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Invasive Alien Plants in Wetlands of Kanchanpur District, Western Nepal

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ABSTRACT

Wetlands have a significant role in conservation of biodiversity and genetic resources but this important habitat has been degrading worldwide due to biological invasions and other anthropogenic activities. Successful management of wetland invasive species requires information on their spatial distribution, factors governing their invasions, risk of invasion at currently unoccupied sites, and prioritization of management efforts. In this study we sampled nineteen wetlands of Kanchanpur district, western Nepal to record invasive alien plant species (IAPS), identify their dispersal pathways and factors determining their abundance. Cover of IAPS were estimated visually; nitrogen and phosphorus content were measured in water samples; major drivers of wetland invasions were identified by multivariate analyses; and potential dispersal pathways of *Eichhornia crassipes* were identified by Focus Group Discussion with subsequent prioritization by scoring method. We recorded four IAPS, of which *Ipomea carnea* ssp *fistulosa* (63%) and *Eichhornia crassipes* (42%) were the most frequent. Though the frequency of *E. crassipes* was less than that of *I. carnea* ssp. *fistulosa*, *E. crassipes* was found to be dominant in terms of coverage. We found that 26% of the wetlands of Kanchanpur district were highly invaded (i.e., Cover of IAPS > 50%) by these IAPS, 42% were moderately invaded (Cover < 50%) and 31% were free of invasion. Intentional introduction to feed fishes was the main pathway of *E. crassipes* dispersal but the pathway was not known for other three IAPS. Elevation, nitrate and phosphate concentration in water were the major environmental variables determining occurrence and abundance of IAPS in wetlands. Management interventions involving control of IAPS in their dispersal pathways and prevention of their spread in to the non-invaded wetlands through community awareness are the recommended management interventions to protect wetlands of Kanchanpur district from further invasion by IAPS.

Keywords: Dispersal pathways, *Eichhornia crassipes*, Eutrophication, Tarai, Wetland invasions.

INTRODUCTION

Wetlands are among the most productive ecosystems on the earth and provides wide array of goods and services to humanity (Doods et al. 2008). These important ecosystems are under various threats, and plant invasions are considered as one of the major threats (IUCN 2004, Zelder and Kercher 2004). Invasive species are considered second only to habitat loss as the greatest threat to biological diversity (CBD 2000). Inland freshwater wetlands are especially vulnerable to plant invasions as they acts as landscape sinks where plant propagules and pollutants, including nutrient from upstream can accumulate (Zelder and Kercher 2004). Invasion by alien plants can negatively affect wetland ecosystems by outcompeting native vegetation, reducing species diversity, decreasing wildlife habitat, reducing water quality, and altering nutrient cycling (Zelder and Kercher 2005).

Increasing trade and tourism associated with globalization and the expansion of the human population and the transformation of native ecosystems have facilitated the intentional and accidental movements of species outside their native range and subsequent establishment of alien populations in introduced range (Levine and D'Antonio 2003, Hulme 2009, Seebans et al. 2013). In the introduced range, the probability of the occurrence of invasive alien species and their abundance are determined by a number of factor such as land use practices and proximity to human settlement, road, agricultural areas, etc. (Catford and Downes 2010, Chytry et al. 2012, Mattingly and Orrock 2013). Specific to aquatic invasion, the other relevant predictors include factors that influence water quality such as proximity to road (Buchan and Padilla 2000), distance to the nearest waterway, lake size, lake depth (Roley and Newman 2008) and native species present (Olson et al. 2012). Identifying factors that govern plant invasions is necessary to understand the processes behind biological invasions, management of invasive species, and also to formulate policies that address threats to biodiversity (Bradly and Marvin 2011). Developing a scientific basis for monitoring and managing invasive species and implementing measures to manage pathways to prevent introductions are the major focuses of the Convention on Biological Diversity Aichi Target 9 (http://www.cbd.int). Similarly, a detailed distribution data is essential for successful invasive species management (Bradly and Marvin 2011). In addition, identifying environmental factors that may increase the likelihood of invasion, and predicting areas vulnerable to invasion, is another important aspect of invasive species management in wetlands (Gallien et al. 2010, Bradley and Marvin 2011).

Establishment of invasive alien plant species (IAPS) is one of the major factors for the degradation of Nepal's wetlands including Ramsar sites (IUCN 2004, Tiwari et al. 2005, Shrestha 2019). For example, *Eichhornia crassipes* has altered aquatic ecosystems (IUCN, 2004) and is one of the major threats to biodiversity and ecosystem health of tropical and subtropical wetlands in Nepal (MFSC 2014). Other IAPS such as *Ipomea carnea* ssp. *fistulosa* is also becoming abundant in areas near wetlands, thereby affecting habitats of water birds and other wetland dependent fauna (MFSC 2014). Successful management of wetland IAPS requires a comprehensive information, including mapping the current distribution of invasive species, understanding the drivers of invasions, determining risk of invasion at currently unoccupied sites, and prioritizing control and management efforts. Inventory and spatial mapping of IAPS with their potential dispersal pathways and drivers are necessary to draw a conclusions on the invasion process and is the first step towards developing a management strategy for invasive species. In this research, we aimed to (1) identify invasive alien plant species (IAPS) in the wetlands of Kanchanpur district, western Nepal; (2) undertake spatial distribution mapping of IAPS in these wetlands; 3) identify dispersal pathways of wetland IAPS; and 4) identify major environmental factors governing occurrence and abundance of IAPS in wetlands. The results will be useful for conservation and management of wetlands in Kanchanpur district and other similar regions in Nepal and the South Asia.

MATERIALS AND METHODS

Study area

The study was conducted in wetlands of Kanchanpur district (Latitude: 28.50° - 29.05° N; Longitude: 80.52° - 80.90° E; area 1610 km^2) in western Nepal which is located in Sudurpaschim Province (Figure 1). Physiographically, the district has two regions: Tarai and Siwalik. The elevation ranges from 160 to 1528 m above sea level (http://ddckanchanpur.gov.np/ne-brief-introduction). This research was carried out in both invaded and non-invaded wetlands of Kanchanpur district. We selected lakes as represenative of wetlands considering the problems of plants invasions, and excluded paddy fields, spring and rivers in the study. DoF (2017) recorded 28 lakes in Kanchanpur district, of them we selected 19 wetlands for this study. Remaining nine lakes were either heavily modified for fish farming and crop cultivation or remained dry except during monsoon season. Size of the studied lakes range from 0.005 km^2 (Brahma Tal) to 0.11 km^2 (Puranii Tal) with mean of 0.03 km^2. Five lakes are larger than 0.05 km^2. In general wetlands in Kanchanpur districts are under threat due to plant invasions, land use changes, overgrazing, vegetation clearance and sedimentation (DoF 2017). There are a number of lakes with high religio-cultural values. For example, Jhilmila Tal (Lake) is the most remarkable wetland in Kanchanpur district with >25,000 annual visitors (DoF 2017). Kalikich Tal in Kanchanpur district share boundaries with Suklaphanta National Park.

The climate of Kanchanpur district is dry tropical type with rainy summer and dry winter seasons. Mean monthly maximum and minimum temperatures are 37°C in July and 8°C in January, respectively. The mean annual precipitation between 2008 –2018 was 2079 mm with the highest monthly precipitation in July at 659 mm and the lowest in November at 5 mm (Department of Hydrology and Meteorology, Nepal; data obtained on November, 2019). Sal (*Shorea robusta*) forest, mixed deciduous forest, riverine forest and grassland are common vegetation types of Kanchanpur district.

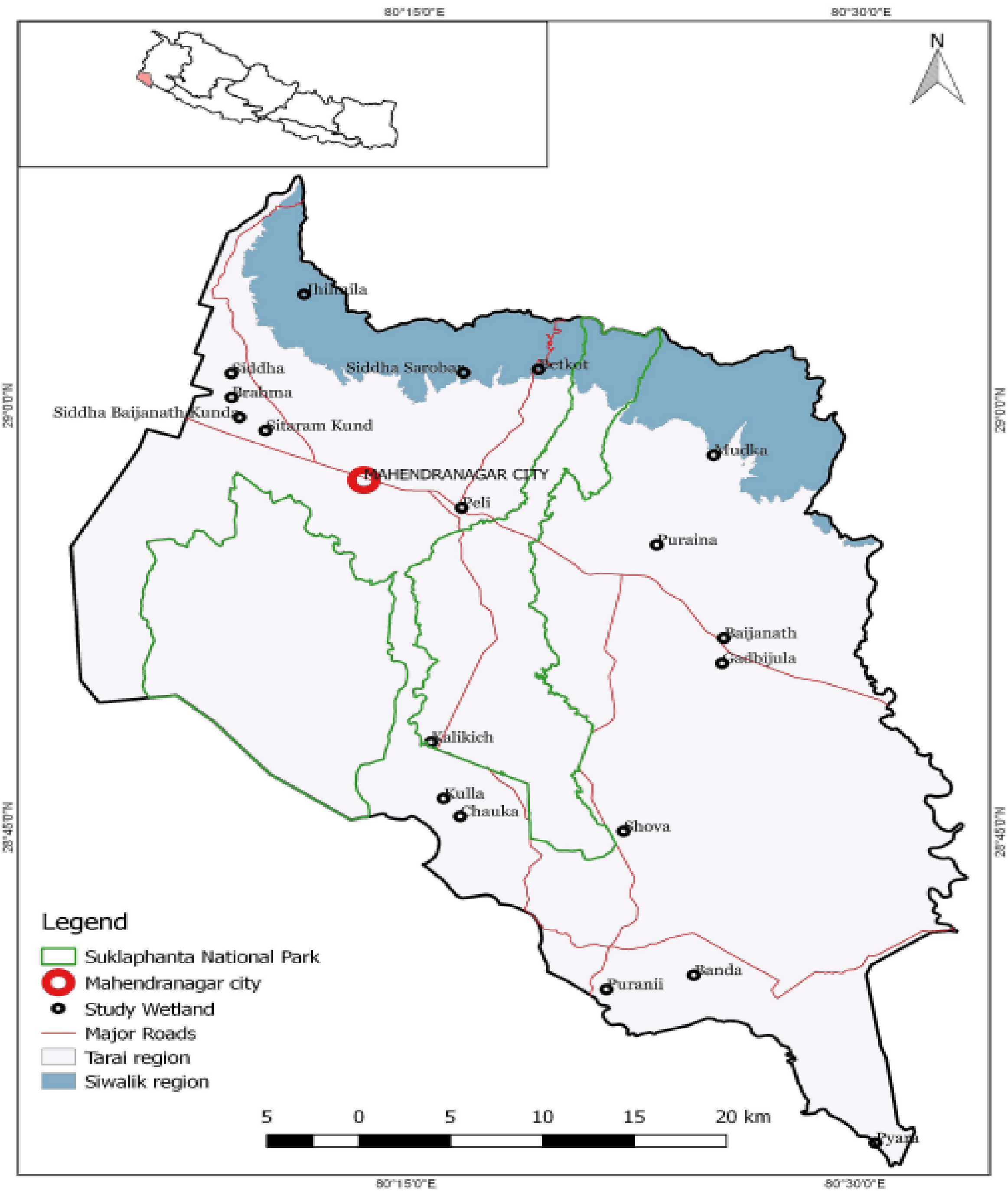

Figure 1. Location of Kanchanpur district in Nepal (Inset map) and the studied wetlands in Kanchanpur district

Inventory of invasive alien plant species in wetlands

For the documentation of IAPS from different wetlands, a checklist of 26 IAPS with six wetland species reported from Nepal by Shrestha (2019) was used. For visual estimation of IAPS cover, wetlands smaller than 2500 m^2 area were considered as single sampling unit. The larger wetlands (>2500 m^2) were divided into 50 m × 50 m grids in Google earth map using GIS and each grid was considered as a sampling unit. The coverage of every IAPS present in each grid was recorded according to Daubenmire cover class method in which cover of any species in a grid was recorded as 1 (<5% cover), 2 (5-25%), 3 (25-50%), 4 (50-75%), 5 (75-95) or 6 (>95%) (Daubenmire 1959). Specimens of each IAPS was collected to prepare herbarium and to deposited at Tribhuvan University Central Herbarium (TUCH) for future reference. Livestock grazing in surrounding areas was recorded as high (>80% land area with sign of grazing and trampling), medium (20-80%) and low (< 20%). Geographic coordinates (latitude and longitude) of each lake was recorded using Global Positioning System (GPS) receiver.

Water sampling and analysis

Nitrate and phosphate are the major nutrients responsible for eutrophication of wetlands which increases the likelihood of plant invasions in the wetlands (Shaker et al. 2017). Thus, from each wetland, single composite water sample was collected to determine nitrogen and phosphorus. In smaller wetlands (<2500 m^2), three sub samples (500 ml) were collected from the shoreline at equidistant and 1 L composite sample was collected from the mixture of three sub samples. The number of sub samples were higher in larger wetlands (>2500 m^2) depending on the size of the individual wetland. Nitrate, phosphate, chloride content and pH were determined by Phenol Disulphonic method, Ammonium Molybdate method, Argentometric titration method and pH meter with electrode, respectively (Trivedy and Goel 1984) at laboratory of the Central Department of Environmental Science, Tribhuvan University, Kirtipur, Kathmandu.

Focus group discussion

Nineteen Focus Group Discussions (FGD), one at each wetland area, were carried out for understanding the introduction history and potential dispersal pathways in a group of 6-8 people. The FGDs were conducted in Nepali language. Participants were first informed about the invasive species and their potential impacts on the environment and livelihoods. Colored photographs of 26 IAPS found in Nepal were shared among participants to familiarize IAPS with them. The major issues discussed during FGD were: (i) overall knowledge of plant invasions and the IAPS found in the associated wetlands and surrounding landscapes; (ii) introduction pathways of each IAPS found in the wetland; and (iii) potential risk of spreading IAPS from the particular wetland to other wetlands in the landscape. When multiple introduction pathways of a particular IAPS were reported, participants of the FGDs were asked to prioritize dispersal pathways in a decreasing order of importance from first (being most important/ frequent) to fourth (least important).

Data analysis

Distribution map and frequency: The spatial distribution maps of the wetland IAPS were prepared by using geographic coordinates of each wetland and mean cover of each IAPS recorded during field sampling. Map available from LRMP (1986) was used as base map and QGIS software (version 2.18; www.osgeo.org/projects/qgis) was used to prepare maps. In the maps presence of IAPS in wetlands along with their mean cover (%) were shown. Each of the six Daubenmire cover classes estimated for each IAPS in field was converted into mid values (e.g. 2.5% for cover class 1, 15% for 2, etc.) (Daubenmire 1959). From these mid values, mean cover of each species was determined for each wetland. For simplicity, mean cover were again grouped into three cover classes (<25%, 25-50%, >50%) and represented in the map showing distribution of IAPS. The frequency (%) of each IAPS was calculated as the number of wetlands in which a particular IAPS was present, expressed as the percentage of total wetlands include in the present study (*i.e.* 19).

Prioritization of dispersal pathways: Dispersal pathways were prioritized from the information obtained from FGDs by scoring method as used by Shrestha et al. (2019) to prioritize IAPS for management. Different possible pathways that were ranked first, second, third and fourth during FGDs were given scores of 4, 3, 2, and 1, respectively. Thus for the each pathway, the total score was obtained by the summation of the scores given in each FGD. For each pathway, score percentage was calculated to prevent data skewness (Shrestha et al. 2019). The pathway with the highest score percentage was considered as the major pathway responsible for introduction and dispersal of the particular IAPS in the study area.

Identification of major environmental factors: Variation of the cover of wetland IAPS with nitrate and phosphate concentration was analyzed by linear regression. In addition, multivariate analyses were performed to understand the relationship between cover of wetland IAPS and environmental variables. Cover of wetland IAPs was taken as species data

Table 1. Cover of four invasive alien plant species (IAPS) in 13 wetlands in the study area. The IAPS were absent in remaining six wetlands included in this study

SN	Wetland (Tal)	Elevation (m asl)	Cover (%) of invasive alien plant species			
			Alternanthera philoxeroides	***Eichhornia crassipes***	***Ipomoea carnea* ssp. *fistulosa***	***Pistia stratiotes***
1	Baijanath	196	0	56	5	0
2	Banda	183	3	2	3	0
3	Chauka	172	0	85	2	0
4	Gadbijula	181	0	0	20	0
5	Kalikich	198	5	32	17	9
6	Kulla	156	0	33	14	10
7	Mudka	348	0	0	1	0
8	Peli	206	0	0	20	1
9	Puraina	234	0	0	14	0
10	Puranii	172	4	5	3	0
11	Pyara	144	0	50	25	0
12	Shova	175	0	1	1	0
13	Siddha Sarobar Banda	414	0	0	0	14
	Mean		1	20	9	3

whereas distance of wetland from road, distance from settlement, grazing intensity, elevation, water pH, nitrate, phosphate and chlorine concentration were taken as environmental data. Distance of each wetland from the nearest road and settlement were measured by QGIS Software using ruler of Google Earth Pro. Firstly, unconstrained gradient analysis, Detrended Correspondence Analysis (DCA), was performed, which revealed a gradient length of 2.7. The data shows length of gradient more than 2.5 s.d. units. Thus, Canonical Correspondence Analysis (CCA) was done to understand the relationship of wetland IAPS with environmental variables (Ter Braak and Verdonschot 1993). The variance explained by environmental variables was determined by One Way Analysis of Variance (ANOVA) using RStudio (R Development Core Team 2016).

RESULTS AND DISCUSSION

Distribution pattern

Of the six wetland IAPS reported from Nepal by Shrestha (2019), only four species *i.e.*, *Eichhornia crassipes*, *Ipomea carnea* ssp. *fistulosa*, *Pistia stratiotes* and *Alternanthera philoxeroides* were found in the wetlands of Kanchanpur district that we studied (Figure 2). Nearly two-third of the studied wetlands (13 out of 19) were invaded by one or more IAPS (Table 1). Among four IAPS reported in the study area, *I. carnea* ssp. *fistulosa* was the most frequently occurring species (63%), followed by *E. crassipes* (42%), *P. stratiotes* (21%) and *A. philoxeroides* (16%). In addition, *P. stratiotes* was also observed in Rani tal inside Suklaphanta National Park (Pers. Obs., BB Shrestha, Oct 13, 2019). *Eichhornia crassipes*, the most damaging wetland IAPS globally has been also reported from different Ramsar sites of Nepal like Koshi Tappu, Beeshajari and Pokhara lake cluster but not from other Ramsar sites like Mai Pokhari, Jagdishpur and Ghodaghodi lakes (Shrestha 2019). *Eichhornia crassipes* is now present in all continents except Antarctica, and has invaded all tropical and subtropical countries as well as some parts of Mediterranean basin (Parsons and Cuthberston 2011). In India, *E. crassipes* and *A. philoxeroides* are considered as serious aquatic IAPS (Masoodi and Farred 2010). For example wetlands in Jharkhand state of India are also infested by *E. crassipes, P. stratiotes,* among others, thereby adversely affecting the fish pond and agricultural fields (Jha 2017). Similarly, *E. crassipes*, *A. philoxeroides* and *P. stratiotes* are also problematic in China (Wu and Ding 2019).

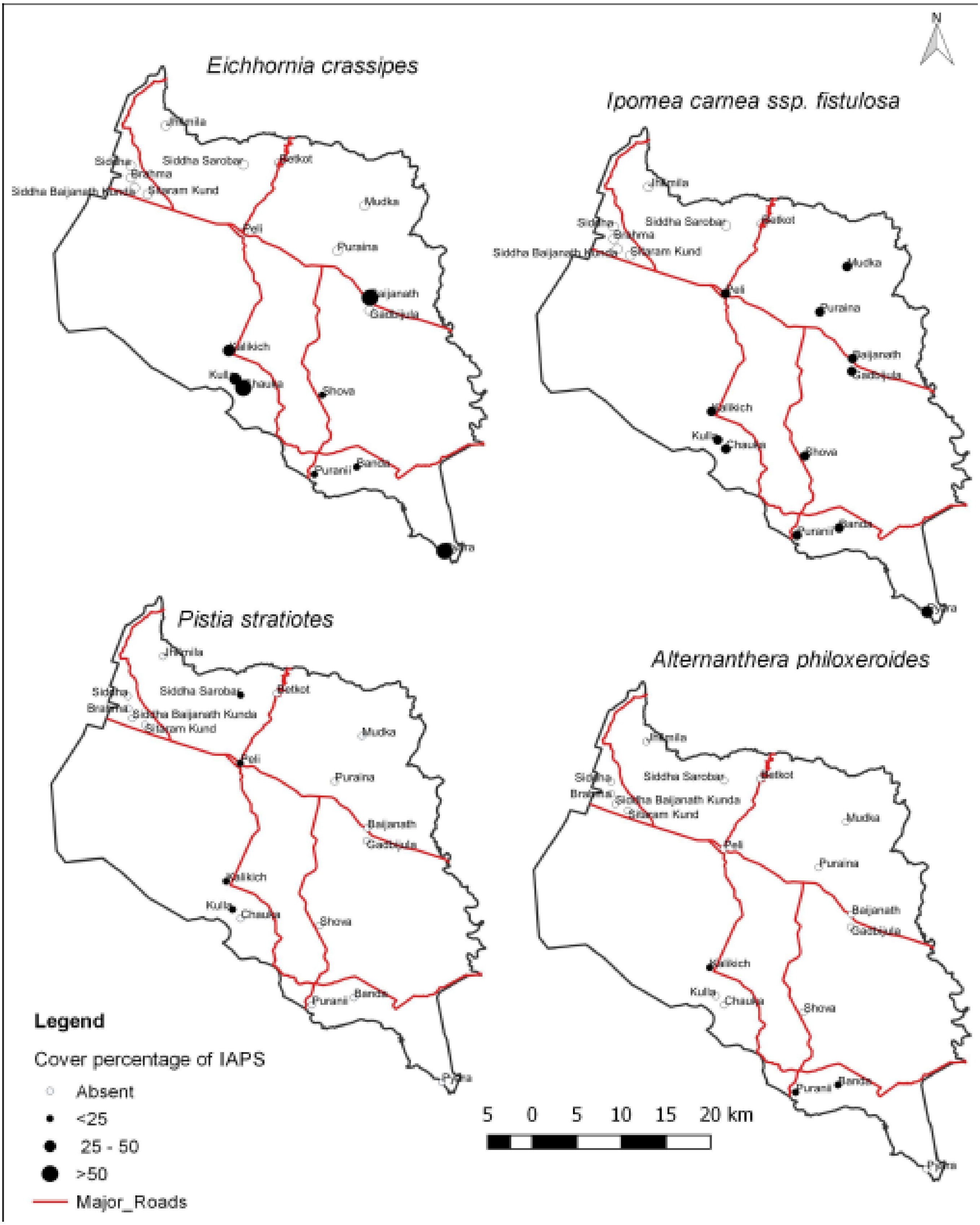

Figure 2. Spatial distribution of invasive alien plant species in wetlands of Kanchanpur district

Figure 3. Invasion by *Eichhornia crassipes* in Pyara Tal. Also seen is patches of *Ipomoea carnea* ssp. *fistulosa* on the left and at forefront (flowering)

It has been found that 26% of the wetlands of Kanchanpur district were highly invaded (IAPS cover >50%) by these IAPS; 42% moderately invaded (cover <50%); and 32% were free of invasion. Of the severely invaded wetlands all are situated at lower elevation except Siddha Sarobar Banda Tal (Figure 2, Table 1)

Among four wetland IAPS recorded from the studied wetlands of Kanchanpur district, *Eichhornia crassipes* appeared to the most problematic and abundant species. In spite of a relatively low frequency of *E. crassipes*, it was the most abundant species in terms of cover. For example, *E. crassipes* covered >50% of wetland surface in Baijanath, Chauka and Pyara lakes (Figure 2, 3, Table 1). It is also one of the four aquatic plants that have been included in the list of 100 of the world's worst invasive species (Lowe et al. 2000).

Dispersal pathways

Dispersal of propagule is one of the most important factors in determining distribution of IAPS (Primack and Miao 1992). During FGDs, we identified three dispersal pathways of *Eichhornia crassipes*. Intentional introduction of *E. crassipes* to use as fish feed was the most commonly reported pathway of introduction to the studied wetlands (score percentage 16%), while other pathways included intentional introduction for ornamental value (3%) and accidental introduction during flooding (3%). Intentional introduction of IAPS like *Alternanthera philoxeroides*, *E. crassipes*, *Myriophyllum aquaticum* and *Pistia stratiotes* for ornamental and other uses is the most common pathway in China (Ding and Xie 1996). In some instances, these IAPS have been also introduced as an effort to remove nutrients from eutrophic lakes and rivers in China (Ding et al. 2008, Zuo et al. 2012, Qin et al. 2016). However, introduction of IAPS for phytoremediation of nutrients was not reported by the participants of FGDs in Kanchanpur district. Participants of FGDs were unaware of the dispersal pathway of the remaining three species – *A. philoxeroides, Ipomea carnea* ssp. *fistulosa* and *P. stratiotes*. However, intentional introduction of *P. stratiotes* for ornamental values and *I. carnea* ssp. *fistulosa* for controlling soil erosion along roadside and as hedge plant in agroecosystem have been reported in different parts of Nepal (Shrestha 2016). It appears that local people and stakeholders in the study area were not aware of the environmental damage that *E. crassipes* would have after its' introduction in wetlands. Inability of FGD participants to explain the introduction pathways of three of the four IAPS found in the study areas would also mean that local people do not pay much attention to the spread of these IAPS. Therefore, awareness program particularly involving fish farmers who are mainly responsible for introduction of *E. crassipes* to non-invaded wetlands in study area is highly recommended.

Table 2. Importance of environmental variables on distribution of wetland IAPS analyzed based on CCA analysis and statistically significances are shown in bold.

Environmental variables	Variance explained	F-value	p-value
Elevation (El)	0.309	6.3627	**0.009**
Nitrate (Ni)	0.160	3.2945	**0.029**
Phosphate (Ps)	0.157	3.2314	**0.034**
pH	0.066	1.3608	0.240
Chloride (Cl)	0.063	1.2906	0.254
Grazing (Gz)	0.065	1.3408	0.264
Distance to settlement (Dis_st)	0.061	1.2551	0.317
Distance to road (Dis_rd)	0.046	0.9520	0.381

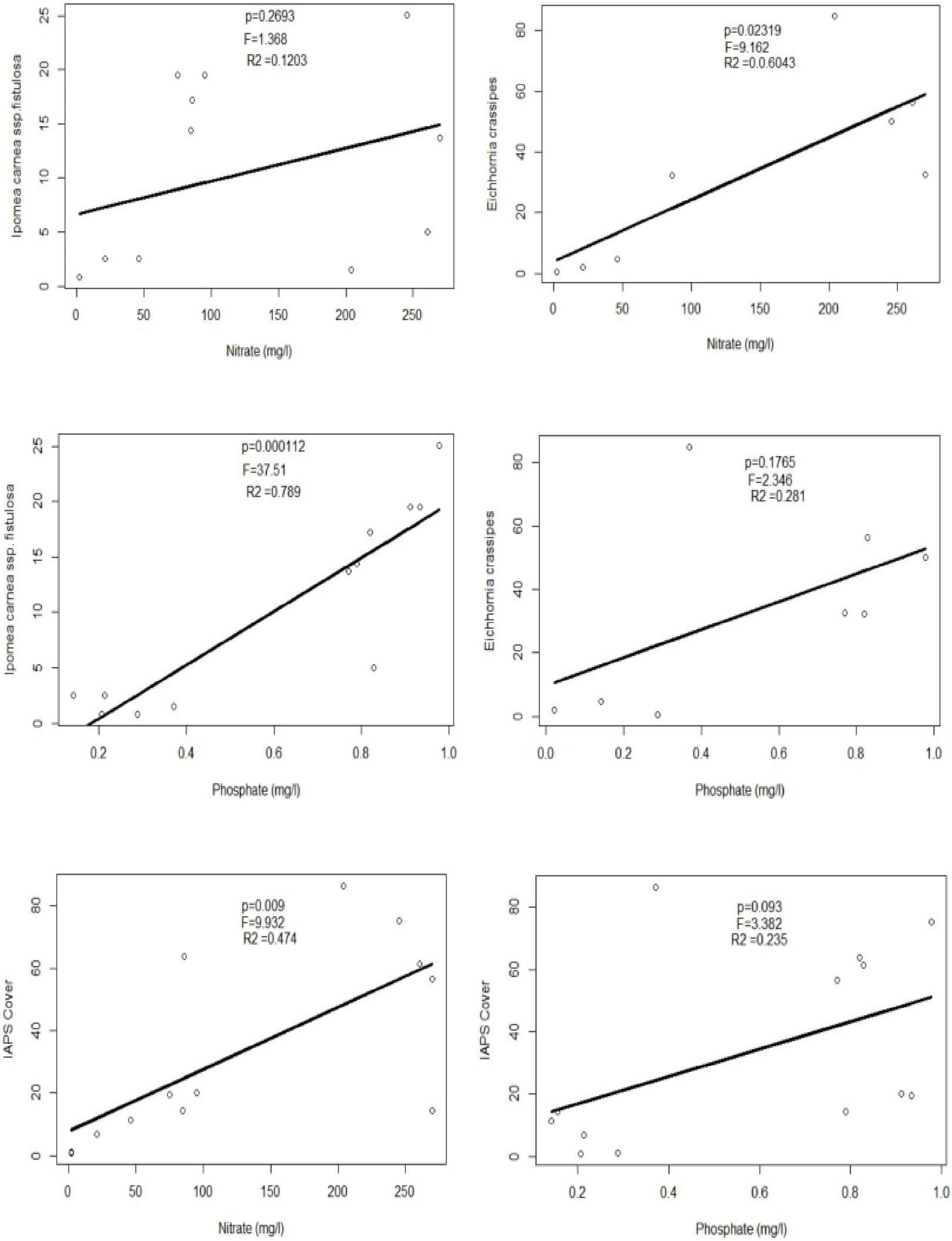

Figure 4. Variation of the cover (%) of *Ipomoea carnea* ssp. *fistulosa*, *Eichhornia crassipes*, and all species combined with concentration of nitrate and phosphate in water. Fitted lines is based on linear regression

Environmental variables

A Canonical Correspondence Analysis (CCA) revealed that elevation of wetland was the most important environmental variable to determine the occurrence of IAPS in wetlands of the present study area (Table 3). The wetlands located at higher elevation (220-420 m asl), mostly in Siwalik region, had only one IAPS but the wetlands located at lower elevation (<220 m asl) in Tarai region had 2-3 IAPS (Table 1). High probability of the occurrence of IAPS in low elevation wetlands in Tarai could be attributed to high propagule pressure in these wetlands which are located in human dominated and urbanized landscape (Cadotte et al. 2017). Negative correlations between elevation and richness of IAPS in wetlands has been also reported by Shaker et al. (2013).

Another important variable that governed the occurrence of IAPS in wetlands were concentration of nitrate and phosphate in water (Table 2). In addition, cover of IAPS also increased with increasing concentration of nitrate and phosphate in water of wetlands (Figure 4). Factors that influence water quality are among the most relevant predictors of plant invasions in wetlands (Buchan and Padilla 2000). In particular, nutrient enrichment often promotes plant invasions in wetlands (Loo et al. 2009, Holdredge et al. 2010, Shaker et al. 2013, Zhao et al. 2015). High nutrient and other resource availability also increases competitive ability of invasive weed such as *Alternanthera philoxeroides* compared to congeneric native species.

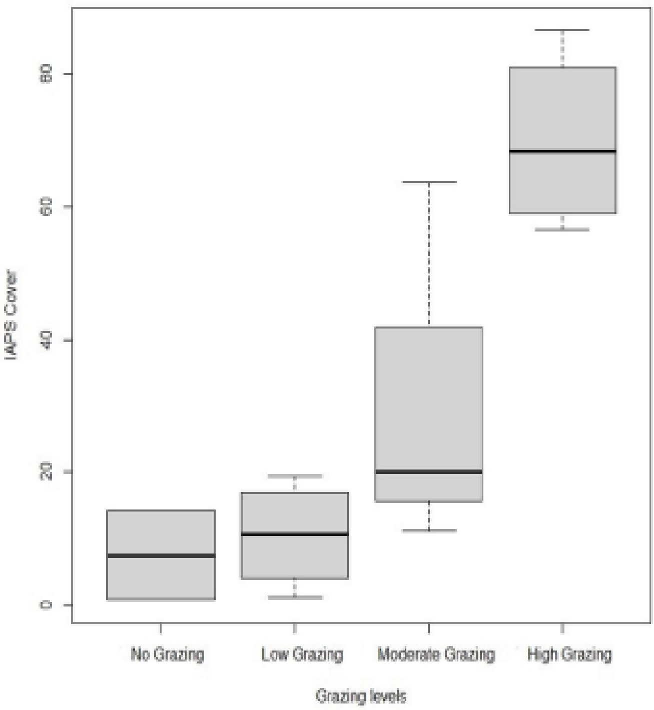

Figure 5. Change in cover of invasive alien plant species (IAPS) with different levels of grazing in the land surrounding the wetlands

Cover of IAPS (all species combined) increased with increasing levels of livestock grazing in the surrounding lands (Figure 5), which could be associated with increased flow of nutrient to wetlands, and hence eutrophication, due to high level of livestock grazing (Heathwaite 1995, Maasri and Gelhaus 2011). Other environmental variables such as water pH, chloride concentration, and distance to settlement and road were found less important in determining the occurrence of IAPS in our study area. Buchan and Padilla (2000) also reported the proximity to road as a weak predictor of the probability of the occurrence of *Myriophyllum spicatum* in lakes of Europe. In our study area, many wetlands are accessible by roads and in general, there is little variation in distance to road which could be why road proximity did not have significant impact on the occurrence of IAPS. However, some of the previous studies reported that the distance to settlement and road significantly affect the occurrence and abundance of IAPS in different ecosystems (Trombulak and Frissell 2000, Seipel et al. 2012, Menuz et al. 2013).

CONCLUSIONS

Our results showed that more than two-third of the wetlands studied were invaded by one or more IAPS with more than half of the surface area of a few wetlands covered by globally noxious weeds such as *Eichhornia crassipes*. While management interventions such as the physical/mechanical removal aimed to reduce abundance of IAPS is suitable in these invaded wetlands, prevention of IAPS introduction should be a management priority in the IAPS-free, non-invaded wetlands. Since intentional introduction by fish farmers was a major dispersal pathway of *E. crassipes*, educating these and other local communities of the potential risks associated with IAPS introduction can help to prevent IAPS invasion in the IAPS-free wetlands. Public education aimed to improve capacity of local communities to identify IAPS is helpful for their early detection and eradication. Furthermore, our data revealed that eutrophic lakes with high nutrient content were likely to have high abundance of IAPS, suggesting that any effort to prevent wetland eutrophication may also indirectly help in IAPS control. Options for the management of IAPS vary with the species in question and bio-physical environmental conditions of the ecosystems to be managed. Therefore, results of the present study can be used to prioritize wetlands for IAPS control and prevention, restoration of invaded wetland, and monitoring of wetlands across the study area.

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Authors' contribution: BBS conceptualized and designed the study; PB collected and analyzed data, and prepare first draft of the manuscript; BBS revised and finalized the manuscript.

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