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Distribution of invasive plants and their association with wild ungulates in Barandabhar Corridor Forest, Nepal

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Abstract

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Invasive and alien plant species (IAPS) are considered as major threats to native biodiversity because IAPS alter ecosystem structure and their functions. We assessed the association of four major IAPS (*Mikania micrantha, Chromolaena odorata, Lantana camara*, and *Parthenium hysterophorus*) and the abundance of wild ungulates in Barandabhar Corridor Forest (BCF), Chitwan, Nepal. We collected data on the presence of wild ungulates in IAPS invaded habitats through direct observation and sign surveys. Our study showed that the cover of *M. micrantha* was significantly high in Sal forest (Prominence value PV = 73.23) followed by riverine forest (PV = 40.5) and grassland (PV = 37.7) whereas *P. hysterophorus* was high in grasslands (PV = 22.9). Similarly, *C. odorata* was significantly high in Sal forest (PV =141.6%), and *L. camara* was high in mixed forest (PV = 22.6). It was found that there was a significant negative association of IAPS (p = 0.002) with wild ungulates. The abundances of deer and wild pigs were more in the buffer zone than in the non-buffer zone. The abundance of deer decreased with increasing cover of *C. odorata*, *M. micrantha*, and *P. hysterophorus* (p = 0.002). Similarly, the abundance of wild pigs decreased with increasing cover of *M. micrantha* and *L. camara*. IAPS were not uniformly distributed in different habitats and abundances of wild ungulates were less in IAPS invaded habitats. Hence, it is important to initiate management plans to control IAPS spread to avoid their negative impacts on wild ungulate population such as deer and wild pigs.

Keywords

biodiversity, conservation, herbivores, *Mikania micrantha*, Sal forest

Introduction

Globally, invasive and alien plant species (IAPS) are considered as major threats to biodiversity (Rai et al., 2012; Clusella-Trullas and Garcia, 2017) as many negative impacts on ecological and socio-economic aspects are reported in various studies (Sala et al., 2000; Auge et al., 2013; Simberloff et al., 2013; Vilà and Hulme, 2017). IAPS spread rapidly to cover various habitats such as the grass lands, waste lands, forests, residential areas and the agricultural fields (Parks et al., 2005). Then, IAPS replace native plant species leading to the change in ecosystem processes (Grice, 2006; Goodenet al., 2009; Vilà et al., 2011). In addition to this, IAPS invasion alters biogeochemical cycles and decrease the productivity of the invaded areas (Mack et al., 2000; Hayes and Holzmueller, 2012; Latombe et al., 2017; Shrestha et al., 2019). IAPS also affect the abundance of different wild animals, including the wild ungulates (Vila and Weiner, 2004; Doyle et al.,

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2007; Grigorescu et al., 2020; Gorchov et al., 2021). Thus, there is an antagonistic interactive effect between IAPS and the wild animals in the world (Doyle et al., 2007).

The study of IAPS in Nepal started five decades ago (Banerji, 1958) and a total of 166 IAPS are reported (Tiwari, 2005; Timsina et al., 2011; Shrestha, 2016). Over the years, several studies have shown that IAPS increase aggressively (Siwakoti et al., 2016; Shrestha et al., 2018) and have negative impacts in grassland, farmland and forest as soil properties are changed, and native plant species are displaced (Baral et al., 2017; Shrestha et al., 2019). However, studies related to associations of IAPS on different animal are limited in Nepal. To our knowledge a single study has shown impacts of IAPS on the distribution of mammals in the Chitwan National Park (Baral, 2004). It is, thus, important to know spatial distribution of IAPS and their impacts on different animals (Shrestha et al., 2019) because several habitats are often invaded by invasive species (Ram, 2008; Murphy et al., 2013). To fill in the study gaps related to IAPS and wild animals in Nepal, we studied the associations of IAPS and the distribution of wild ungulates. The present study was aimed to 1) evaluate the intensity of distribution of invasive species in different habitats, 2) evaluate the type of association of IAPS and the abundance of wild animals such as deer and wild pigs. To fulfill our aim, we used grids-based study to record numbers of the wild deer (Chital, Sambar, Northern red muntjac) and Wild pig and also

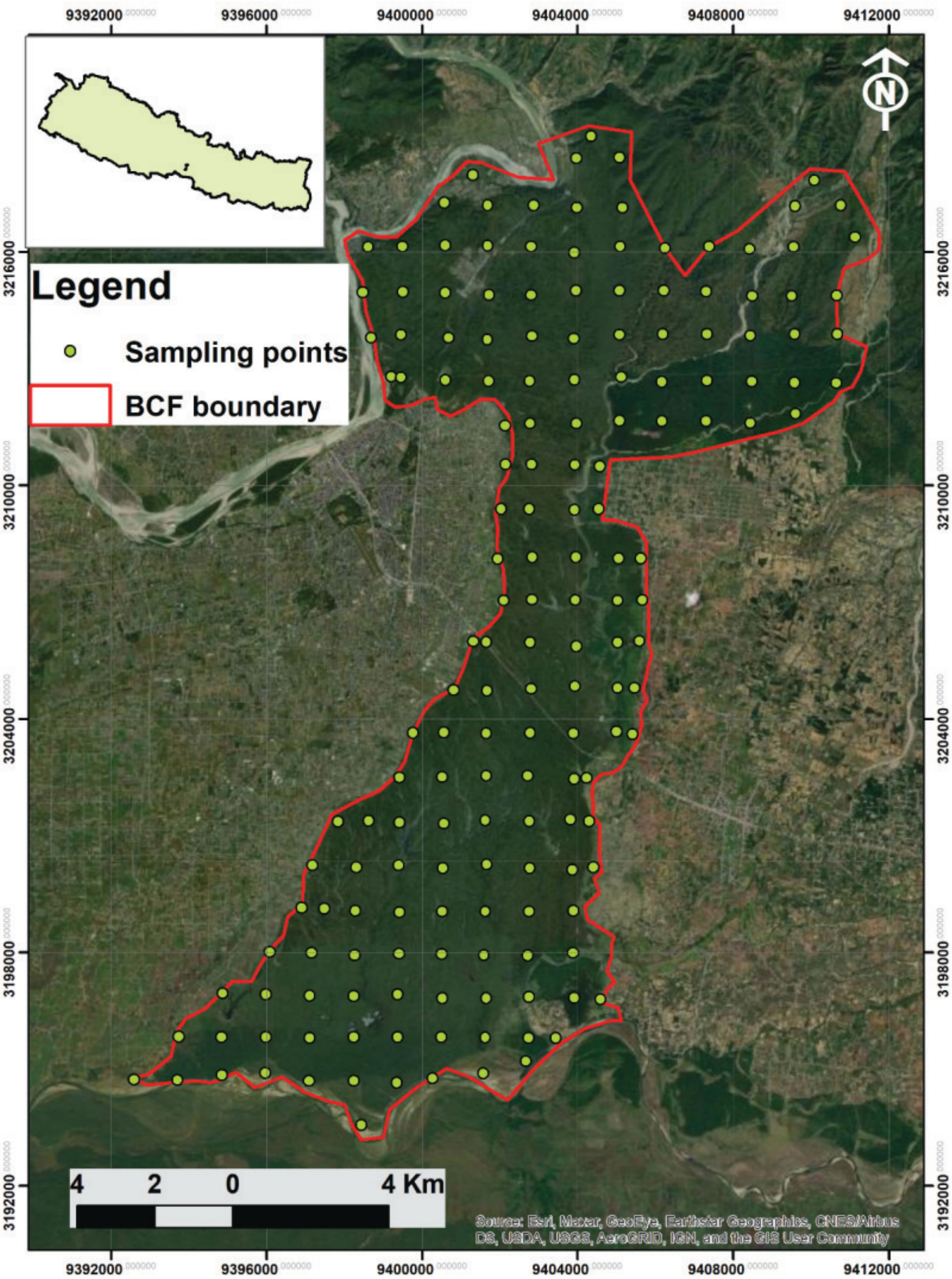

Fig. 1. Study area indicating sampling points. Map in the inset shows the location of Barandabhar Corridor Forest, Nepal.

noted the coverage of four highly invasive species, *Mikania micrantha, Chromolaena odorata, Lantana camara* and *Parthenium hysterophorus* in Barandabhar Corridor Forest (BCF). This forest is biologically important corridor that connects Chitwan National Park with Mahabharat range.

Materials and methods

Study area

Barandabhar Corridor Forest (BCF) is located at N 27°34' to N 27º40' latitude and E 84º21' to E 84º28' longitude within the Chitwan valley of Nepal. BCF is a bio-corridor in the Chitwan Annapurna Landscape (landscape connecting Chitwan National Park and Annapurna Conservation Area) (Fig. 1), covering an area of 96.02 km^2 (Bhattarai and Kindlmann, 2012; Adhikari et al., 2019). BCF is bisected by east-west highway into two parts, the southern part is in the buffer zone and managed by Chitwan National Park, whereas the northern part is the protected forest and managed by Division Forest Office, Chitwan. BCF has the tropical type of climate with an average temperature of 25 °C, but the summer temperature may rise to 43 °C. The average annual rainfall is 2,000 mm, which is maximum during the monsoon season (June and September) (Thapa, 2011; DHM, 2019). The flora of the BCF is dominated mainly by Sal forest following riverine forest, mixed forest, and grasslands (Dhakal and Yadava, 2011; Adhikari et al., 2021). This heterogeneous habitat of BCF harbors 32 species of mammals including wild ungulates such as Chital, Sambar, Northern red muntjac, Wild pig, Hog deer and Greater one-horned rhino (Lamichhane et al., 2016). Rapti, Khageri, Budi Rapti River system and Beeshazari Lake system, Batulpokhari Lake, Rhino Lake, Tiger Lake make the vegetation denser and wetter. The patches of short grasslands are scattered inside the Sal forest. The habitat of BCF is categorized as grasslands, riverine forest, mixed forest, and Sal forest which are covered by the major IAPS such as *Mikania micrantha, Chromolaena odorata, Lantana camara* and *Parthenium hysterophorus* (Khadka, 2017). This corridor is surrounded by highly populated settlements such as Ratnanagar Municipality in the east, Kalika on the north-east, and Bharatpur Metropolitan City in the west (Adhikari et al., 2021).

Research design

We considered that ungulates spatially distribute in the study area. The study area was divided into 194 grids of size 1 km × 1 km to minimize the potential bias overcome to collect the data. Among 194 grids, we selected 174 sampling grids for the study (Fig. 1). We avoided 20 sampling points due to non-accessibility as these points were in the swampy areas. The sampled points were located one in each grid at the interval of 1 km far from each other. We used Google Earth Pro for designing the grids and sampled points. These points were loaded in the GPS for easy tracking. Near the centre of each selected grid, a plot of size 10 m × 10 m quadrat was sampled to record the information about habitat types, canopy cover of the trees, IAPS coverage, signs or dropping, or direct recording of the ungulates.

Habitat types and IAPS

The dominant habitat types, coverage of major IAPS, canopy cover, distance to water sources were recorded within the plots. The habitat type of BCF was categorized into four categories as Sal Forest, riverine forest, mixed forest, and grassland (Table 1). We collected the information on coverage of highly colonized and dominated IAPS such as *M. micrantha, C. odorata, L. camara* and *P. hysterophorus* (Fig. 2). The list of IAPS for Nepal reported by Shrestha (2016) was used as a reference. The percentage of the coverage of IAPS in each plot was valued visually (Smartt et al., 1976). The coverage of the IAPS estimated was

Table 1. Description of different variables recorded during field study

SN	Variables	Description and codes used in analysis
1	Species variables	
	1.1. Wild ungulates	Deer: Chital (CH), Sambar (SD), Northern red muntjac (MJ), Wild pig (WP)
	1.2. Invasive and alien plant species (IAPS)	Four IAPS that cover the maximum ground cover: *Mikania micrantha* (Mika), *Chromolaena odorata* (Chro), *Lantana camara* (Lant) and *Parthenium hysterophorus* (Part)
2	Habitat types	
	2.1. Sal Forest (SF)	The main dominant species is *Shorea robusta* C. F. Gaertn. and the associate species is *Terminalia alata* Heyne ex Roth
	2.2. Riverine Forest (RF)	Forest present along the rivers and their catchment area. The major tree species are *Trewia nudiflora* L., *Bombax ceiba* L. and *Dalbergia sissoo* DC.
	2.3. Mixed Forest (MF)	Forest of *Shorea robusta* C. F. Gaertn. *Dillenia pentagyna* Roxb., *Careya arborea* Roxb., *Xeromphis uliginosa* (Retz.), *Terminalia alata* Heyne ex Roth, *Lagerstroemia parviflora* Roxb.
	2.4. Grassland (GL)	The patches of the grassland including *Imperata* spp, *Narenga porphyrocoma*, *Saccharum bengalense* and *Saccharum spontaneum*, present inside the large patch of forest and in the flood plain of Rapti, Budi Rapti and Khageri river
3	Canopy cover (CC)	Canopy cover (CC) measure in percentage
4	Distance to water source (DW)	Euclidean distance measured from sampling point to the nearest waterhole

Fig. 2. Wild ungulates recorded in BCF (a) Chital (*Axis axis)*, (b) Sambar (*Rusa unicolor*), (c) Northern red muntjac (*Muntiacus vaginalis*), (d) Wild pig (*Sus scrofa*). Photos by Jagan Nath Adhikari.

classified into the five categories such as no invasion (0%), very low invasion (1 to 20%), moderate invasion (20 to 40%), high invasion (40 to 60%), very high invasions (60 to 80%), and totally invasions (>80%). The distance from the road, settlements, nearest water resources was measured as Euclidean distance from the sampling point to the nearest waterhole by using ArcGIS, the field we collected the following variables (Table 1).

IAPS cover mapping

Total IAPS cover map was prepared using geographical coordinates recorded during the field study. The Inverse Distance Weighted (IDW) algorithm (Hengl, 2009) in ArcGIS 10.4 (ESRI, 2011) was used to interpolate values of expected IAPS cover on the basis of total IAPS cover field data. IDW algorithm of interpolation is used to evaluate the values of target variables at a new location. The weightage of the prediction location closer to the sampling points have greater than the locations far from the sampling point (Huang et al., 2011).

Data collection on ungulates abundance

Among the reported six species of wild ungulates – Chital (*Axis axis*), Sambar (*Rusa unicolor*), Northern red muntjac (*Muntiacus vaginalis*), Wild pig (*Sus scrofa*), Greater one-horned rhino (*Rhinoceros unicornis*), Hog deer (*Axis porcinus*) from BCF, we selected only four (Chital, Sambar, Northern red muntjac and Wild pig) for study (Fig. 3). We avoided two ungulates – Greater one-horned rhino and Hog deer. Greater one-horned rhinos are mega herbivores and need more food and space than other ungulates (Owen-Smith, 1988) and reported in very low numbers. Hog deer is a tall grassland specialist and found in the tall grassland habitat nearer to the Chitwan National Park, but habitat is almost absent in other parts of Barandabhar Corridor except small patches scattered in the flood plain of the Rapti River (Dhungel and O'Gara, 1991; Bhattarai and Kindlmann, 2013). Among four selected ungulates, Sambar is listed in Vulnerable category whereas other ungulates are in Least Concerned according to IUCN Red List (https://www.iucnredlist.org). Similarly, Chital, Northern red muntjac and Sambar are listed as Vulnerable and Wild pig as Least Concerned according to Nepal Mammal Red Data Book (Jnawali et al., 2011). These ungulates are the principal prey species of Tiger and Leopard in lowland Nepal (Wegge et al., 2009; Bhattarai and Kindlmann, 2013; 2012).

Signs of wild ungulates were surveyed to collect information about their presence. The sign abundance of the wild ungulates were collected from 6:00 A.M. to 10:00 A.M. and 15:00 P.M. to 18:00 P.M. as there was maximum mobility of ungulates during these hours during the day (Shrestha, 2004; Adhikari et al., 2021). The fresh dropping was observed and counted within the plot. One patch of fresh dropping was considered as belonging to a single individual. We assume that ungulates deposit their droppings at a uniform rate in a pre-defined time (Gopalaswamy et al., 2012).

Fig. 3. (a) *Chromolaena odorata*, the highly dominated IAPS, (b) The grassland invaded by *Mikania micrantha*, (c) *Lantana camara* (d) *Parthenium hysterophorus*. Photos by Jagan Nath Adhikari.

Data analysis

Prominence value

The prominence values (PV) of each dominant IAPS were calculated and used to quantify the abundance of IAPS at the different type of habitats using the method developed by Dinerstein (1979). The prominence value reflects the relative availability of plant species in the habitats and is defined as the mean percentage cover of a species multiplied by the square root of the frequency of the occurrence of that species in the vegetation samples plot (Dinerstein, 1979). We calculated the prominence value for each IAPS species using the following formula (Jnawali, 1995).

$$PV_s = M_s (\sqrt{f_s})$$

Where PV_s is prominence value for species s, M_s is mean percentage cover of species s, and f_s is frequency of occurrence of species s.

To find out correlations among pairs of predictors, we calculated the variance-inflation factors in the model by using 'vif' function in the 'car' library (Fox and Monette, 1992). The above-mentioned factors were not problematic as their scores were very low (<1.5) dropped from the regression model.

To find the best subset of predictors in a regression model, we used 'regsubsets' functions in 'leaps' package (Lumley and Miller, 2020). The quality of the adjustment of the models was measured by the adjusted coefficient of determination (R^2) and Mallow' Cp (Mattos et al., 2020). After choosing the best subset of predictors, determinants of the abundances of deer and wild pigs were tested using generalized linear mixed models (GLMM), where we used habitat as random factor. We tested the effects of different variables (zones, distance from water, canopy cover, *M. micrantha, C. odorata, L. camara* and *P. hysterophorus*) on species deer and wild pig abundance. The analyses were carried out by using the lme4 function in the lmerTest package (Bates et al., 2014) in R 4.0.0 (R Core Team, 2018).

Multivariate analysis

We used Redundancy analysis (RDA) to extract and the relationship between deer and wild pigs with different invasive species, buffer zone and non-buffer zone. RDA is a direct gradient analysis technique, which summarizes linear relationships between components of response variables that are "redundant" with (i.e., "explained" by) a set of explanatory variables (Legendre and Legendre, 1998). The significance of explanatory variables was tested using the Monte Carlo permutation test (n = 4999). All tests were carried out using Canoco 5.04 (Ter Braak and Šmilauer, 2012).

Results

Prominence value of IAPS

The prominence value (PV) of *C. odorata* was higher in Sal forest and grassland whereas PV of *M. micrantha* was higher in Sal forest followed by riverine forest and grassland. Similarly, PV of *L. camara* was higher in mixed forest, and PV of *P. hysterophorus* was higher in grassland (Table 2).

IDW algorithm method of interpolation evaluated that higher area of the BCF was invaded by IAPS (40–60% coverage) (Fig. 4). There is almost no space left by the invasive species. Similarly, the abundance of ungulates was comparatively higher in the areas with low IAPS abundance (Fig. 4).

IAPS distribution, wild ungulates abundance and association of IAPS with ungulates

The RDA analysis showed that the distribution of the four common IAPS was found in non-buffer zone area away from the occurrences of deer and wild pigs (Fig. 5).

Table 2. Prominence value of dominant IAPS

IAPS	SF	RF	MF	GL	Total
Chro	141.6	2.2	4.02	20	167.9
Mika	73.23	40.5	3.3	37.7	154.7
Lant	8.11	4.34	22.6	1.01	36.06
Part	0.38	4.35	4.62	22.9	32.24

The abundance of deer was found higher in buffer zones than in non-buffer zones, increased away from water bodies but abundance decreased in areas with *C. odorata*, *M. micrantha*, and *P. hysterophorus* growth. Similarly, wild pigs decreased with increasing coverage of *M. micrantha* and *L. camara* (see Table 3 and Fig. 5).

Discussion

Prominence value and distribution of IAPS

Our study showed that the prominence of IAPS was highest in Sal forest followed by grassland and riverine forest. The open areas located in the forest were highly invaded by IAPS than densely forested areas (Table 2). The suitable habitat of invasive species such as *L. camara* was across 62 districts and *M. micrantha* was confined only in 35 districts in Nepal (Shrestha, 2016). The study of Murphy et al. (2013) in the Chitwan National Park showed a riverine and subtropical mixed hardwood forests were widely invaded by *M. micrantha* than tall grassland, short grassland and Sal forest. However, *M. micrantha* invasion extends to the tropical regions in the east and central Nepal, mostly in riverine forest (Poudel et al., 2004; Murphy et al., 2013). *C. odorata* invasion was found mainly in Sal forest and grassland as reported by Thapa et al. (2016). *P. hysterophorus* was found to have strong negative effects on the vegetation composition in Nepal (Timsina et al., 2011). *P. hysterophorus* is highly invasive in nature as seeds are easily transported by animals, water (Javaid et al., 2007; Timsina et al., 2011). Our study too found that *P. hysterophorus* invasion

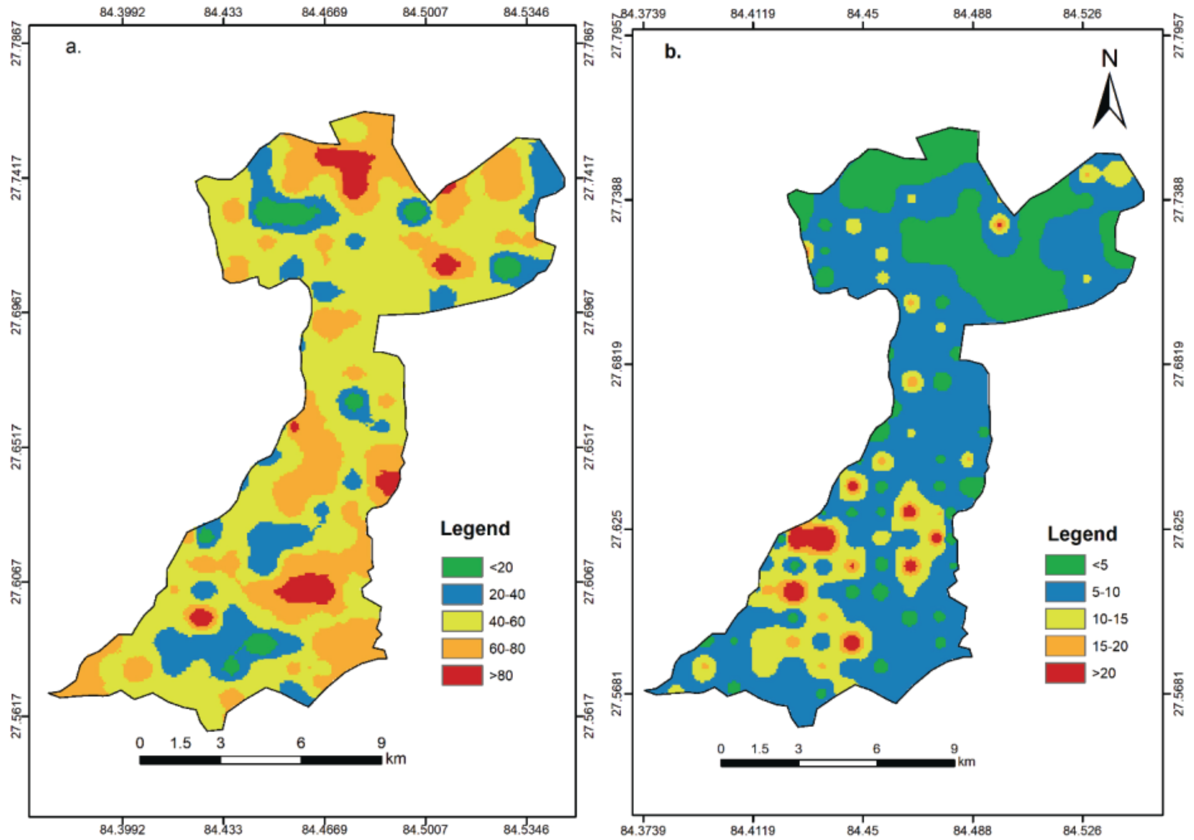

Fig. 4. (a) Comparison of distribution and coverage of total IAPS (b) and total sign abundance of the ungulates reported.

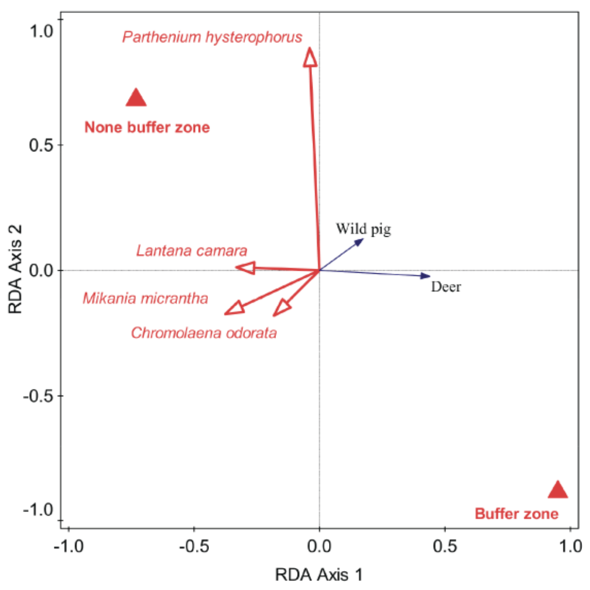

Fig. 5. RDA ordination diagram (biplot) showing association of IAPS with buffer zone and non-buffer zone area, and coverage of different invasive species. Monte-Carlo permutation test of significance of all canonical axes: F = 5.8, p = 0.002. 1 1st RDA axis explained 14.03% and the 2nd 0.59% of the total variation in the data. Names in italics are invasive species.

was in the open habitats scattered in the forest and grasslands. However, its abundance was low compared to other study species (Table 2).

Association of IAPS distribution and wild ungulates

The abundance of deer was higher in the buffer zone area than non-buffer zone area in our study. The abundance of deer decreased in *C. odorata, P. hysterophorus* and *M. micrantha* invaded habitats but abundance of wild pigs significantly decreased with increase in abundance of *C. odorata* and *M. micrantha*. IAPS reduce the quality of the grasslands as native plant species are replaced by invasive species (Mack and D'Antonio, 1998; Schirmel et al., 2016; Gorchov et al., 2021). Invasive plant species also reduce the ecosystem functions (Parks et al., 2005; Schirmel et al., 2016). Although the effects of IAPS are mostly negative (Vilà et al., 2011), there are some reports of positive effects on animals as IAPS provide the habitat (Severns and Warren, 2008) and food (Schirmel et al., 2016). Our study showed that deer and wild pigs were more abundant in *L. camara* invaded habitats. This may be because tall *L. camara* provide shade and it is easy to hide and save their kids from the predator. It is also reported that ungulates rarely use *M. micrantha* as food, though of the habitats are seriously destroyed by *M. micrantha* (Baral, 2004; Subedi, 2012; Murphy et al., 2013) and the population of wild ungulates is low in *M. micrantha* invaded habitats (Murphy et al., 2013).

Our study found that distance from the water sources had effect on distribution of IAPS showing IAPS abundance was high near the water sources. However, the abundance of deer was more in habitats that were far from the water sources in BCF as BCF is rich in water resources that provides favorable conditions of the growth of IAPS (Shrestha et al., 2018).

Conclusion

Our study showed that distribution and cover of IAPS in BCF were associated with the abundance of the wild ungulates. Comparatively, the abundance of ungulates was low in IAPS invaded habitats. Grasslands and habitats with low canopy were highly invaded by IAPS. Distance from the water sources played significant role in invasion of IAPS. Our study is preliminary and highlighted the negative association of IAPS with abundance of wild ungulates in lowland habitats in Nepal. Further studies are needed to evaluate the significance of a direct cause-effect between IAPS and ungulates. These should also focus on management of different IAPS.

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Table 3. The regression analysis to show the relation of the deer species and wild pigs with different IAPS coverage and distance from water resources (all Degrees of freedom = 1)

	Deer		Wild pigs	
	Pr(>F)	R^2	Pr(>F)	R^2
Zones	0.001	0.180	0.713	–
Distance from water	0.014	0.092	0.630	–
Chromolaena odorata coverage	<0.001	0.215	0.025	0.371
Parthenium hysterophorus coverage	0.010	0.102	0.308	–
Lantana camara coverage	0.103	–	0.072	–
Mikania micrantha coverage	<0.001	0.372	0.048	0.287

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