adenophora* has invaded nearly all habitats from grasslands to forest understories, although its cover was relatively low in closed-canopy forests. It was also reported as the most problematic in natural ecosystems of High Mountains and High Himal regions. However, in prioritization, its score was relatively low, indicating low abundance in these regions.

4. Discussion

4.1. Local knowledge

This study documents the local knowledge and understanding about IAPs, and compiles community perceptions of the effects of IAPs with a prioritization exercise. For an effective management of invasive species, proactive participation of community members is indispensable (Shackleton et al. b, this issue). Building community awareness and trust about the ecological and economic impacts of IAPs is the first step towards community participation in managing IAS (Boudjelas, 2009; Wald et al. this issue). The majority of the participants in the FGDs were unaware of the exotic nature of IAPs and their broader effects. Nevertheless, local communities have been negatively impacted by several IAPs. Furthermore, negative impacts reported by the communities were in line with existing information in scientific literature and the species prioritized by them were among the world's worst invasive weeds (see section 4.2 and 4.4). This justifies that agrarian and forest-dependent

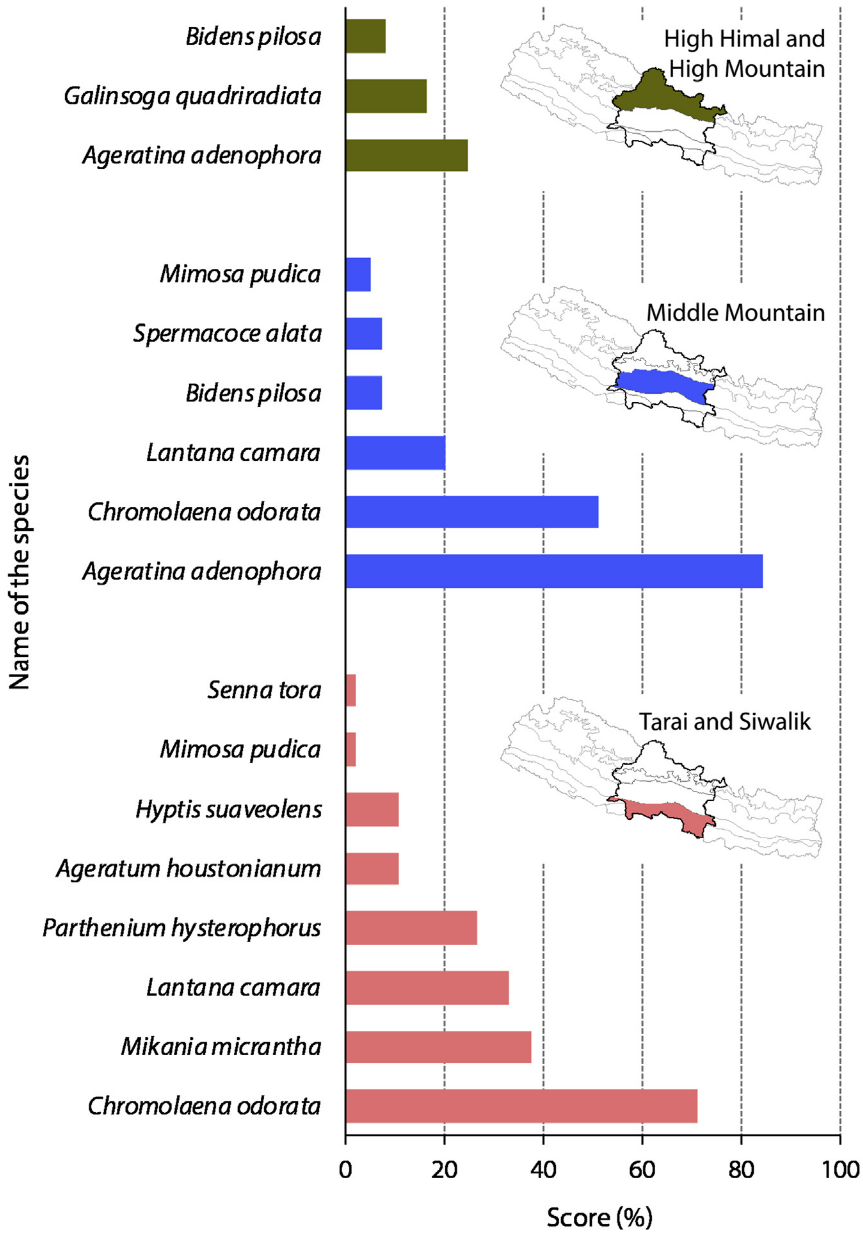

Fig. 3. Score percentage of invasive alien plants of natural ecosystems based on the prioritization by participants of the focus group discussions across physiographic regions.

communities have valuable local ecological knowledge and can closely monitor environmental changes and the impacts of IAPs – even though communities are not formally informed or educated. The lack of awareness may be due to the failure of the state to disseminate the information related to biological invasions to local communities. This lack of public awareness surrounding biological invasions and uptake local policy has also been reported in developed countries such as the USA and developing countries such as South Africa (Colton and Alpert, 1998; Shackleton and Shackleton, 2016; Cole et al. this issue). To address this issue, several organizations both in developed and developing countries have recently produced community education materials and programs on biological invasions (e.g., Weedbuster program in New Zealand, http://www.weedbusters.org.nz/; Australia, https://www.daf.qld.gov.au/plants/weeds-pest-animals-ants/weeds/weedbusters; Parthenium awareness week in India, https://naarm.org.in/observation-of-parthenium-awareness-week/). These community education programs help to raise the awareness of local people about invasive species and encourage communities to participate in their management (Boudjelas, 2009; Bravo-Vargas et al. this issue). Community education programs and the participation of communities in the project implementation are important social components of invasive species management (Larson et al., 2011; Pages et al. this issue) which can aid the long-term success of projects.

4.2. Impacts and benefits

Although communities of the present study area were not aware of the origin, dispersal, and long-term impacts of IAPs, they were aware of the direct and immediate negative impacts that IAPs have had on their livelihoods, biodiversity, and ecosystem services. Increased labor input in weeding, reduced crop production, livestock poisoning, and reduced forage production in natural ecosystems due to IAPs can have direct negative impacts on the livelihoods of agrarian and forest-dependent communities (Rai and Scarborough, 2015; Shackleton et al., 2017; Shackleton et al. a, this issue). These impacts of IAPs on the livelihood of local communities may be substantial in developing countries, like

Nepal, but qualitative and quantitative information is lacking and often has a limited influence on policy responses. For example, impacts of invasive species on the livelihood of small holder agrarian communities in six east African countries have resulted in substantial economic loss (annual loss of US$ 0.9–1.1 billion; Pratt et al., 2017). Therefore, future research on socio-economic dimensions of IAPs in Nepal should focus on quantifying the impacts and economic cost of IAPs on livelihoods, which can be used as evidence to promote control and management of IAPs.

The impacts reported by the participants of the FGDs in this study matched well with the previous scientific findings. For example, Noa et al. (2004) reported the poisoning effect of *A. houstonianum* on livestock and Zachariades et al. (2009) mentioned smothering of other vegetation and interference with tree regeneration by *C. odorata*. Negative impacts of *C. odorata* to native biodiversity, forage for livestock, and crop production have been also reported in eastern Africa (Shackleton et al., 2017). Similarly, negative community perceptions and impacts of *M. micrantha* are mirrored by other communities in Nepal (Rai and Scarborough, 2015).

About 60% of the IAPs evaluated in the present assessment were reported to have some direct benefits and services. Six of these IAPs invading agroecosystems were used as forage and these species were given relatively a low score in the prioritization exercise. This might reflect the trade-off between the benefit of IAPs and the community preference for management (Shackleton and Shackleton, 2017). Such species may not need active control currently but need to be monitored using ecological and socio-economic tools, and prioritized later if they start to have impacts. Some of the IAPs (e.g. *C. odorata, A. adenophora*) invading forest and other natural ecosystems were also reported to have some benefits but they were also given the highest score during prioritization for management. This reflects a situation when the cost of species out-weighs the benefit. Such species reported to have high costs with low or no benefit (e.g. *A. houstonianum, P. stratiotes, P. hysterophorus*) need to be targeted immediately for management.

4.3. Community management

Communities responded and adapted to the increasing abundance of IAPs by converting IAPs biomass into useful products such as compost, charcoal and bio-briquette, which has been noted elsewhere such as in the case of *L. camara* in India (Kannan et al., 2016) and *Acacia dealbata* in South Africa (Ngorima and Shackleton, this issue). Some of these products have a market value (Singh, 2013) and can help to diversify incomes (Rai et al., 2012). They can partly compensate for the loss of provisioning services (e.g., fodder supply) of the invaded ecosystems. Biomass and other utilization can also be considered as a cultural method of IAPs management and a potential strategy to reduce costs and improve benefits of invasive species (Radosevich et al., 2007; Kannan et al., 2016). Many communities also responded to the rapid spread of IAPs by manual uprooting, which has been commonly practiced in other parts of Nepal (Rai et al., 2012; Shrestha et al., 2018a). Local utilization and manual uprooting can have some impacts on reducing abundance and controlling the further spread of IAPs but these activities are simply insufficient to combat the increasing effects of IAPs unless they are the components of an integrated management strategy (van Wilgen et al., 2011). Therefore, local communities and formal institutions need to work together to ensure the long-term control of IAPs.

4.4. Prioritization

The management of invasive species and environmental management in general is a complex and long-term process that is often constrained by limited and irregular resources (fund and logistics) availability (Wilson et al., 2006; van Wilgen et al., 2011). Therefore, for an efficient allocation of limited resources, prioritization of invasive species is a prerequisite to cost-effectively manage high impact species (Branquart et al., 2016). Among various processes of species prioritization, our results showed that community consultation could help to successfully prioritize IAPs for management intervention and has other benefits such as social learning, co-development of management and building trust (Shackleton et al. b, this issue). The species ranked as a high priority for their impacts and management by the participants in this study have also been reported as highly noxious invasive species elsewhere. The top prioritized IAPs in agroecosystems in this study, *Ageratum houstonianum*, is spreading rapidly in Nepal (Siwakoti et al., 2016) while it was already reported as a notorious weed in India (Singh et al., 2011). This weed is non-palatable and highly toxic to livestock, and leads to extra work in collecting forage and crop production – and has no benefits (Noa et al., 2004). It has higher invasion potential than congeneric invasive *A. conyzoides* (Singh et al., 2011). *A. houstonianum* was not considered problematic 11 years ago in the national level assessment (Tiwari et al., 2005), probably due to sparse occurrence, but a recent survey has reported this species as the fifth most frequent out of 23 IAPs in Nepal and has had an upslope range expansion of > 800 m since previous reports (Siwakoti et al., 2016). Climatically suitable area of this species has been also predicted to increase by 70% in future (representative concentration pathway (RCP) 4.5 scenarios for the year 2050) from the current suitable area (Shrestha et al., 2018b). This indicates that the IAPs such as *A. houstonianum* can spread rapidly and incur substantial damage in a short period if there is no timely management response (Radosevich et al., 2007). Species given a high priority for management in natural ecosystems including *C. odorata, M. micrantha* and *L. camara* are listed among 100 of the world's worst IAS (Lowe et al., 2000) while another high priority species *A. adenophora* is one of the noxious invasive weeds in subtropical to tropical Asia and the Pacific regions (Yu et al., 2016).

4.5. Way forward: community engagement and planning

Community participation in Nepal has had a long and successful history in forest management and biodiversity conservation (Acharya, 2002; Bajracharya et al., 2005; Shrestha et al., 2010). Therefore, the management of invasive species could have been highly effective had local communities been educated and involved earlier, especially since there is evidence that forest-dependent and agrarian communities of Nepal have reported a high willingness to contribute for the management of IAPs in forests (Rai and Scarborough, 2013). Therefore, increased engagement with communities is highlighted as crucial in Nepal's National Biodiversity Strategy and Action Plan 2014–2020 for the management of invasive species (MFSC, 2014). Yet, to our knowledge, no initiative has been taken by the Government of Nepal to execute this plan. Recently, a pictorial community education manual has been published in Nepali language covering IAPs found in Kailash Sacred Landscape Nepal (Joshi et al., 2016). The production of an IAPs management toolkit (print as well as audio-visual) with information on field identification of IAPs, their short and long-term impacts, and locally relevant best management practices could help to increase the community awareness and their participation in IAPs management. The national level network of CFUGs, which is the biggest network of communities involved in forest conservation and environmental management in Nepal, can be instrumental for disseminating knowledge and information related to biological invasions to the grassroots level. Furthermore, the inclusion of IAPs management activities in the forest management plan of community forests can help to make local community aware and take initiatives to manage IAPs.

Need of integrating community perception into the management planning of IAPs has been increasingly realized (Potgieter et al. this issue). Members of local communities participate actively when management interventions are targeted to the species prioritized by them (Boudjelas, 2009). This is because communities feel ownership of the plan and take higher responsibility. Studies showed that the bottom –up and collaborative planning promote co-design and co-implementation of management efforts (Reed et al., 2017; Shackleton et al. b, this issue). Our analysis also showed that the community priority of IAPs for management varied with physiographic regions. Although our study area included all physiographic regions in central Nepal, the communities of eastern and western Nepal may have different priorities because the diversity and abundance of IAPs are not uniform from east to west in Nepal (Tiwari et al., 2005) – therefore plans need to be region specific. For example, *C. odorata* was given the highest priority for management in natural ecosystems by communities in the Tarai and Siwalik region – but has limited distributions in western Nepal (Poudel, 2016). Therefore, this community prioritization exercise should be developed further into prioritization plans and regional or national strategies, that also draws on ecological, and economic data as well as spatial planning based on the abundance of the various IAPs (Radosevich et al., 2007 > ; Larson et al., 2011; van Wilgen et al., 2011).

Biological invasions have been given little attention in conservation and adaptation policies and plans of Nepal. Although invasive species have been mentioned as a problem in some policy documents of Nepal (Siwakoti and Shrestha, 2014), their management has remained a due task (Shrestha, 2018). The formulation of a national strategy for the management of invasive species in progress (Rajesh Malla, Department of Forest Research and Survey, pers. comm. on 24 May 2018). Findings of this research on the social dimension of IAPs would provide science-based evidence to the national strategy. With these findings, the recommended activities include 1) production and wide dissemination of community education materials related to biological invasion using the national network of CFUG and other suitable means; 2) quantification of the impacts of IAPs at national level and their economic cost on livelihood; and 3) management focus, but not limited, to the species prioritized by agrarian and forest-dependent communities.

Acknowledgements

We acknowledge Climate Change Research Grants Program under the Mainstreaming Climate Change Risk Management in Development project implemented by the Nepal Academy of Science and Technology, financed by the Climate Investment Funds, and administered by the Asian Development Bank for financial support. Thanks to Sajita Dhakal, Samiksha Banjade, Sangita Thapa, Gajendra Chataut, Kussum Shrees and Sonia Pujara for their assistance in the field to collect data. Ross T. Shackleton (Stellenbosch University, South Africa) and two anonymous reviewers edited and provided critical comments which has substantially improved the quality of the manuscript. We are also thankful to Prithvi Shrestha, The Open University, UK for language edit.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jenvman.2018.06.034.

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