INVASIVE ALIEN PLANT SPECIES AND THEIR EFFECT ON THE HABITAT UTILIZATION OF MAMMAL SPECIES IN SHUKLAPHANTA NATIONAL PARK, NEPAL

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Central Department of Zoology

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DECLARATION

I hereby declare that the work presented in this thesis has been done by myself, and has not been submitted elsewhere for the award for any degree. All sources of information have been specifically acknowledged by reference to author(s) or institution(s).

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On the recommendation of the supervisor, Assoc. Prof. Dr. Hari Prasad Sharma, this thesis submitted by Ms. Chandra Chand entitled "Invasive alien plant species and their effect on the habitat utilization of mammal species of Shuklaphanta National Park, Nepal" is approved for the examination for the partial fulfillment of the requirements for the degree of Master of Science in Zoology with special paper Ecology and Environment.

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The thesis work submitted by Ms. Chandra Chand entitled "Invasive alien plant species and their effect on the habitat utilization of mammal species of Shuklaphanta National Park, Nepal" has been accepted as partial fulfillment for the requirements of the degree of Master of Science in Zoology with special paper Ecology and Environment.

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LIST OF ABBREVIATIONS AND ACRONYMES

Abbreviated form	Details of Abbreviations
IAPS	Invasive Alien Plant Species
ShNP	Shuklaphanta National Park
GPS	Global Positioning System
GIS	Geographic Information System
IVI	Importance Value Index
IUCN	International Union of Conservation of Nature

ABSTRACT

The introduction and colonization of invasive alien plant species (IAPS) is one of the most serious threat to the conservation of native flora and fauna. Such threats are noted in the various protected areas including lowlands of Nepal with negative impacts on the species and ecosystem services. The impacts of IAPS on threatened mammal species especially on their occurrences is little known. This study identified the effects of IAPS on the occurrence and habitat utilization of threatened mammal species at Shuklaphanta National Park (ShNP), Nepal from 11 November 2020 to 11 June 2021. During the study period, ShNP was categorized into IAPS invaded and non-invaded habitats. The occurrence of threatened mammal species was recorded from 210 plots of 10 m X 10 m along the line transect. Altogether 11 IAPS were recorded among seven families during this study. Among them Blue Billygoat Weed (*Ageratum houstonianum*) was abundant species in the study area. Altogether 25 mammal species were recorded in the study area, whereas 11 mammal species were threatened. Among the threatened mammal species, 10 species were in IAPS invaded habitat and all 11 species in IAPS non-invaded habitat. In IAPS invaded habitat, the sign of Fishing Cat (*Prionailurus viverrinus*) was recorded only from IAPS non-invaded habitat. The higher occurrence of threatened mammal species was recorded nearer the forest as the abundance of IAPS decreased with decreasing distance to the forest. In addition, the higher occurrence of mammal species was found with increasing the distance to water source, distance to road, distance to human settlement and distance to agricultural land as the abundance of IAPS decreased with increasing distance to water source, road, human settlement and agricultural land. The threatened mammal species utilizes the IAPS non-invaded habitat rather than the IAPS invaded habitat. For providing suitable habitat for threatened mammal species, the removal or control of the invasive alien plant species from ShNP is recommended.

1. INTRODUCTION

1.1 Background

The species either accidentally or deliberately move away from their native areas are alien species (Pysek et al. 2004). These alien species with high reproductive rates and their potential to spread rapidly over large areas are regarded as invasive alien species and are both plants and animals (Lowe et al. 2000, Pysek et al. 2004). The rapid spreading of invasive alien plant species (IAPS) is increasing especially on different land uses in the changing climate (Meyerson and Mooney 2007) and infrastructure development including road and transportation (Adhikari et al. 2020). With globalization, the transportation of IAPS has also been increased through trade, tourism, travel and other human disturbances or activities (Lahkar et al. 2011) and such disturbance are particularly suitable for IAPS (Mack et al. 2000, Knight et al. 2009).

Furthermore, many tourism-related activities, such as, boating and fishing had promoted the distribution of IAPS (Pathak et al. 2021). The promotion of tourism in protected areas such as Chitwan National Park, substantially increased the movement of people into these protected areas, resulted in rapid spread of IAPS into the protected area (Murphy et al. 2013). In addition, various non-native species are introduced to the area outside of their natural range in order to enhance tourism (Arismendi and Nahuelhual 2007), for example, sports fish species such as Salmon and Trout are intentionally introduced into non-earthly habitat to strengthen the possibilities of recreational fishing in Lake Llanquihue in Southern Chile. Typically, IAPS produce either large number of viable seeds (Brooks et al. 2004), and often display early sexual maturity (Pysek et al. 2003). This, in turn, minimizes the competition from native species and enhances the chances of survival of IAPS (Mack et al. 2000, Knight et al. 2009). IAPS can have remarkable negative interactions with native flora and fauna (Mooney et al. 2005, Hardesty-Moore et al. 2020). Major impacts of IAPS include the loss of native species and biodiversity (Kohli et al. 2006), habitat alteration (Murphy et al. 2013), and deterioration of ecosystem productivity and nutrient cycling (Charles and Dukes 2008, Vila et al. 2011).

After the several generations, the IAPS adapt to the introduced habitat (Baker 1986), as they are more likely to adapt to new climatic conditions (Hellmann et al. 2008) and negatively impact the ecosystem (Vila et al. 2011, Shrestha and Shrestha 2021). Several studies had showed that due to the presence of water soluble phenolic and sesquiterpene lactones, such as parthenin in Parthenium, they exhibited allelopathic nature (Timsina et al. 2011). As a consequence of these chemicals, the growth of other plants through the contamination of soil was inhibited (Belz et al. 2007, Rashid et al. 2008). As a result IAPS become dominant in the introduced habitat (Khaniya and Shrestha 2020).

In some localities people use some IAPS as a food, medicine, fuel, or fodder mainly as a part of their control (Kull et al. 2007). For examples, Silver Wattles (*Acacia dealbata*), Black Wattles (*A. mearnsii*) and Green Wattles (*A. decurrens*) are used globally for economic, environmental and ornamental purpose (Kull et al. 2007). Sometimes IAPS were used as alternative sources of fodder for livestock (Shrestha et al. 2018). However, invasive alien plant species have negative impact on agricultural production, forest regeneration (Shrestha et al. 2018), livestock grazing (Lahkar et al. 2011, Khaniya and Shrestha 2020) and human health (Rai and Singh 2020). For example, habitat uses by Indian Muntjac (*Muntiacus muntjak*) in Baluran National Park, Java, revealed their avoidance of IAPS invaded habitat (Tyson 2007).

Biological invasions can have impacts on pollinator communities as they divert pollinators and dispersers of native species towards themselves (Aravind et al. 2010). The berries of Lantana (*Lantana camara*), attract frugivorous birds and mammals, help to disperse seeds widely (Aravind et al. 2010). Hence, hinder the reproductive success of native species (Brown et al. 2002). Physiographic and climatic diversity of Nepal providing habitats for the species from various part of world (Chaudhary et al. 2020), however the effects of invasion have been very limited. Therefore, the research on the potential extent of IAPS and its impacts on the occurrence and habitat use of mammal species in Shuklaphanta National Park (ShNP) Nepal is prerequisite for identification of habitat of mammal species that are vulnerable to invasion by IAPS and will be immensely helpful for the park managers to chalk out a robust management strategy for controlling the invasive species in the park.

1.2 Objectives

1.2.1 General objective

The overall aim of the study was to identify the effects of invasive alien plant species on the habitat utilization of mammals in ShNP.

1.2.2 Specific objectives

The specific objectives of the study were:

i. To assess the abundance of invasive alien species in ShNP.
ii. To identify the impacts of IAPS on the occurrence of mammal species in ShNP.

1.3 Rationale of the study

Invasive alien plant species (IAPS) are spreading into protected areas worldwide (Foxcroft et al. 2017). They are one of the major factors for increasing biodiversity loss (Kohli et al. 2006, Shrestha and Shrestha 2021), and are believed to be the second largest factor (Vitousek et al. 1996). In addition, their impact is noticed through encroachment and habitat loss (Bhattarai 2012). They showed negative impacts on native species, habitat alteration (Shrestha et al. 2015, Chaudhary et al. 2016) and nutrient cycling (Rai and Singh 2020, Pathak et al. 2021); thus alter structure and function of ecosystem (Charles and Dukes 2008) and this in turn can affect the distribution and habitat utilization of mammal species (Aravind et al. 2010).

Although the effect of IAPS on native flora and fauna, including endemic species are increasing in Nepal (Shrestha and Shrestha 2021), we have little knowledge on their distribution and spreading factors. The spread of IAPS in protected areas including Ramsar sites is a special case of concern (Vitousek et al. 1996, Basaula et al. 2021). They cover the habitat of threatened faunal species (Ferdinands et al. 2005). This may alter the highly preferred habitat of mammal species into less preferred habitat and access to threatened mammals which are critical to ecosystem (Murphy et al. 2013.

Though the studies on the IAPS and their distribution are carried out now a days, there are countable studies that have looked at the effect of IAPS on mammal species (Adhikari et al. 2022). It means that managers/policy makers have insufficient data on the severity of the impact of invasive alien plant species on mammal species in Nepal. It's creating a problem for developing policies for minimizing the effect rate. Therefore, the data obtained from this study can be used by policy makers for developing a site-species specific management plan.

1.4. Limitation of the study

- The study had limited on the study of invasive alien plant species.

2. LITERATURE REVIEW

Biological invasion had been considered as one of the causes of global environmental changes (Vitousek et al. 1996) and a leading cause of decline and loss of native biodiversity (Kohli et al. 2006) and ecosystem services (Pejchar and Mooney 2009). The negative impact of IAPS was intensified by ongoing climate change (Simberloff 2000). The prevalence of IAPS was noticed globally, but their impact is likely to be higher in developing countries like Nepal due to lack of expertise and limited resources available for their management (Shrestha 2016). In Nepal, of 182 naturalized flowering plants, 27 species are IAPS (Shrestha and Shrestha 2021), four species, Siam Weed (*Chromolaena odorata*), Lantana (*Lantana camara),* Mile-a-minute Weed (*Mikania micrantha*), and Water Hyacinth *(Eichhornia crassipes*), are among the World's 100 worst invasive alien species (Lowe et al. 2000).

2.1. Invasive alien plant species and their threats

Globally the biological invasion had been considered as the second major cause of biodiversity loss next to habitat degradation (Gaertner et al. 2009). Invasive alien plant species (IAPS) had negative effect on native species (Bradley et al. 2018), and cause a substantial decline in the abundance and diversity of native plant species (Pyšek et al. 2012, Bhatta et al. 2020, Utz et al. 2020). The IAPS invades in agro ecosystems and the natural environment including protected areas and Ramsar sites from tropical lowland to temperate mountainous region (Shrestha 2019). IAPS become a major threat to our environment and economy (Shabbir and Bajwa 2006). IAPS remarkably reduced the fitness and growth of native plant species (Vila et al. 2011). The impact of IAPS were mainly reported from biodiversity loss, livestock poisoning, reduced agricultural production and forage supply (Shrestha et al. 2018).

The impact of IAPS such as modification of the plant community structure and suppression of native plant species growth had been reported globally (Singh et al. 2014). Along with vehicles used (Adhikari et al. 2020), natural dispersal such as river (Nath et al. 2019, Bhatta et al. 2020) and human settlement affect significantly the introduction of IAPS into new sites (Nath et al. 2019). Furthermore, the nearness of the protected areas to settlement might promote the invasions (Simberloff 2009). The forest edges might trap the seeds of IAPS carried through wind (Joshi et al. 2015).

Thus, facilitated the invasion (McNab and Loftis 2002) as they ease the establishment of IAPS (Baret et al. 2008, Joshi et al. 2015). The amount of light required for the growth and reproduction of most IAPS was reduced by the high tree canopy cover (Baret et al. 2008). The number of IAPS found in the interior of the forest with high tree canopy was not as much as found at forest edge and gap (Khaniya and Shrestha 2020). Several other studies also had showed a decline in the abundance or species richness of IAPS with increasing canopy cover (McNab and Loftis 2002). This lessen the probability of invasion by IAPS and their colonization in forest ecosystem (Hartman and McCarthy 2008). While thinning of the canopy elevated the level of light which energized the germination and establishment of IAPS (Baret et al. 2008).

Thus, IAPS were less common in undisturbed forest (Shrestha et al. 2017). With steady increased in human movement and global trade, the intensity of biological invasion had been increased in all ecosystems and landscapes (Shrestha 2017). Human activities increased propagule pressure of IAPS (Simberloff 2009). Wetland IAPS like Water Hyacinth and Water Lettuce (*Pistia stratioites)* were also transported to new locations for their ornamental values (Shrestha et al. 2017). Bush-morning Glory (*Ipomoea carnea*) had been introduced to hilly region for controlling soil erosion along roadside and also as hedge plant in agro ecosystem (Shrestha et al. 2017, Shrestha and Shrestha 2021).

2.2. IAPS effects on mammal species

Invasive alien plant species (IAPS) can alter the ecosystem; reduce the availability of food resources; cause the mammal species to change the way of habitat utilization (Dutra et al. 2011). IAPS dominance over habitat; decreased diversity of food resources available for herbivores and omnivores (Brooks et al. 2004, Rerani 2019). Because of this, the food available for carnivores also decreased. Thus, the distribution and abundance of mammal species have been influenced significantly through effects on habitats and resources (Ogutu and Owen-Smith 2003). The National Trust for Nature Conservation in recent years suggested that the Greater One-horned Rhino (*Rhinoceros unicornis)* (Murphy et al. 2013), and other large herbivore populations had declined in areas with high Mikania infestation (Lahkar et al. 2011). Therefore, IAPS was likely to destroy primary habitats of threatened and important species (Lahkar et al. 2011, Murphy et al. 2013). Several studies revealed that with increasing abundance of IAPS, abundance and diversity of the small-mammal community decreased (Freeman et al. 2014).

Similarly, Shrestha et al. (2015) and Shrestha et al. (2019) suggested that Parthenium had been expanding its distribution to the habitats of endangered mammals. Likewise, a handful of studies from Asia recommended large herbivores were currently facing unprecedented challenges from habitat loss (Ahrestani and Sankaran 2016). For example Four-horned Antelope (*Tetracerus quadricornis*) showed the negative influence by Lantana in the tropical forests of India (Baskaran et al. 2011). Similarly, Mesquite (*Prosopis juliflora)* modifying the natural ecological processes (Shackleton et al. 2015) with negative implications for wild ungulates (Adhikari et al. 2022). IAPS invasion into open grasslands affected the Deer species (Arandhara et al. 2021, Adhikari et al. 2022); directly by reducing the habitat and also indirectly by reducing the grass biomass on which it feeds (Arandhara et al. 2021).

Globally, IAPS endangered the sensitive and biodiverse ecosystem by altering riparian watersheds (Lambert et al. 2010). These were key habitat for carnivores and other mammal species (Hardesty-Moore et al. 2020). But a couple of studies put forwarded sometimes mono-specific stands of IAPS encouraged the foraging of consumer as they restructured the habitat for them, especially who benefit in the altered habitat (Utz et al. 2020). The dense stands of IAPS might protect small mammals from predators, which in turn could increase foraging pressure on seeds that small mammals feed upon (Dutra et al. 2011, Utz et al. 2020).

Moreover, IAPS might lead to decline in small mammals if they provide fewer food resources compared to the native species they displaced (Utz et al. 2020). For example, the abundance and diversity of mammal species decreased as the abundance of Cheat Grass (*Bromus tectorum*) has increased. The change in the small mammal communities likely effected through higher and lower trophic levels and had the potential to cause major changes in ecosystem structure and function (Freeman et al. 2014). Large mammal species utilized the IAPS non-invaded habitat and the cleared areas more than the IAPS invaded habitat (Rerani 2019) due to which species richness, abundance and diversity decreased with increasing invasion duration and cleared areas (Rerani 2019). However, these protected areas also face a number of management challenges, and one of these is an increasing number and abundance of IAPS (MFSC 2017, Bhattarai et al. 2017).

2.3. IAPS in protected areas

Despite the fact that protected areas are crucial for biodiversity preservation and the provision of essential ecosystem services (Millennium Ecosystem Assessment 2005), invasive alien plant species threatened the ecological integrity of protected areas worldwide (Millennium Ecosystem Assessment 2005, Foxcroft et al. 2007). There is a lack of comprehensive data on the effects of alien species in protected areas at the international and/or regional levels (GISP 2007). IAPS can spread naturally through river water, birds, and mammals as well as into and inside protected regions (Foxcroft et al. 2007). A protected ecosystem has a number of entry points for IAPS, including human-dominated boundaries, linking roadways, and natural systems like rivers (Foxcroft et al., 2007).

The richness of the IAPS also increases as the number of visitors to protected areas rises (Allen et al. 2009). They may deteriorate and lessen wildlife habitat and foraging areas, deplete soil and water supplies, and lessen the native diversity of the area (DiTomaso et al., 2010; Hulme et al. 2013). Recent, progressive human encroachment at protected area limits (Radeloff et al. 2010), should be particularly concerning as it will increase the supply of alien plant propagules. The pressure caused by IAPS in protected areas may be indicated by species inventories, but further work is needed to assess the impacts of invasive alien plant species. The issues brought on by IAPS, entering protected areas pose a significant difficulty in addition to, and frequently in conjunction with, existing challenges (Loope et al. 1988: Macdonald et al. 1988). Furthermore, managers urgently need an acceptable evidence base to prioritize control targets (Cook et al. 2010) because just a small percentage of IAPS in protected areas are expected to constitute a harm to biodiversity (Groves 2002; Hulme 2012). Unfortunately, the evidence base to support effective and targeted management of invasive alien plant species in protected areas is often poor (Andreu et al. 2009).

3. MATERIALS AND METHODS

3.1 Study Area

This study was conducted in Shuklaphanta National Park (ShNP; 28°45'- 28°57'N to 80°07'-80°21'E), which is located in a lowland of Sudur Paschhim Province of Nepal (Figure 1). It comprises an area of 305 km^2 with 243.5 km^2 of buffer zone. The park was established in 1976 as a Shuklaphanta Wildlife Reserve for the conservation of Barasingha (*Recervus duvaucelii*) population in Nepal. The ShNP's main habitat includes forest, grassland and wetland (Shrestha and Pantha 2018). The species composition of the forest are Sal (*Shorea robusta*), Kadam (*Adina cordifolia*), Kumkum (*Mallotus philippinensis*), Jamun (*Syzygium cumini*), Pitalu (*Trewia nudiflora*), Crape Myrtle (*Lagertroemia parviflora*), Bahera (*Terminalia bellirica*), and Chebulic Myrobalan (*Terminalia chebula*). Shuklaphata is the largest grassland with an area of approximate 16 km^2 dominated by Congon Grass (*Imperata cylindrical*), Baruwa Sugarcane (*Saccharum bengalensis*), Wild Sugarcane (*Saccharum spontaneum*), and Halfa Grass (*Desmostachya bipinnata*). A total of 56 mammal species has been recorded from the ShNP (Poudyal et al. 2020). This park is a home to endangered wildlife species including Bengal Tiger (*Panthara tigris tigris*), Asian Elephant (*Elephas maximus*) and Greater One-horned Rhino (*Rhinoceros unicornis*). Barasingha, Spotted Deer (*Axis axis*), Hog Deer (*Axis porcinus*), Samber Deer (*Rusa unicolor*), Northern Red Muntjac (*Muntiacus vaginalis*), Wild Boar (*Sus scrofa*), and Nilgai (*Boselaphustrago camelus*) are the main species of ungulates. The people in the buffer zone are mainly engaged in agriculture and animal husbandry. They rely heavily on the park for cattle grazing and firewood food lumber and grass collection (Bot 2003).

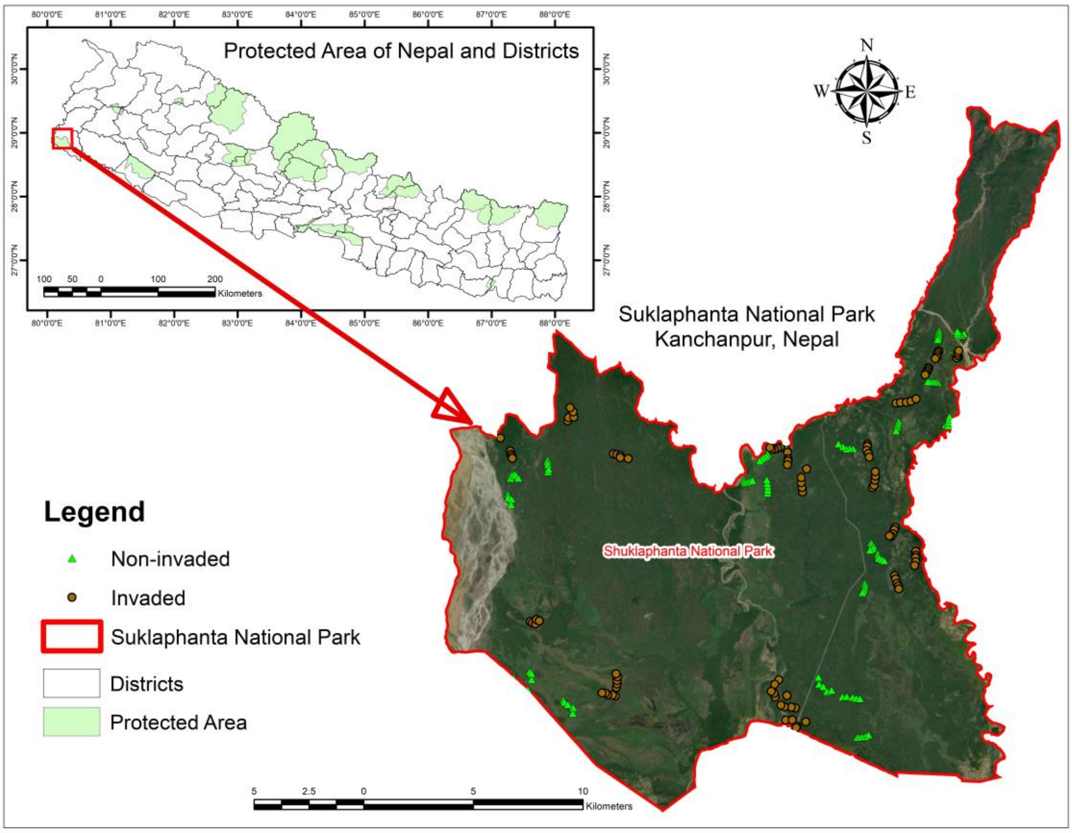

Figure 1: Study area in Shuklaphanta National Park

3.2 Field data collection

The preliminary study was conducted from 28 October to 3 November 2020, and the potential invasive alien plant species (IAPS) sites within the park were identified following consultation with park officials and field visits. During that time, the study area was categorized as IAPS invaded (if any invasive species cover the area >10%) and IAPS non-invaded habitat (if the area is without invasive plant species or sparsely distributed i.e. less than 10% coverage). The study area was at the grassland and forests of ShNP. A total of 42 transects with approximately 250 m length were established from 11 November 2020 to 11 June 2021 equally in both habitats. The interval between two transects was at least 250 m. Sometimes, the variation in length was made due to the presence of rivers, stream or lakes. Five plots of 10 m X 10 m were established along the transect, alternately at the interval of 50 m. In each plot, five nested subplots with 1 m X 1m were established: four at the corners and one at the center of the plot. In the plot, presence/absence of IAPS, individual of each IAPS species (in IAPS presence habitat), forest canopy (in the forest sites), sign of herbivores and carnivores mammal species such as foot prints, scratches, burrows, and fecal were recorded. In addition, the elevation and latitude and longitude of each plot were also recorded by Global Positioning System (Garmin Etrex 10). Furthermore, the nearest distance to the forest, agricultural land, road, household, and water sources were also recorded with GPS from the center of each plot, however, the distance >250 m was measured with Geographic Information System. Three nested subplots were used diagonally for observation. The IAPS number was counted from the nested subplots. IAPS cover of individual species was estimated visually by cover-class scale value (Zobel et al. 1987). The sign of each mammal species was identified in the field whereas confused sign was verified with the sign of zoo animals at Central Zoo, Lalitpur, Nepal.

3.3. Data Analysis

Both ecological and statistical data analysis were performed. The IAPS density, frequency, abundance, relative density, relative frequency, relative abundance and Importance Value Index (IVI) were calculated.

3.3.1 Density and Relative Density

Density represents the numerical strength of a species in the study area. Density is an average number of individuals of a given species over the total number of samples studied in an area. Density and relative density was calculated following Curtis (1951).

$$\text{Density} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrat studied}}$$

$$\text{Relative Density} = \frac{\text{Number of individual of species} \times 100}{\text{Total number of quadrat}}$$

3.3.2 Frequency and Relative Frequency

Frequency is the number of sampling units (as %) in which a particular species occurs. Frequency and relative Frequency was calculated as per Curtis (1951).

$$\text{Frequency} = \frac{\text{Total number of quadrat studied} \times 100}{\text{Total number of sampling units}}$$

$$\text{Relative frequency} = \frac{\text{Frequency of the species} \times 100}{\text{Total frequency of all species}}$$

3.3.3 Cover-class Scale Value and Relative Cover-class Scale Value

The technique involves visually designating different six cover classes to each quadrat. Each species within the quadrat is usually assessed separately. Canopy cover is typically considered as ground cover and basal cover are difficult to estimate.

Cover-class (%)	Cover mid-point
0-5	2.5
5-25	15.0
25-50	37.5
50-75	62.5
75-95	85.0
95-100	97.5

3.3.4 Importance Value Index

The importance value index is ecological measure that gives an overall picture of the importance of the species in the vegetation community. It is calculated as the sum of relative frequency, relative density and relative coverage for each species (Curtis 1951).

IVI = RD + RF + RC

Where RD = Relative density; RF = Relative frequency; RC = Relative cover-class scale value; IVI = Importance value index

3.3.5 Statistical Data Analysis

A descriptive statistic including mean, standard deviation and percentage were calculated. A Chi-square and Mann-Whitney U Test were calculated to determine the difference in IAPS invaded and non-invaded habitat for categorical and continuous data, respectively. Logistic regression was performed to determine the effects of

IAPS on threatened mammal species in the study area. Five variables including invasive alien plant species cover, distance to nearest forest (m), distance to nearest water source (m), distance to road (m) and tree canopy (%) were tested for correlation with threatened mammal species presence. All statistical test were performed in R Program (R Core Team 2019).

4. RESULTS

4.1 Species composition of IAPS

Altogether 210 plots (IAPS invaded habitat: 105; IAPS non-invaded habitat: 105) were surveyed during this study period. A total of 11 invasive alien plant species from seven families were recorded during this study. Among the recorded species, 36.37% (n = 4) species belongs to Asteraceae, and followed by Fabaceae (18.18%, n = 2), and single species of each family Papaveraceae, Amaranthaceae, Verbenaceae, Lamiaceae, and Convolvulaceae.

In IAPS invaded habitat, the Blue Billygoat Weed (*Ageratum houstonianum*) was recorded from 49.52% (n = 52 of 105) of plots, and followed by Sickle Senna (*Senna tora*) 38.10%, (n = 40 of 105), Lantana (*Lantana camara*) 20.95%, (n = 22 of 105), Parthenium (*Parthenium hysterophorus*) 20%, (n = 21 of 105), Coffee Senna (*Senna occidentalis*) 19.05%, (n = 20 of 105), Bushmint (*Mesosphaerum suaveolenes*) 15.24%, (n = 16 of 105), Billygoat (*Ageratum conzyoides*) 12.38%, (n= 13 of 105), Mexican Poppy (*Argemone mexicana*) 8.57%, (n= 9 of 105), Rough Cocklebur (*Xanthium strumarium*) 7.62%, (n = 8 of 105), and Spiny Pigweed (*Amaranthus spinosus*), and Bush Morning Glory (*Ipomea carnea*) both had 5.71% (n = 6 of 105) (Figure 2).

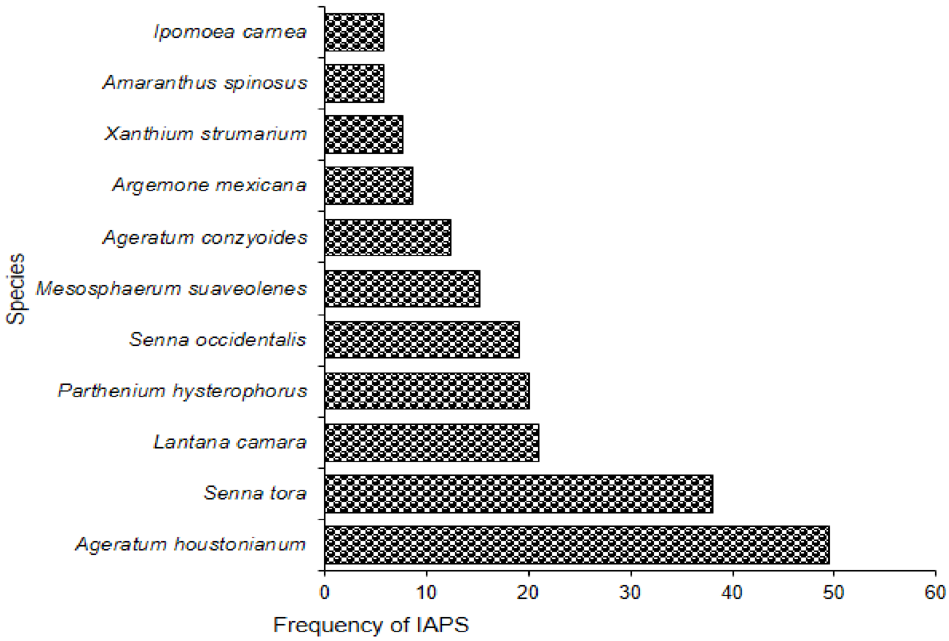

Figure 2: Frequency of IAPS, Shuklaphanta National Park, Nepal, 2021

The highest Importance Value Index was recorded for *A. houstonianum* (110.48), and followed by *S. tora* (105.18), *P. hysterophorus* (31.11), *M. suaveolenes* (11.21) and *L. camara* (10.69). Likewise, IAPS with lowest IVI was *I. carnea* (2.87), followed by *A. spinosus* (2.95), *X. strumarium* (3.95), *A. mexicana* (4.33), *A. conzyoides* (7.26), and *S. occidentalis* (9.98) (Table 1).

Table 1: Importance Value Index (IVI) of different IAPS in IAPS invaded habitat. RD = Relative density; RF = Relative frequency; RC = Relative cover-class scale value; IVI = Importance Value Index, Shuklaphanta National Park, Nepal, 2021

IAPS	Density	RD	Frequency	RF	Cover-class scale value	RC	IVI
Ageratum houstonianum	98.31	43.22	49.50	24.42	25.95	12.36	79.63
Senna tora	98.69	43.38	38.10	18.78	19.49	9.28	71.08
Lantana camara	0.41	0.18	20.95	10.33	2.32	1.10	11.61
Parthenium hysterophorus	24.27	10.67	20.00	9.86	4.24	2.02	22.46
Senna occidentalis	0.68	0.31	19.05	9.39	1.15	0.55	10.23
Mesosphaerum suaveolenes	4.22	1.86	15.24	7.51	1.92	0.91	10.26
Ageratum conzyoides	0.36	0.16	12.38	6.10	0.01	0.00	7.09
Argemone mexicana	0.12	0.06	8.57	4.23	1.12	0.53	4.81
Xanthium strumarium	0.22	0.10	7.62	3.76	0.99	0.47	4.33
Amaranthus spinosus	0.15	0.07	5.71	2.82	0.14	0.07	2.96
Ipomoea carnea	0.06	0.03	5.71	2.82	0.38	0.18	3.03

The IAPS occurrence was increased with increasing distance to forest (Figure 3). The abundance of IAPS varied from study plots to the forest distance. Fewer IAPS invaded plots were found near to the forest [10% (0-200 m); 10.39% (201-400 m); 10.97% (401-600 m); 14.96% (601-800 m); 16.84% (801-1000 m); and 36.64% (1001-1200 m)]. The IAPS abundance was decreased with increasing distance to water (Figure 3). The higher IAPS distribution was found nearer to water sources [64.10% (0-1000 m); 14.32% (1001-2000 m); 11.64% (2001-3000 m); 4.01% (3001-4000 m); 2.66% (4001-5000 m); 1.98% (5001-6000 m); 1.31% (6001-7000 m)]. The

IAPS abundance was decreased with increasing distance to settlement area (Figure 3). The higher IAPS distribution was found near to settlement area [73.10% (0-1500 m); 23.48% (1501-3000 m); 2.07% (3001-4500 m); 1.27% (4501-6000 m) and 0.07% (6001-7500 m)]. The IAPS abundance was decreased with increasing distance to agricultural land (Figure 3). The higher IAPS distribution was found near to agricultural land [75.82% (0-1500 m); 22.35% (1501-3000 m); 1.54% (3001-4500 m); 0.23% (4501-6000 m) and 0.07% (6001-7500 m)]. The IAPS abundance was decreased with increasing distance to road (Figure 3). The higher IAPS distribution was found near to road [48.58% (0-500 m); 22.53% (501-1000 m); 19.84% (1001-1500 m); 7.92% (1501-2000 m) and 1.34% (2001-2500 m)].

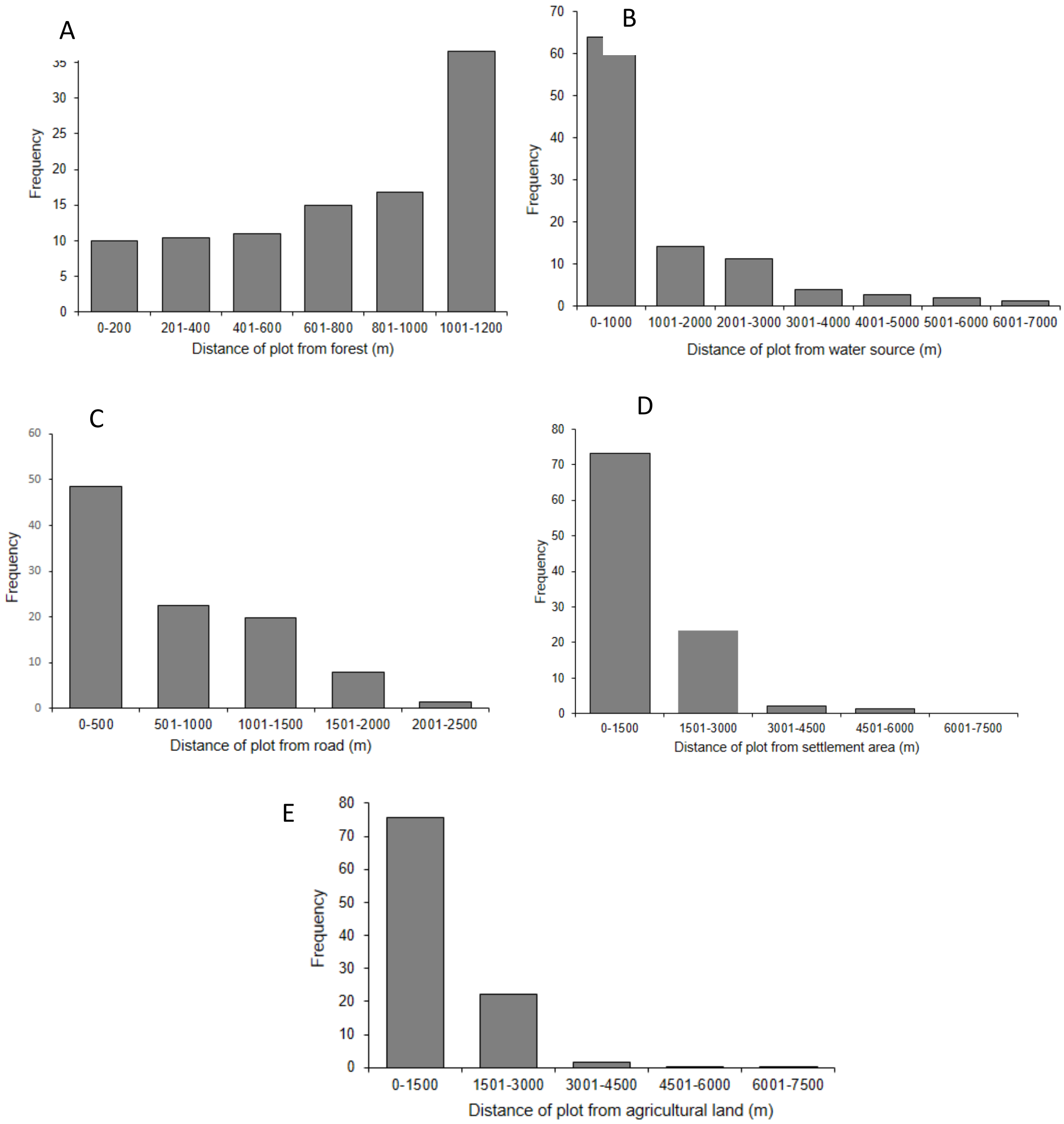

Figure 3: Frequency of IAPS compared to nearest (A) forest, (B) water, (C) road, (D) settlement area and (E) agricultural land

4.2. Mammal Species composition

Altogether 25 mammal species from seven orders and 14 families were recorded in the study plots during this study (Table 2). Order Carnivora had the highest diversity (10 species; 40%; five families), and followed by Artiodactyla (seven species; 23.33%; three families), Rodentia (two species; 6.67%; two families), Lagomorpha and Primates (two species; 6.67%; one family) and Proboscidea and Perissodactyla (one species; 3.30%; one family) (Figure 8). Among them, 11 species of mammals have been included in IUCN Redlist of Threatened Species (IUCN 2022). There wasn't variation on occurrence of mammal species between IAPS invaded and non-invaded habitat (Supplementary Table 1), while the threatened mammal species had negative response toward IAPS invaded habitat (Table 5).

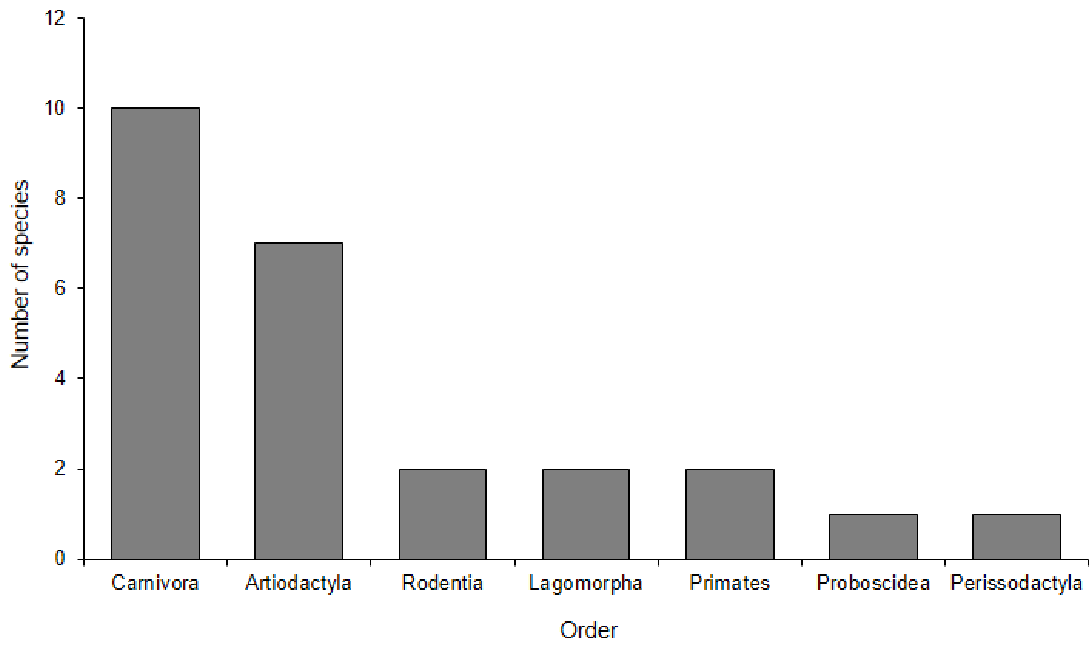

Figure 4: Number of mammal species in different Orders, Shuklaphanta National Park, Nepal, 2021

In IAPS non-invaded habitat, the mammal species were recorded in 88.57% (n = 93 of 105) of plots; order Artiodactyla was recorded in 91.40% (n = 85 of 93) of plots and followed by Carnivora 54.84% (n = 51 of 93), Proboscidea 30.11% (n = 28 of 93), Perissodactyla and Rodentia 15.05% (n = 14 of 93), Primates 10.75% (n= 10 of 93) and Lagomorpha 6.45% (n = 6 of 93), whereas the threatened mammal species were recorded from 63.81% (n = 67 of 105) of plots; order Proboscidea was recorded from 41.79% (n = 28 of 67) of plots and followed by Artiodactyla 37.31% (n = 25 of

67) , Carnivora 28.35% (n = 19 of 67), Perissodactyla 20.90% (n = 14 of 67) and each Lagomorpha and Primates had 1.49% (n = 1 of 67).

In IAPS invaded habitat, the mammal species were recorded from 84.76% (n = 89 of 105) of plots; order Artiodactyla was recorded from 94.38% (n = 84 of 89) of plots and followed by Carnivora 51.69% (n = 46 of 89) of plots, Proboscidea 21.35% (n = 19 of 89) of plots, Rodentia 19.10% (n = 17 of 89) of plots, Primates 13.48% (n = 12 of 89) of plots, Perissodactyla 8.99% (n = 8 of 89) and Lagomorpha 7.87% (n = 7 of 89) of plots, whereas the threatened mammal species were recorded from 50.48% (n = 53 of 105) of plots. The occurrence of threatened mammal species was reduced as compared to IAPS non-invaded plots. In these plots, order Proboscidea was recorded from 35.85 % (n = 19 of 53) of IAPS presence plots, which is followed by Artiodactyla 43.59% (n = 17 of 53), Carnivora 13.30% (n = 14 of 53), Perissodactyla 15.09% (n = 8 of 53), Lagomorpha 5.13% (n = 2 of 53) and Primates 2.56% (n = 1 of 53).

Table 2: Mammal species in the study area Shuklaphanta National Park, Nepal, 2021

Name of mammal species	Scietific Name	Habitat	Order	Family	IUCN status	Feeding guild
Spotted Deer	*Axis axis* Erxleben, 1777	Both	Artiodactyla	Cervidae	LC	Herbivorous
Hog Deer	*Axis porcinus* Zimmermann, 1780	Both	Artiodactyla	Cervidae	EN	Herbivorous
Barasingha	*Rucervus duvaucelii* G. Cuvier, 1823	Both	Artiodactyla	Cervidae	VU	Herbivorous
North Red Muntjac	*Muntiacus vaginalis* Boddaert, 1785	IAPS absence	Artiodactyla	Cervidae	LC	Herbivorous
Cattle	*Bos Taurus* Linnaeus, 1758	Both	Artiodactyla	Bovidae	LC	Herbivorous
Nilgai	*Boselophus tragocamelus* Pallas, 1766	Both	Artiodactyla	Bovidae	LC	Herbivorous
Wild Boar	*Sus scrofa* Linnaeus, 1758	Both	Artiodactyla	Suidae	LC	Omnivorous
Rhesus Monkey	*Macaca mulatta* Zimmermann, 1780	Both	Primates	Cercopithecidae	LC	Herbivorous
Tarai Grey Langur	*Semnopithecus hector* Pocock, 1928	Both	Primates	Cercopithecidae	NT	Herbivorous
Hispid Hare	*Caprolagus hispidus* Pearson, 1839	Both	Lagomorpha	Leporidae	EN	Herbivorous
Indian Hare	*Lepus nigricollis* F. Cuvier, 1823	Both	Lagomorpha	Leporidae	LC	Herbivorous
Indian Creasted Porcupine	*Hystrix indica* Kerr, 1792	Both	Rodentia	Hystricidae	LC	Omnivorous
Five-stripped Palm Squirrel	*Funambulus pennantii* Wroughton,1905	Both	Rodentia	Sciuridae	LC	Herbivorous

Asiatic Elephant	*Elephas maximus* Linnaeus, 1758	Both	Proboscidea	Elephantidae	EN	Herbivorous
Greater One-horned Rhino	*Rhinoceros unicornis* Linnaeus, 1758	Both	Perissodactyla	Rhinocerotidae	VU	Herbivorous
Bengal Fox	*Vulpes bengalensis* Shaw, 1800	IAPS presence	Carnivora	Canidae	LC	Omnivorous
Golden Jackel	*Canis aureus* Linnaeus,1758	Both	Carnivora	Canidae	LC	Omnivorous
Small Indian Civet	*Viverricula indica* Corbet and Hill, 1992	Both	Carnivora	Viverridae	LC	Omnivorous
Indian Grey Mongoose	*Herpestes edwardsii* E. Geoffroy Saint-Hilaire, 1818	Both	Carnivora	Herpestidae	LC	Omnivorous
Jungle Cat	*Felis chaus* Schreber, 1777	Both	Carnivora	Felidae	LC	Carnivorous
Rusty Spotted Cat	*Prionailurus rubiginosus* I. Geoffroy Saint-Hilaire, 1831	Both	Carnivora	Felidae	NT	Carnivorous
Fishing Cat	*Prionailurus viverrinus* Bennett,1833	IAPS absence	Carnivora	Felidae	VU	Carnivorous
Leopard	*Panthera pardus* Linnaeus, 1758	Both	Carnivora	Felidae	VU	Carnivorous
Bengal Tiger	*Panthera tigris tigris* Linnaeus, 1758	Both	Carnivora	Felidae	EN	Carnivorous
Smooth Coated Otter	*Lutrogale perspicillata* I. Geoffroy Saint-Hilaire, 1826	IAPS absence	Carnivora	Mustelidae	VU	Carnivorous

The average elevation of the study area was 191.1 ± 14.91 m (SD) (range: 161 to 226 m), whereas 191 ± 14.91 m (SD) (range: 161 to 226 m) for IAPS invaded habitat and 190.5 ± 15.17 m (SD) (range: 163 to 221 m) for IAPS non-invaded habitat. Proportionally, more threatened mammal species occurrences was found in IAPS non-invaded habitat than IAPS invaded habitat , but there is not variation in their occurrence between invaded and non-invaded habitat ($\chi^2 = 0.767$, df = 1, $p = 0.382$). More threatened mammal species occurrence was found nearer the forest [35% (0-200 m); 15% (201-400 m); 10% (401-600 m); 13% (601-800 m); 11% (801-1000 m) and 10% (1001-1200 m)], but variation in their occurrence between IAPS invaded and IAPS non-invaded habitat ($p < 0.001$; Table 3). The average distance of IAPS non-invaded habitat to the nearest forest was 535.49 m (range: 0 to 1197.39) and 512.30 m (range: 0 to 1199.67) in IAPS invaded habitat (Table 3; Figure 9**)**. More threatened mammal species occurrence was found far from the water sources [7.12% (0-1000 m); 11.22% (1001-2000 m); 5.96% (2001-3000); 20.6% (3001-4000 m); 21.43% (4001-5000 m); 6.12% (5001-6000 m) and 27.55% (6001-7000 m)], but no variation in their occurrence between IAPS invaded and IAPS non-invaded habitat ($p = 0.808$; Table 3). The average distance of IAPS non-invaded habitat to the nearest water sources was 1387.61 m (range: 66.85 to 3622.49 m), and 1589.52 m (range: 37.87 to 6496.98 m) in IAPS invaded habitat (Table 3; Figure 10).

More threatened mammal species occurrence was found far from the road [11.49% (0-500 m); 14.94% (501-1000 m); 20.69% (1001-1500 m); 27.59% (1501-2000 m) and 25.29% (2001-2500 m)], however, no variation in their occurrence between IAPS invaded and IAPS non-invaded habitat ($p = 0.624$; Table 3). The average distance of IAPS non-invaded habitat to the nearest road was 813.07 m (range: 54.53 to 2210.88 m), and 792.80 m (range: 11.02 to 2351.72 m) in IAPS invaded habitat (Table 3; Figure 11). Fewer threatened mammal species occurrence was found near the settlement area [7.95% (0-1500 m); 13.64% (1501-3000 m); 21.59% (3001-4500 m); 25% (4501-6000 m) and 31.82% (6001-7500 m)], thus significant between IAPS invaded and IAPS non-invaded habitat ($p< 0.001$; Table 3). The average distance of IAPS non-invaded habitat to the nearest settlement area was 2115.6 m (range: 295.9 to 4696.3 m) and 1867.7 m (116.9 to 7353.5) in IAPS invaded habitat (Table 3; Figure 12). Fewer threatened mammal species occurrence was found near the agricultural land [5.21% (0-1500 m); 15.63% (1500-3000 m); 26.04% (3001-4500 m); 23.96% (4501-6000 m) and 29.17% (6001-7500 m)], so significant between IAPS invaded and IAPS non-invaded habitat (p = 0.0001; Table 4). The average distance of IAPS non-invaded habitat to the nearest agricultural land was 2070.7 m (range: 257.8 to 4696.3 m) and 1816.6 m (116.9 to 7329.1 m) in IAPS invaded habitat (Table 4; Figure 13).

Table 3: Threatened mammal species presence in IAPS presence and absence habitats of Shuklaphanta National Park, Kanchanpur, Nepal 2021. Range of reported values are given in parentheses. *Significant effects are in bold, Shuklaphanta National Park, Nepal, 2021

Variables	IAPS presence habitat (median)	IAPS absence habitat (median)	Statistics (Mann-Whitney test)
Distance to forest	512 (0-1200)	535 (0-1197)	U =5543; p < **0.001**
Distance to water	1590 (38-6497)	1388 (67-3623)	U =5619; p = 0.808
Distance to road	793 (11-2352)	813 (55-2211)	U =5729; p = 0.624
Distance to human settlement	1868 (117-7354)	2116(296-4696)	U = 7186; p < **0.001**
Distance to agricultural field	1817 (117-7329)	2071(258-4696)	U = 7182; p < **0.001**

A B

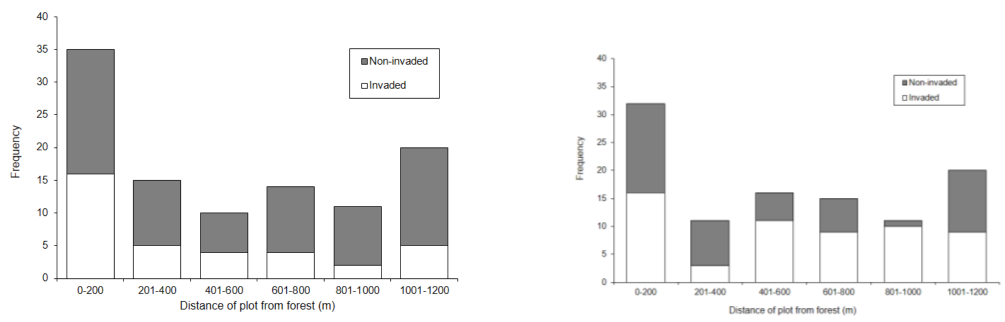

Figure 5: Frequency of occurrence of threatened mammal species in IAPS invaded habitat (A) and IAPS non-invaded habitat (B) compared to nearest forest, Shuklaphanta National Park, Nepal, 2021

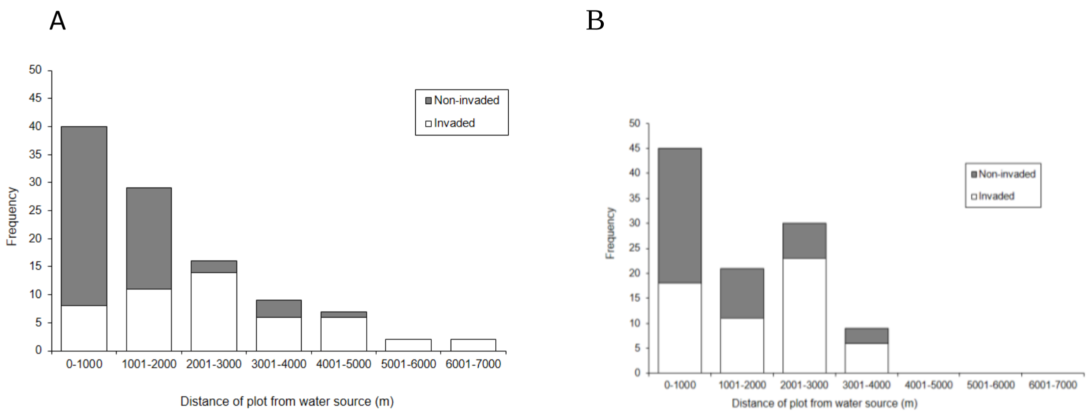

Figure 6: Frequency of occurrence of threatened mammal species in IAPS invaded habitat (A) and IAPS non-invaded habitat (B) compared to nearest water source, Shuklaphanta National Park, Nepal, 2021

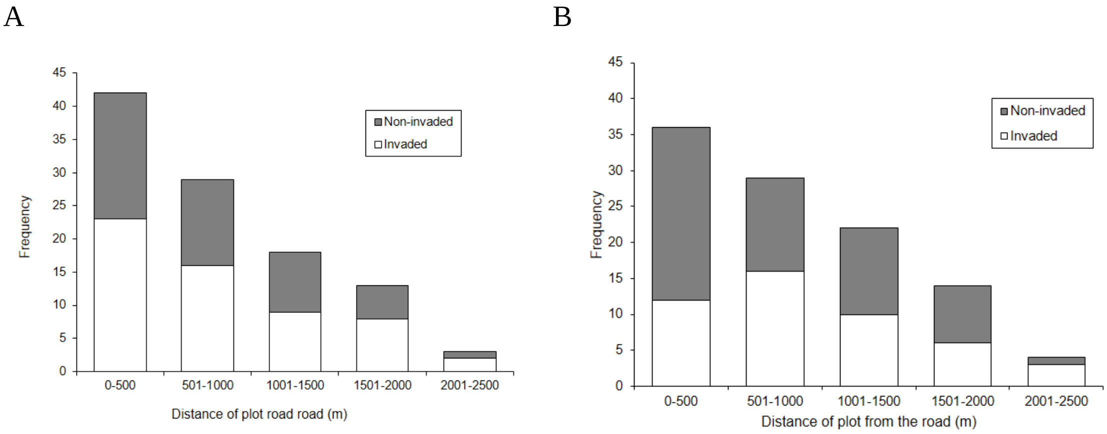

Figure 7: Frequency of occurrence of threatened mammal species in IAPS invaded habitat (A) and IAPS non-invaded habitat (B) compared to nearest road, Shuklaphanta National Park, Nepal, 2021

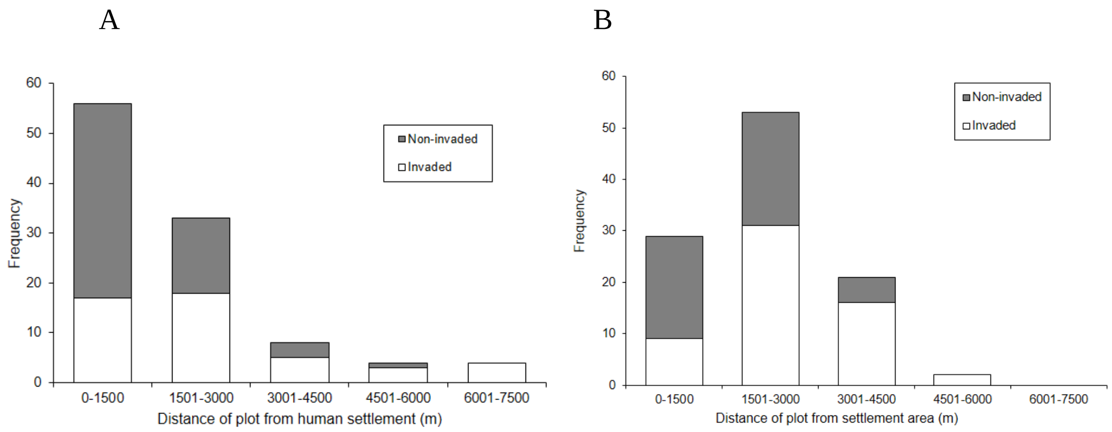

Figure 8: Frequency of occurrence of threatened mammal species in IAPS invaded habitat (A) and IAPS non-invaded habitat (B) compared to nearest human settlement, Shuklaphanta National Park, Nepal, 2021

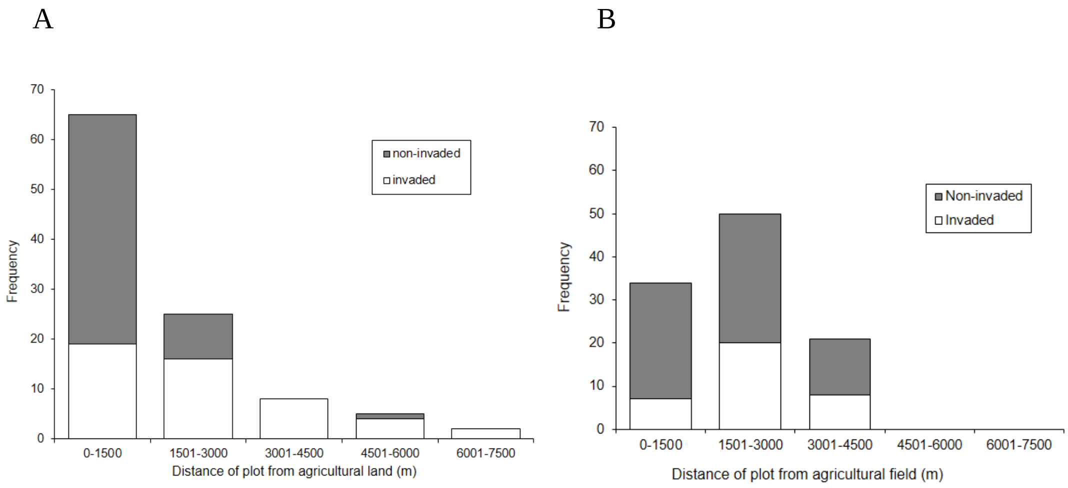

Figure 9: Frequency of occurrence of threatened mammal species in IAPS invaded habitat (A) and IAPS non-invaded habitat (B) compared to nearest agricultural land, Shuklaphanta National Park, Nepal, 2021

Table 4: Model- averaged variables estimates describing the threatened mammal species presence in the IAPS invaded habitat of Shuklaphanta National Park Nepal. Model variables include invasive alien plants species cover, distance to forest (m), distance to water (m), distance to road (m). Estimates were averaged from all models. *Significant effects are in bold, Shuklaphanta National Park, Nepal, 2021

Variables	Estimate	SE	Z	P
(Intercept)	-1.351	0.518	-2.609	**0.009**
Invasive alien plant species cover	0.227	0.364	0.625	0.532
Tree canopy	0.000	0.004	0.086	0.932
Distance to forest	-0.003	0.001	-3.288	**0.001**
Distance to road	0.000	0.000	0.028	0.978
Distance to agricultural land	0.001	0.000	3.677	**0.000**
Distance to water	0.000	0.000	0.233	0.816

5. DISCUSSION

This study documents the abundance of IAPS in the Shuklaphanta National Park (ShNP) and their impact on the habitat utilization of mammal species in ShNP. Among the 11 IAPS invaded in the study area, the Blue Billygoat Weed is abundant species. The effect of IAPS invasion on the mammal species in overall is not remarkable, however, the threatened mammal species avoids their invaded habitat. Their effect to the threatened mammal species might be mainly due to habitat loss and lack of palatable plant species by the IAPS invasion (Murphy et al. 2013). The study on the effect of Mesquite on the Blackbuck population revealed that IAPS had a negative effect on the mammal species (Arandhara et al. 2021), and indicated that the spatial detectability and density distribution of Blackbuck increase significantly with the extent of grassland, habitat openness and grass biomass, but decreases with Mesquite cover. This study suggested that IAPS reduce the abundance of common native species, this might be due to effect of IAPS on the chemical properties of the abiotic factors (Timsina et al. 2011).

5.1 Plant invasions in ShNP

Shuklaphanta National Park is experiencing an invasion that is escalating gradually. Although there hasn't been much invasion of the grasslands up to this point, however, if the invasion continues, it may also suffer the problem as Chitwan National Park. Where there was a lot of livestock and human disturbance, the invasion was more noticeable. The dissemination of the IAPS inside the park is aided by the fact that people rely on the park for the collecting of thatch and fodder. These upheavals gave invasive alien plant species a chance to colonize the park. Additionally, the invasion was noticeably worse in the park's wetlands. Lantana camara and Parthenium hysterophorus, which are among the worst in the world, were spotted in the park (Bhandari 2019).

5.2 Impacts of IAPS on mammal species

In this study, forest seem less affected by the invasion of IAPS, this could be due to the formation of dense wall from adjacent vegetation. This reduces the interior lighting and wind speeds, which might lower the probability of IAPS establishment in the interior of the forest (Hansen and Clevenger 2005). Thus, more threatened mammal species were noticed at nearer to forest in this study too, it was probably due to availability of more grazing area. As the forest carry immense amount of biodiversity, spreading of IAPS in forests is a special cause for concern as it may change forest structure and composition, affecting native species assemblages (Aravind et al. 2006).

In this study, the abundance of IAPS is higher near the water sources, this might be due to the flow of propagules along the current of water, as river served as corridors for the dispersal of IAPS (Parendes and Jones 2000). Besides, the rivers provide suitable habitat and act as reservoir of propagules for further invasions (Parendes and Jones 2000). Thus, the IAPS abundance was higher at nearer to water sources. Furthermore, IAPS affected water supply in different way, such as, increased disease vector, increased microbial activities, and biochemical oxygen demand (Howard and Matindi 2012). Therefore, these areas might be avoided by the threatened mammal species. Thus, the occurrence of threatened mammal species decreases at nearer to the water source in IAPS invaded habitat.

In this study, the abundance of IAPS is higher nearer the road, this might be due to the dispersal of seed through vehicles as well as contaminant of transport materials. Thus road facilitates the dispersal of seed to new site (Shrestha et al. 2019). In addition, the road edges provide suitable microhabitats for IAPS establishment and serve as dispersal corridor for species like Parthenium (Shrestha 2018). Furthermore, a number of direct road connect thousands of vehicles, through these road various IAPS thought to have dispersed. A study conducted in China revealed that most of the current areas predicted to be suitable for Crofton Weed were found along road edges and river complex (Wang and Wang 2006) and these river and road complex had enhanced the rapid spread of Crofton Weed (Dong et al. 2008, Sang et al. 2010).

Besides, there was significant relationship between type of road and the frequency of the weed’s occurrence. The study carried out in Manas National Park of India, also suggested that roads have significantly influenced the occurrence of IAPS namely, Siam Weed and Mile-a-minute Weed (Nath et al. 2019). But the level of invasion from IAPS nearer to roads might be different, expected for more invasion in frequently used road tracks than in infrequently used road tracks (Parendes and Jones

2000). Therefore, the threatened mammal species occurrence was higher at distance from the road, as it possessed lower abundance of IAPS.

In this study, the abundance of IAPS is also higher closer to human settlement, this might be due to the facilitation in the dispersal of IAPS through various human activities. Plant invasion have been assisted by the migration and infrastructure development such as road constructions across landscapes (Shrestha and Shrestha 2021). In the hilly region of Nepal, migration had taken in pursuit of better opportunities (Jaquet et al. 2015). Due to this, remarkable proportion of farmland were abandoned (Jaquet et al. 2015). This had allowed natural regrowth of vegetation including IAPS. Several species of IAPS were introduced as ornamental plants (Jackson 1994) and botanical collection in botanic gardens outside of their native range (Shrestha et al. 2016). Therefore, IAPS abundance was higher nearer to settlement area (Shrestha 2016). Hence, the occurrence of threatened mammal species was not so much nearer to human settlement.

In this study, the abundance of IAPS also higher nearer the agricultural land. Though Nepal is agricultural country, various agricultural products are imported every year and along with these contaminant imported agricultural product various IAPS species get introduced (Shrestha and Shrestha 2021). It was probably due to agricultural practices and seed dispersal through manures (Shrestha 2016). Sometimes, IAPS such as Parthenium used as an animal bedding (Shrestha et al. 2015).

In this study, highly invaded habitat of study area were avoided by threatened mammal species. Like in Chitwan National Park (Murphy et al. 2013), Bardia National Park (Bhatta et al. 2020) and Parsa Wildlife Reserve (Chaudhary et al. 2020), a lot of principal habitat of threatened species were encroached by IAPS in Shuklaphata National Park too. The ShNP has important habitat for threatened species such as Swamp Deer and Spotted Deer, seems reduced as a result of invasion of unpalatable plant species. The impacts associated with the encroachment comprised the loss of preferable habitat for ungulates (Thapa et al. 2018).

From this study, it was revealed that the effect of IAPS was higher on threatened mammal species. The IAPS invasion into open grasslands affects the Blackbuck directly by reducing the habitat openness, and also indirectly by reducing the grass biomass on which it feeds (Arandhara et al. 2021). The invasion of Ipomoea in grassland was the biggest threat to the Greater One-horned Rhino habitat in Pabitora Wildlife Sanctuary (Lahkar et al. 2011). Sarma et al. (2009) highlighted the number of Greater One-horned Rhino straying from the sanctuary due to changes in grassland dynamics.

Likewise, the Hispid Hare are currently facing unusual challenges from habitat loss (Ahrestani and Sankaran 2016). On the distribution of herbivores, it should focus primarily on the function of biotic factors like habitat and quality and quantity of food resources. Globally, the distribution and abundance of large herbivores have been significantly influenced by impacts on habitats and resources. Among the IAPS invasion effects, the reduced resources for native plant species and altering their functioning of ecosystem is critical for biodiversity conservation, and also can impact on the survival of wildlife population.

5.3 Implications for IAPS management

Three main approaches are used to manage invasive species: prevention, eradication, and control (Radocevich et al. 2009). In order to prevent the entry of potentially invasive alien species, stringent quarantine and ongoing monitoring are necessary. It is the original and most effective technique for managing invasive species, but given the globalization of trade and rising levels of human mobility, even a partial application is ineffective. Preventing the arrival of invasive alien plant species into Nepal is nearly impossible due to the open border with India and heavy trade dependence. Eradication is the total elimination of an invasive species from its native habitat or geographic area, and it is only achievable when the species is restricted to a small area. However, invasive alien plant species spread quickly and rapidly cover wide regions, by the time management recognize the issue and begin to take action, it is frequently too late to eradicate the problem.

Control involves limiting the number of invasive species in the area that has been invaded and halting their spread to lessen their negative effects on the ecology and economy. It may or may not lead to the eradication of certain species from a certain area. Due to the high quantity and extensive presence of IAPS, only method available for managing IAPS across landscapes is "control". Integration of physical, chemical, and biological techniques is necessary for the regulation of the IAPS. The management efforts of IAPS have taught us several important lessons, one of which is that eliminating these weeds with just one strategy is ineffective. To properly manage the IAPS, a set of intervention techniques must be carefully chosen (Bhandari 2019). Unfortunately, Nepal has not yet begun the methodical and scientific management of the IAPS. However, communities and development partners have made some attempts to manage a few IAPS by exploiting their biomass to meet demand for energy and organic manure. Physical removal of IAPS has been used in wetlands. For instance, *Eichhornia crassipes* is routinely eradicated from Chitwan's Beeshajari Lake System (a Ramsar site).

The use of biological control agents is a crucial component of biological IAPS management strategies. In Nepal, biological control agents are present only for two IAPS: Leaf Feeding Beetle (*Zygogramma bicolorata*) and Winter Rust (*Puccinia abrupta*) for Parthenium (Shrestha et al. 2015). Stone and Leaf Spot Fungus (*Passalora ageratinae*) for *Ageratina adenophora* (Hinz et al. 2019). However, these biological control agents were not introduced officially after quarantine screening but spread naturally into Nepal from India and other Asian countries. *Z. bicolorata* seems to be the most effective biological control agent of IAPS present in Nepal but its population is still small and their effectiveness is erratic with year to year variation (Shrestha et al. 2015). For effective control of *P. hysterophorus*, it seems necessary that the control by *Z. bicolorata* need to be complemented by other biological control agents, displacement by competitive plant species, and other cultural, physical and chemical measure (Adkins and Shabbir 2014).

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The abundance of IAPS decreases with the decreasing of distance from the forest. This might be due to the slightest disturbance in the forest. As a result, the occurrence of threatened mammal species nearer the forest is increasing. In contrast, IAPS invasion is high near water sources, roads, human settlements, and agricultural land, as they are widely distributed and also frequently come into contract with invasion. Thus, these habitats are less preferred by threatened mammal species. A better understanding regarding the phenomena and management option to this biodiversity threat is necessary to guide managers, policy makers, researchers and the general public.

Worldwide mammal species are declining so an area specific management plan is necessary to prevent this trend in the ShNP as these areas also have near threatened, endangered and vulnerable mammal species.

6.2 Recommendations

Following recommendations are highlighted on the basis of observation and result of entire study:

- Now a days, road and vehicles are major sources for the dispersion of IAPS propagules. Thus, regular cleaning of means of transportation may help in reducing invasion of IAPS.
- Well managed quarantine system will also be the effective way to prevent invasion.
- Regular monitoring will be helpful to avoid introducing species disasters.
- Introduction of various biological agents may control rapid spreading of IAPS in some level. Along with this, different physical and chemical approaches can also be useful to eradicate and control IAPS.
- Yearly survey of the habitat of mammal species must be take place.

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APPENDICES

Supplementary Table 1: Model- averaged variables estimates describing the mammal species presence in the IAPS presence habitat of Shuklaphanta National Park Nepal. Model variables include invasive alien plant species cover, distance to forest (m), distance to water (m), distance to road (m). Estimates were averaged from all models, Shuklaphanta National Park, Nepal, 2021

Variables	Estimate	SE	Z	P
(Intercept)	2.575	2.478	1.039	0.299
Invasive alien plant species cover	0.012	0.013	0.898	0.369
Tree canopy	0.000	0.024	-0.012	0.991
Distance to forest	-0.005	0.003	-1.698	0.090
Distance to road	-0.004	0.003	-1.665	0.096
Distance to agriculture	0.000	0.002	0.202	0.840
Distance to water	0.001	0.001	1.136	0.256

PHOTO PLATES

Rhesus Monkey feeding on nuts

Swamp Deer herds at Shuklaphanta

Bengal Fox spotted on Fireline

Common Leopard in search of prey

Spotted Deer Fecal

Wild Boar Fecal

Greater One-horned Rhino footmark

Bengal Tiger Pugmark

Quadrat establishment

During survey