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Forest regrowth reduces richness and abundance of invasive alien plant species in community managed *Shorea robusta* forests of central Nepal

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Abstract

Background: Natural forests are generally considered to be less prone to biological invasions than other modified ecosystems, particularly when canopy cover is high. Few decades of management of degraded forests by local communities in Nepal has increased canopy cover and altered disturbance regimes. These changes might have reduced the abundance of invasive alien plant species (IAPS) in forests. To understand the status of IAPS in such forests, we studied two community managed *Shorea robusta* forests (Sundari and Dhusheri) of Nawalpur district in central Nepal. In these two forests, vegetation sampling was done using circular plots 10 m radius at forest edge, gaps, and within canopy. Variation of IAPS richness and cover across these microhabitats were compared, and their variation with tree canopy cover and basal area analyzed.

Result: Altogether 14 IAPS were recorded in the study forests; among them *Chromolaena odorata*, *Ageratum houstonianum*, and *Lantana camara* had the highest frequency. *Mikania micrantha* was at the early stage of colonization in Sundari Community Forest (CF) but absent in Dhuseri CF. Both IAPS cover and richness was higher at forest edge and gap than in canopy plots and both these attributes declined with increasing canopy cover and tree basal area.

Conclusion: The results indicate that increase in canopy cover and closure of forest gaps through participatory management of degraded forests can prevent plant invasions and suppress the growth of previously established IAPS in *Shorea robusta* forests of Nepal. This is the unacknowledged benefit of participatory forest management in Nepal.

Keywords: Biological invasions, *Chromolaena odorata*, Community Forests, Ecosystem-based management, Forest canopy gap, Forest edge

Background

Invasive alien plant species (IAPS) displace native species, reduce biodiversity, alter species composition, and negatively affect tree regeneration in forests (Belnap et al. 2005, Baret et al. 2008, Minden et al. 2010). In addition, they also alter soil microbial community, litter quality, and thus the overall ecosystem functions of the forests (Ehrenfeld 2003, Martin et al. 2009). Plant invasions occur in forests as a result of human disturbances leading to the formation of canopy gaps (Baret et al. 2008, Burnham and Lee 2010). Disturbances mostly increase resource availability, and facilitate the colonization of such habitats by IAPS which often have higher competitive abilities than the native species (Parendes et al. 2000). Therefore, the IAPS can easily colonize forest gaps and edges by taking advantage of high resources availability including light radiation (Yamamoto 2000, Funk 2013). In canopy gaps,

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IAPS dominate the vegetation and may lead to the local extinction of native species (Vargas et al. 2013). Similarly, forest edges trap airborne propagules of IAPS and facilitate invasion (Joshi et al. 2015). Thus, areas with small patches or more edge density are more vulnerable to invasion by IAPS (Mavimbela et al. 2018).

Widespread occurrence of IAPS has become a serious problem for biodiversity conservation and forest management in Nepal (MFSC 2014, Shrestha 2019). The IAPS is spreading into forests under different management regimes such as community managed forests (hereafter referred as community forests, CF), national forests, and those inside protected areas. The CF management has been considered as one of the most successful participatory program for management of degraded forests particularly in hilly regions of Nepal (Shrestha et al. 2010). Although, various aspects of CF management such as carbon stock (Thapa-Magar and Shrestha 2015) and deforestation and poverty reductions (Oldekop et al. 2019) have been explored, the status of the IAPS has been seldom analyzed. Furthermore, IAPS has not been integrated formally in the management plans of CFs and the impacts of CF management on IAPS diversity and abundance remains understudied in Nepal (Shrestha 2019). In this context, we aimed to test hypothesis that IAPS richness and cover decline with increasing tree canopy and basal area in forests, taking two CFs of Nawalpur district as a case. The overall aim of the research is to study the diversity and abundance of IAPS in the two selected CFs and the specific objectives were (1) to carry out the inventory of IAPS in Sundari and Dhuseri CF of Nawalpur district; and (2) to analyze spatial pattern of the distribution of the IAPS in relation to tree canopy cover and tree basal area. The results have direct implications for integrating IAPS management component in the operational management plans of the CFs.

Materials and methods

Study area

The study was carried out in the Nawalpur District, which is located in the south-central part of Nepal. Among the 208 community forests (CF) in the district (personal communication on 4 April 2020 with Hari Gautam, Assistant Forest Officer, Division Forest Office, Nawalpur), two were selected for the present study; they were Sundari CF (27°43′5′′–27°44′50′′ N, 84°14′20′′–84°16′30′′ E; elevation 175–365 masl; area 4.038 km^2) and Dhuseri CF (27°41′20′′–27°42′60′′ N, 84°13′10′′–84°14′15′′E; elevation 160–300 masl; 3.847 km^2) (Fig. 1). These two CFs are among the most effectively managed CF in terms of good governance, poverty alleviation programs, and protection of the forests. They also have the longest history (> 30 years) of participatory forest management in Nawalpur district. Both these forests are located in the foothill of Mahabharat range with slope 0–40° (DCFUG 2007, SCFUG 2007). They were handed officially to the local communities (called Community Forest Users' Group) for management as "community forest" by then District Forest Office in 1996 but communities started conservation of forest several years before the official handover.

Before community management was initiated, both forests were highly degraded (personal communication with Chakra Mani Khanal and Indra Prashad Adhikari, Nawalpur District, January 2016). There were 1219 user households of Sundari CF and 829 households of Duseri CF. Communities were allowed to collect firewood and fodder under certain regulations but livestock grazing has been prohibited. As a part of management, silvicultural activities were undertaken that included clearing ground vegetation (including weeds), pruning, thinning, and singling. These tasks have been done every year from October to December. To guide the forest management activities, each forest has operational plan that was approved by District Forest Office. Management of IAPS has not been included in these operational plans.

The study area has dry subtropical climate. The average annual precipitation is 2388 mm, with nearly 80% precipitation occurring during monsoon which lasts from June to August. The mean maximum temperature is 31 °C and minimum temperature 19 °C. Both study CFs have *Shorea robusta* Gaertn. (local name: *Sal*) as dominant tree. Other associated tree species are *Terminalia bellirica* (Gaertn.) Roxb. (*Barro*), *Dalbergia sissoo* DC. (*Sissoo*), and *Cassia fistula* L. (*Rajbriksha*). Common shrub species include *Colebrookea oppositifolia* Sm. (*Dhursil*), *Rauvolfia serpentina* (L.) Benth. ex Kurz (*Sarpaganda*), and *Pogostemon benghalensis* (Burm.f.) Kuntze (*Rudhilo*). Animals like *Prionailurus viverrinus* Bennett (Jungle cat), *Hystrix indica* Kerr (Porcupine), *Macaca mulatta* Zimmermann (Rhesus), *Corvus splendens* Vieillot (House crow), and *Python molurus* Linnaeus (Python) are present in the study area (DCFUG 2007, SCFUG 2007).

Vegetation sampling

Reconnaissance survey of the study forests was done in June 2016. Forest boundaries were marked with the help of global positioning system (GPS, Garmin). Based on the canopy cover, there were three microhabitats present in the study forests: canopy, canopy gap, and Edge. The "canopy" is the core interior area of forest with tree canopy > 80%; "canopy gap" represents the open area inside the forest formed after death or felling of trees or due to recurrent fire and grazing in the past that prevented tree regeneration; and "edge" is the margin of forest with adjacent settlement and road. These three microhabitats were represented proportionately during sampling. Altogether, 100 plots (50 plots each in Sundari and

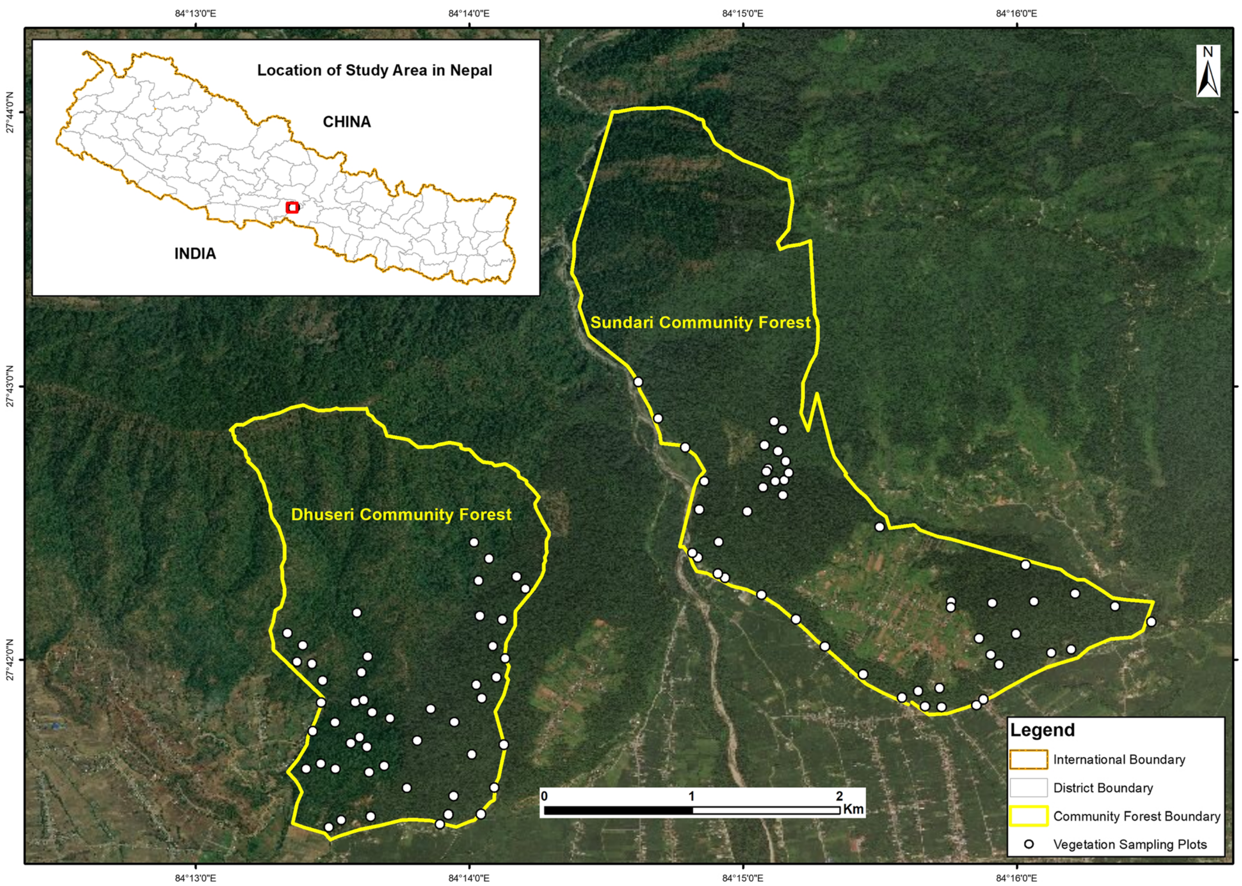

Fig. 1 Google Earth Map showing location of vegetation sample plots in Sundari (right) and Dhuseri (left) Community Forests

Dhuseri CFs) of 10 m radius were sampled by systematic sampling method with 51 plots in canopy, 28 plots in edge, and 21 plots in gap. In each plot, diameter of trees at breast height (DBH, 130 cm) was measured with the help of measuring tape. The IAPS present in each plot were recorded. A checklist of 25 IAPS of Nepal reported by Shrestha (2016) was used for recording IAPS. Tree canopy cover as well as the cover of individual IAPS were estimated visually following cover class method of Daubenmire (1959). According to this method, cover was designated to one of the following six cover classes: 1 = < 5% cover, 2 = 5–25%, 3 = 25–50%, 4 = 50–75%, 5 = 75–95%, and 6 = 95–100%.

Data analysis

Field data were used to calculate frequency, cover, and species richness of IAPS, tree basal area, and tree canopy cover. The frequency (%) of each IAPS was calculated separately for each study forest as the percentage of plots (circular plot of 10m radius) in which the species occurred (Zobel et al. 1987). The IAPS richness was measured as the number of IAPS recorded in each sampling plot. Cover class of each IAPS in each plot was converted into mid value of cover (e.g. 2.5% for cover class 1, 15% for class 2). The mid values of the individual IAPS present in each plot were summed to get the combined cover of IAPS in each plot. Mean cover of each IAPS in canopy, canopy gap, and edge were also calculated. Basal area of each individual tree having DBH ≥ 5 cm was calculated. The basal area of all the individual trees in each plot, irrespective of the species identity, was summed to get tree basal area of a plot. Tree canopy cover in each plot was calculated in the same way as it was done for IAPS.

Cover and species richness of IAPS were compared among three microhabitats: canopy, canopy gap, and edge. The data did not meet the assumptions of normality and homoscedasticity. Therefore, cover and species richness were compared by non-parametric tests such as Kruskal–Wallis followed by Mann–Whitney *U* tests in Statistical Package for Social Science (SPSS) version 20.0 (Armonk 2011). Furthermore, IAPS richness and IAPS cover were considered response variables whereas tree canopy and tree basal area were considered predictor variables using generalized linear model, Poisson family to model proportion, and count responses. Over dispersion was checked using residual deviance and degree of freedom. We used quasipoisson error instead of poisson error structure to account the over dispersion. For example, in the case of IAPS richness model, the over dispersion coefficient was found 1.9 and in canopy cover model the coefficient was found 21.8. These statistical analyses were conducted using R (version 3.3.2) (R Development Core Team 2016), over dispersion was checked by performance (Lüdecke et al. 2020), and package ggplot2 (Wickham 2016) was used for data visualization.

Results

Diversity and abundance of IAPS

Altogether, 14 IAPS were recorded from the study forests (Fig. 2). There were 13 IAPS in Sundari CF and 12 in Dhuseri CF. Eleven species were common to both CFs but *Mikania micrantha* and *Xanthium strumarium* were recorded only in Sundari CF; and *Parthenium hysterophorus* was found only in Dhuseri CF. *Chromolaena odorata* was the most frequent IAPS which was found in nearly half of the plots in both forests. Other frequent IAPS were *Spermacoce alata* and *Ageratum houstonianum*. *Lantana camara* was frequent (28%) in Sundari CF but rare (2%) in in Dhuseri CF (Fig. 2).

IAPS richness and cover

The IAPS richness and cover were significantly higher at forest edge and gap than at the plots in canopy (Fig. 3). Species richness of IAPS at edge and gap was 6.5 and 5.3 times higher, respectively, than in canopy. Similarly, IAPS cover at edge and gap was 10.2 and 11.4 times higher than in canopy. All but one species had the highest cover either at canopy gap or forest edge (Table 1).

Dash (-) represents the absence of species. Data in bold face represents the highest value among three microhabitats

Species richness of IAPS declined significantly with increasing tree canopy cover and basal area (Fig. 4). Similarly, the cover of IAPS also declined with increasing tree canopy cover and basal area (Fig. 4). Among the two predictor variables considered in this study, tree canopy was found to have stronger negative effect on IAPS species richness and cover than that tree basal had (higher values of R for Tree canopy, Fig. 4).

Discussion

Diversity of invasive alien plant species

The number of invasive alien plant species (IAPS) recorded in two community managed forests (CF) (14 species) accounts 54% of the 26 species of IAPS reported from Nepal (Shrestha 2019). The number of IAPS varies with the extent of geographic area covered and the climatic conditions. For example, 14 IAPS were reported from Parsa National Park (area 627 km^2) located in central Nepal (Chaudhary et al. 2020) and 12 IAPS from Bardiya National Park (968 km^2) in western Nepal (Bhatta 2019). Physiographically, both these parks extends in Tarai and Siwalik regions. Area covered in the present study (ca. 8 km^2) is far less than the two national parks mentioned above. Even then, the number of IAPS were nearly equal, suggesting that probability of IAPS invasion is higher in CFs than in national parks located in the same climatic and physiographic region. In general, the number of invasive alien species is expected to be low in protected areas such as the national parks due to buffering effects of the park boundary to the dispersal of invasive alien species (Foxcroft et al. 2011), whereas such buffering system is virtually absent in regions outside protected areas, leading to high probability of the

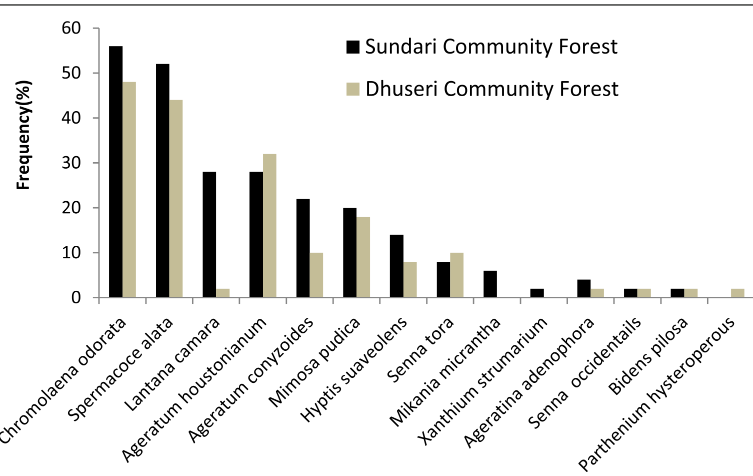

Fig. 2 Frequency of the invasive alien plant species in Sundari and Dhuseri Community Forests

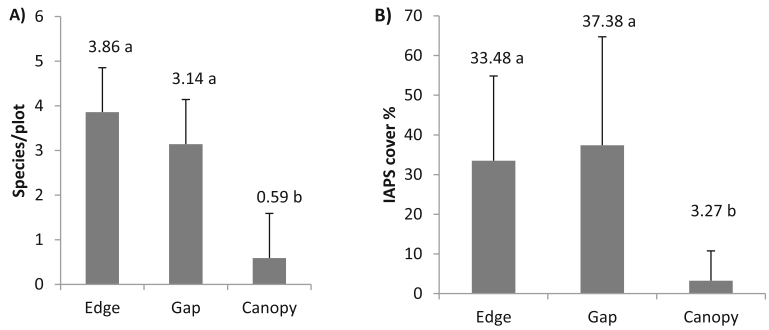

Fig. 3 Invasive alien plant species (IAPS) richness (**a**) and cover (**b**) across microhabitats. The values above the bar followed by the same alphabet are not significantly different ($p < 0.05$)

occurrence of more IAPS. In Kailash Sacred Landscape Nepal (KSL-N; area 13,289 km^2) which extends in four mountain districts of north-western Nepal, Shrestha et al. (2018) reported sixteen IAPS. The number of IAPS present in two CFs of the present study was two species less than the number of IAPS reported in the KSL-N though the present study area is very small as compared to KSL-N. It apparently indicates that there is high number of IAPS in lowlands of Nepal than in mountain landscapes. In another landscape Chitwan-Annapurna Landscape (area 32,090 km^2), which extends from Tarai to high Himalayan regions in central Nepal, 23 IAPS were recorded (Siwakoti et al. 2016).

Three of the IAPS (*Chromolaena odorata, Lantana camara* and *Mikania micrantha*) found in the present study area are among 100 of the world's worst invasive alien species (Lowe et al. 2002). Among them, *Chromolaena odorata* was the most frequently occurring IAPS in both forests with this species present in nearly half of the plots sampled. It suggests that the species is widespread in the landscape surrounding the present study area and it might have arrived there > 30 years ago when the forests were heavily degraded, i.e., before local communities started forest conservation. This is one of the common IAPS in Tarai, Siwalik, and Mid Hills of eastern and central Nepal (Tiwari et al. 2005) and globally in tropical and subtropical regions of Asia, Africa, and Oceania (Zachariades et al. 2009). Other two species were relatively less common with *M. micrantha* entirely absent in Dhuseri CF, suggesting that these two species were at the early stage of invasions. Since these two species are also notoriously invasive in other parts of Nepal (Tiwari et al. 2005) and elsewhere in the world (Lowe et al. 2002), their rapid spread to a larger area shortly is very likely. Rapid management responses can contain these small populations and prevent further spread. A systematic manual cutting through participatory approaches could be an effective measure to control IAPS,

Table 1 Mean cover of invasive alien plant species (IAPS) at three microhabitats

Name of invasive alien plant species	Cover (%)		
	Canopy	Canopy gap	Edge
Ageratina adenophora (Spreng.) R.King and H.Rob.	0.20	**0.56**	-
Ageratum conyzoides L.	0.36	1.11	**1.61**
Ageratum houstonianum Mill.	1.75	**2.70**	1.37
Bidens pilosa L.	-	**1.59**	0.65
Chromolaena odorata (L.) R. King and H. Rob.	5.38	**7.14**	6.87
Hyptis suaveolens (L.) Poit.	0.57	**1.98**	1.07
Lantana camara L.	1.23	**4.05**	2.83
Mikania micrantha Kunth	0.03	**1.27**	1.04
Mimosa pudica L.	0.51	1.15	**1.37**
Parthenium hysteroperous L.	0.03	-	-
Senna occidentalis (L.)Link	0.02	**0.52**	0.03
Senna tora (L.)Roxb.	0.24	-	**0.83**
Spermacoce alata Aubl.	4.26	6.75	**6.87**
Xanthium strumarium L.	-	2.02	-

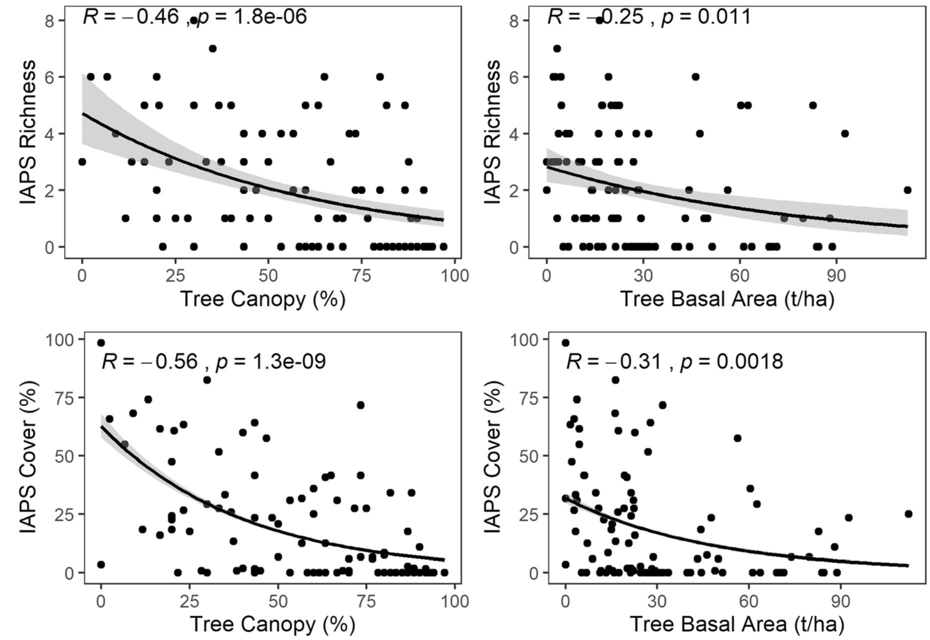

Fig. 4 Variation of invasive alien plant species (IAPS) richness (#species/plot) with tree canopy and basal area as well as the IAPS cover with tree canopy and basal area. The fitted lines were based on the generalized linear model. The total number of sample plots was 100

particularly when population size is small (Rai et al. 2012). Manual uprooting followed by weeding of *L. camara* seeding could also be effective in eradicating small populations of this weed (Prasad et al. 2018). If sustained effort is made for few years, local eradication of these two species from the study forests would be possible. A combination of physical and chemical control methods can be effective for eradication of such small populations (Wittenberg and Cock 2001). However, extra precaution is needed for chemical method because it is not environmentally friendly and may not be easily accepted by public (Bremner et al. 2007).

Variation of IAPS richness and abundance

High tree canopy cover reduces the amount of light available on the ground surface which makes the habitat less favorable for the growth and reproduction of most IAPS (Baret et al. 2008). Such condition reduces the probability of infestation by IAPS and their colonization in forest ecosystem (Hartman et al. 2008). In the study area too, IAPS richness and cover decreased with increasing tree canopy cover and basal area (Fig. 3 and 4). Several other studies also have shown a decline in the abundance or species richness of IAPS with increasing canopy cover (McNab et al. 2002; Norbu 2004). The number of IAPS found in the interior of the forest with high tree canopy was lower than at forest edge and gap (Fig. 3). Though some IAPS were present in all three microhabitats that we studied, their covers were the lowest in the canopy plots (Table 1). Sunlight quantity, positively correlated with gap size, has been found to be one of the most important variables in expansion of IAPS in forest gaps. The forest edges may facilitate species' establishment and the flow of propagules. It may trap airborne propagules of IAPS and facilitate invasion (Joshi et al. 2015).

Several authors have suggested that forest sites with more edge and more gaps should be more likely to contain high number of IAPS (Matlack 1994; Baret et al. 2008). Colonization by IAPS is higher in forest edge and gap; they germinate and grow more rapidly in gap microhabitat within forest than in microhabitat with a closed canopy (McNab et al. 2002). Distribution of these weeds may also be localized in relation to edge and gaps resulting from disturbances such as tree falls, human-made trails, and illicit felling (Joshi et al. 2015). Edge and gap formation generates considerable changes in the distribution and availability of environmental resources (Lockwood et al. 2005). Although, gap dynamics in natural forests have been studied, applications of gap dynamics to forestry practice in relation to IAPS management are limited (Mavimbela et al. 2018). Increase in canopy and closure of canopy gaps in the study forests after community management might have prevented establishment of new IAPS and suppressed the growth of previously established IAPS, particularly *Chromolaena odorata* as reported by local people. The observation made by the local people in the present study area is also supported by a research conducted in South Africa, where density and seed production of *C. odorata* was very low in shade (equivalent to canopy plots) compared to open sites (Witkowski and Wilson 2001). Therefore, suppressed growth of IAPS is the benefit of community forestry program of Nepal which has not been recognized and appreciated. However, additional studies is need covering large areas to test the generality of this assertion. Most of the IAPS establish first near the forest edges with their greater growth (Vargas et al. 2013). It was highly likely that the IAPS currently present in the study forests showed up first in forest edge and subsequently spread into forest interior. This assertion is supported by current distribution of *Mikania micrantha* in Sundari CF, where it was at initial stage of invasion and limited mainly at the forest edge and those gaps located near the forest edge. Given the high level of forest fragmentation and human disturbances, forest edges and gaps may always provide suitable habitats for IAPS to establish. Therefore, such microhabitats should be monitored regularly as a part of integrated IAPS management in community forests for the possible arrival of new IAPS.

Conclusions and management implications

We showed that IAPS cover and richness in the forests declined with increasing tree canopy, suggesting that management intervention in the degraded forests leading to canopy closure can suppress IAPS growth. These results have direct implications for the management of IAPS in forests of Nepal. Ecosystem based management of IAPS, i.e., prevention and control of IAPS though proper management of habitat/ecosystem, has been increasingly felt necessary as the number of IAPS and the areas of natural ecosystems that they have invaded are continuously increasing (Guo et al. 2018). Thousands of small to large patches of forests in Nepal are being managed by local communities, and, as a result of their management, the ecological conditions of forests have improved substantially in terms of vegetation cover, tree stocking, ecosystem services, and biodiversity conservation (Shrestha et al. 2010; Thapa-Magar and Shrestha 2015, Oldekop et al. 2019). Results of this study suggests that these participatory forest managements might have also helped to prevent and control many IAPS. To the best of our knowledge, this ecological benefit has not been acknowledged in scientific (e.g., Shrestha et al. 2010) and policy documents (e.g., MFSC 2014). Paradoxically, neither the local communities have been made well aware of the potential harms of IAPS by government and non-governmental organizations, nor the IAPS management has been adequately included in forest operational plans—the guiding document for forest management (Shrestha et al. 2019). Recognition of IAPS prevention and control as ecological benefits of participatory forest management in policy documents, integration of IAPS management in the operational plans of the CFs, and making communities aware of the potential harms of IAPS to environment and livelihood will improve community participation for IAPS management and restore ecosystem services of the forests in Nepal and elsewhere with similar bioclimatic and socio-economic conditions.

Abbreviations

CF: Community forest; DCFUG: Dhuseri Community Forest Users' Group; GLM: Generalized linear model; IAPS: Invasive alien plant species; KSL-N: Kailash Sacred Landscape Nepal; MFSC: Ministry of Forest and Soil Conservation; SCFUG: Sundari Community Forest Users' Group

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Authors' contributions

BBS conceptualized research and designed the study, supervised the research, and reviewed the manuscript; LK collected and analyzed the field data, and prepared the first draft the manuscript. The author(s) read and approved the final manuscript.

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Availability of data and materials

All data involved in this study are provided by the authors upon request.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable.

Competing interests

All authors declare that they have no competing interests.

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