DOI: 10.1007/s11629-013-2821-3

Biodiversity and Invasibility: Distribution Patterns of Invasive Plant Species in the Himalayas, Nepal

BHATTARAI Khem Raj[1]*, MÅREN Inger Elisabeth[2], SUBEDI Suresh Chandra[3]

1 National Herbarium and Plant Laboratories, Department of Plant Resources, Lalitpur, Post Box 3708, Nepal

2 Department of Geography, University of Bergen, 5007 Bergen, Norway

3 Department of Biological Science, Florida International University, Miami, Florida 33199, USA

**Corresponding author, e-mail: bhattaraikhemraj@gmail.com; Tel: +97715560977; Fax: +97715560549*

Citation: Bhattarai KR, Måren IE, Subedi SC (2014) Biodiversity and invasibility: distribution patterns of invasive plant species in the Himalayas, Nepal. Journal of Mountain Science 11(3). DOI: 10.1007/s11629-013-2821-3

Abstract: Invasive plant species are exerting a serious threat to biological diversity in many regions of the world. To understand plant invasions this study aims to test which of the two plant invasiveness hypotheses; 'low native diversity' vs. 'high native diversity', is supported by the regional distribution patterns of invasive plant species in the Himalayas, Nepal. This study is based on data retrieved from published literatures and herbarium specimens. The relationship between invasive plant species distribution patterns and that of native plant species is elucidated by scatter plots, as well as by generalized linear models. The native plant species and invasive plant species have similar distribution patterns and the maximum number of invasive plant species is found in the same altitudinal range where the highest richness for native tree species is found. There is a clear trend of higher invasive plant richness in regions where native tree species richness is relatively high. Consequently, the native plant richness is highest in the central phytogeographic region, followed by the eastern and the western regions, respectively. The invasive plant species also follows a similar trend. Additionally, the invasive plant species richness was positively correlated with anthropogenic factors such as human population density and the number of visiting tourists. This study supports the hypothesis that 'high native diversity' supports or facilitates invasive plant species. Further, it indicates that native and invasive plant species may require similar natural conditions, but that the invasive plant species seem more dependent and influenced by anthropogenic disturbance factors.

Received: 2 July 2013
Accepted: 16 October 2013

Keywords: Anthropogenic disturbance; Biodiversity; Native species; Biological invasions; Distribution; Himalayas

Introduction

Invasive plant species (IPS) have attracted extensive attention among ecologists, agronomists, foresters, conservationists, farmers and entrepreneurs because of their negative ecological impacts and associated economic loss at various scales (Bhowmik 2005; Saure 2012). The effects of increased globalization, international trade, tourism, transport and travel have dramatically enhanced the spread of IPS which can lower biological diversity, alter ecosystem function, change resource availability, and influence human health (Ricciardi et al. 2000; Sekar 2012). Consequently, invasive plants have become the focus of intense research and management worldwide (Larson et al. 2001; Kennedy et al. 2002; Ehrenfeld 2003).

There are two main views regarding the ability of plants to invade new habitats. The 'traditional' view focuses on properties of the invasive species and plant communities that are invaded (Shea and Chess 2002), whereas a more recent view focuses on the properties of the physical environment that affect species survival, growth, and interactions (Huston 1994). This seems contradictory, since the 'traditional view' has much more recent citation than the 'recent view'. The role of the physical environmental conditions, such as soils and climate, on facilitating plant invasion has received increasing attention (e.g. Crawley et al. 1987; Hobbs and Atkins 1988; Huenneke et al. 1990; Richardson and Bond 1991; Higgins and Richardson 1998). Human influence often contributes to the disturbance of habitats, making them more susceptible to invasion, facilitating many alien plants by freeing nutrients and by changing natural disturbance regimes (Davis et al. 2000).

Nepal, situated in the central part of the Himalayas between 80°04' to 88°12' E longitudes and 26°22' to 30°27' N latitudes, is located in the Himalayan mountain chain in the junction of the Palaeo-artic and the Oriental realms of the earth and in the crossroads of the six floristic provinces of Asia (Hara and Williams 1979). It is divided into three phytogeographic regions; West Nepal (Kumaun frontier to 83°E), Central Nepal (83°E to 86°30'E) and East Nepal (86°30'E to Sikkim frontier) (Stern 1960; Banerji 1963; Hara et al. 1978). Among the three phytogeographic regions of Nepal, the western region comprises the largest area (63,114 km^2), followed by the central region (50,380 km^2) and lastly the eastern region (33,687 km^2). The topography of Nepal shows extreme altitudinal variation and represents all the climatic zones (Bhattarai et al. 2004). Such altitudinal differences and associated changes in environmental conditions makes it particularly vulnerable to the establishment of IPS from a wide range of origins.

Nepal, as part of the Sub-Indian continent, has a long history of introduced plant species. In the 19^{th} century, the British were major contributors, bringing economically important plants from almost every continent to the sub-Indian continent (Islam 1991). The introduction of plant species by gardeners, horticulturists, foresters and the returned British Gorkha soldiers have also contributed to the spread of IPS in Nepal (Kunwar 2003). Many of these introduced species rapidly colonize a variety of habitats and alter the plant community and ecological processes such as nutrient cycling, energy flow or the hydro-dynamic properties of its recipient ecosystem (Huston 2004).

Although many studies have been conducted on plant invasiveness all over the globe (e.g. Kühn et al. 2004; Liu et al. 2005) there is no consensus among invasion ecologists of what factors promote or reduce invasive species richness (Weber 2003). Generally, these studies have confirmed two types of hypotheses. According to the first hypothesis, 'low native diversity' favours more invasions (Elton 1958; Timmins and Williams 1991; Naeem et al., 2000; Kennedy et al. 2002; Pyšeket al. 2002; Dark 2004). According to the second hypothesis ('high native diversity'), habitats with high native species diversity are more prone to have higher invasive species diversity as well (Smith and Knapp 1999; Wardle 2001; Stohlgren et al. 2001; Pyšek et al. 2002; Kennedy et al. 2002; Sax 2002). However, there is still ambiguity over which factors favour invasion (Rodgers and Parker 2003; Heard et al. 2012). This study aims to test which of these two hypotheses are supported by the distribution patterns of IPS in three phytogeographic regions of Nepal and to elucidate how human population density and tourist density influence their diversity. This study also tests the Rapoport's elevation rule which states that there is a positive correlation between elevation and the elevational range of species (Stevens 1992). Although it has been tested for a variety of organisms and lifeforms it has not yet been tested for IPS. This rule is derived from earlier work on latitudinal gradients by Rapoport (1975, 1982), which found that latitudinal ranges of species increase with increasing latitude (Rapoport 1982; Stevens 1989).

1 Methods

1.1 Data source

We used data retrieved for 166 IPS recorded in Nepal which were introduced to an ecosystem other than their natural home (Tiwari et al. 2005). We have verified data from herbarium specimens of National Herbarium and Plant Laboratories at Godawri, Nepal. For each IPS we determined: (a) current habitat within Nepal; (b) introduction date or, in its absence, first recorded date in the country; (c) biogeographic origin, (d) distribution range along the elevation gradient and (e) area of occurrence in Nepal based on various published literature (Hara et al. 1978; Hara and William 1979; Hara et al. 1982; Press et al. 2000; DPR 2001; Tiwari et al. 2005). Data on human population size and density, and the number of tourists and their origin were taken from Central Bureau of Statistics (CBS 2011), to elucidate scale of human disturbance and possible sources for the introduction of IPS to Nepal. We used data on area based on digitized maps of Nepal at 500 m contours to examine species richness area relationships for each 500 m elevation (Bhattarai and Vetaas 2006)

The tree line ecotone is at 4300 m a.s.l. in the northern part of Nepal whereas towards the southern part the lowest elevation limit is at 60 m a.s.l.. The upper recorded limit for IPS in the Nepalese Himalayas is at 4300 m a.s.l.; hence this study covers the elevation range from 100 m a.s.l. up to 4300 m a.s.l.. To examine the relationship between IPS richness and elevation, the total elevation gradient between 100 and 4300 m a.s.l. was divided into forty-three 100 m elevation intervals (vertical elevation bands) (Bhattarai et al. 2004). The elevation range of each species was estimated as the difference between the maximum and minimum elevations where a species was found within the range of survey sites, rounded off to the nearest 100 m (Vetaas and Grytnes 2002). IPS richness is defined as the number of IPS found in every 100 m interval between its upper and lower elevation limits. The mid-point of a species at a given site was calculated by averaging the lowest and highest elevation limits of each species present (Stevens 1992).

1.2 Data analysis

We used exploratory techniques, and regression and correlation for analysis of the data. We used generalized linear models (GLM; McCullagh andNelder 1989; Dobson 1990) to elucidate the relationship between the species richness and elevation. The response variable; species richness, is a discrete data type (counts) and may follow a Poisson error distribution (McCullagh and Nelder 1989), which requires a logarithmic link. A GLM model was generated with a logarithmic link and also one with an identity link function. The difference between a logarithmic link and an identity link function (which assumes a normal error distribution) was assessed by Q-Q diagnostic plots of the residuals from preliminary tests (Hastie and Pregibon 1993; Crawley 1993). Although the counts were very high (invasive species) and the error distribution was almost indistinguishable from normal, we chose the Poisson model based of the nature of the response variable (Crawley 2002). The models were checked with up to third-order polynomial regressions. We used an F-test to test the significance of the models. To test the Rapoport's elevation rule, a smoother was fitted by a generalized additive model (GAM, with four degrees of freedom). Spearman rank correlation was also employed to check for relationships between the numbers of plant species and anthropogenic factors. Regression analyses were performed using S-Plus, version 6.5, whereas the rest of the analyses were carried out by Microsoft excel.

2 Results

2.1 Invasive plant species richness and their distribution patterns

A total 166 IPS were recorded for Nepal, constituting 125 species of herbs, 23 species of shrubs, 11 species of climbers and seven species of trees (Appendix I), belonging to 42 families and the most dominant family was Asteraceae comprising 22 species, then followed by Fabaceae and Solanaceae, which comprised 15 and 12 species, respectively. In comparison to the seven IPS of trees, there are 614 native tree species growing from 100 m a.s.l. up to 4300 m a.s.l. in Nepal. The upper limit for recorded IPS in Nepal Himalayas is 4300 m a.s.l.. The IPS richness increased with increasing elevation up to 1100 m a.s.l. and then decreased with increasing altitude, showing a mid-elevation peak, similar to that of native tree species (Figure 1). Thus, the peak of IPS richness was

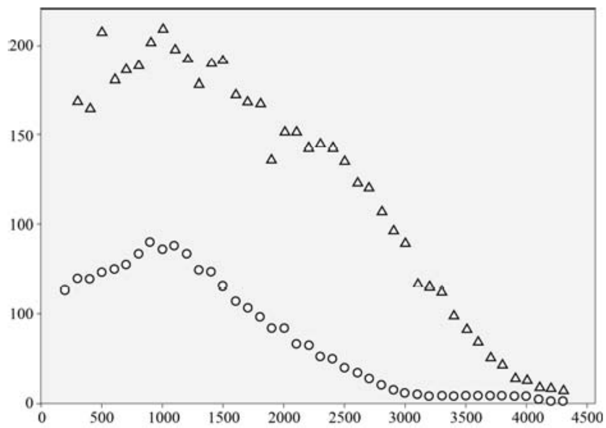

Figure 1 Native tree richness (Δ) and invasive plant species richness (O) in relation to elevation, in the Nepalese Himalayas, from 100 to 4300 m a.s.l..

observed within the same elevation range where optimum tree species richness was found.

As for the relationship between elevation and area, area decreases monotonically with increasing elevation (Figure 2a). There is a linear relationship between log-area and tree richness (Figure 2b), but there is a drop in richness at lower elevations where the area is the largest. There was a positive correlation between the elevation midpoint and the elevation range. In the lower elevation band there is a narrow elevation range but the elevation range increased with increasing elevation. Thus, Rapoport's elevation rule is supported by the IPS (Figure 3).

The eastern and central phytogeographic regions of Nepal harboured relatively more native species, as well as more IPS, compared to the western region (Figure 4). Out of the 166 IPS, 114 were recorded in the eastern phytogeographic region, 115 in the central region and 70 in the western region, respectively. Only 48 IPS were found to occur in all three phytogeographical regions of Nepal.

Regarding the place of origin of these 166 IPS, 123 species are native to the Americas (South America and North America), 14 to Europe, 8 to

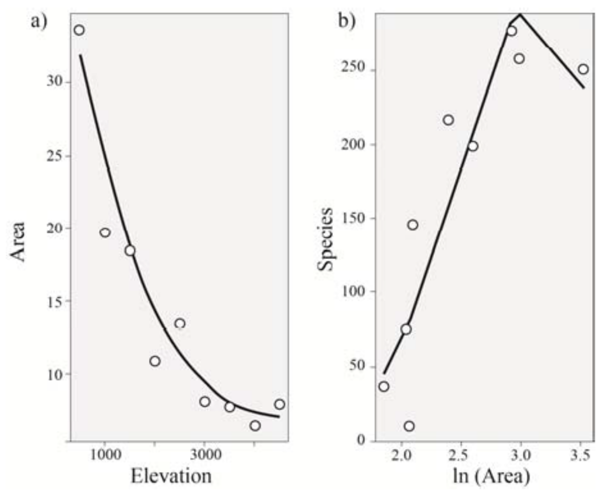

Figure 2 Plots showing the relationship between a) land area and elevation in Nepal; the line is fitted by a generalized additive model (GAM) with three degrees of freedom, and b) area in logarithmic scale and native tree species richness in Nepal.

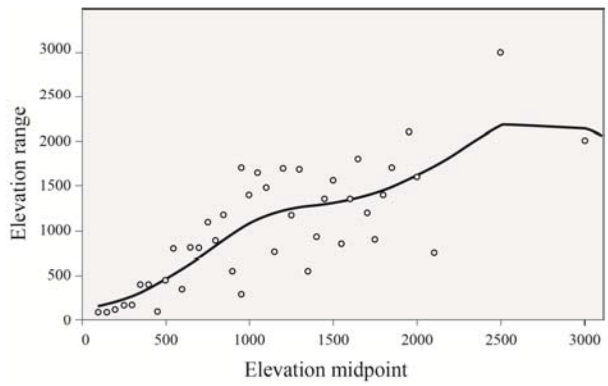

Figure 3 Plot showing the relationship between elevation range and elevation mid-point (m a.s.l.). The line is fitted by generalized additive models with four degrees of freedom, and the line is fitted to guide the reader's eye.

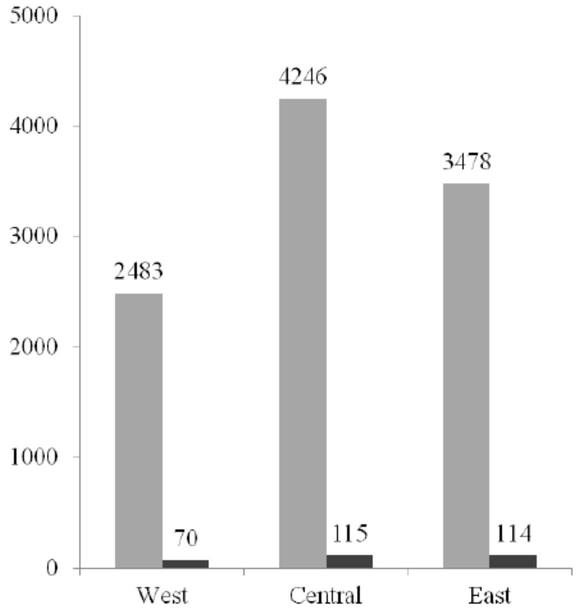

Figure 4 Bar diagrams showing the number of native plant species (grey) and invasive plant species (black) in the three phytogeographic regions of Nepal; Eastern, Central and Western regions.

Africa, 7 to Asia and 14 has a pantropical distribution with uncertain origin (Figure 5). The IPS were found in all types of habitats; forest, cropland, fallow land and wetland. The majority of the IPS, 96 species (*ca.* 57 %), was found in fallow land, followed by cultivated land, wetland and forest area.

Figure 5 Pie diagram showing the nativity of the 166 recorded invasive plant species in Nepal.

During the period from 1962 to 2005, the tourists visiting Nepal were primarily Europeans, followed by Americans, Australians and Africans, in ascending order of visitor numbers (Figure 6a). Out of the three phytogeographic regions of Nepal, most tourists visited the central region, while least visited the western region (Figure 6b). The Spearman rank correlation (Table 1) shows that the IPS correlated positively with the numbers of native trees, size and density of the human population, numbers of tourists but correlated negatively with area. We classified the IPS into woody and non-woody groups and did the same analysis and found that there was highly positive correlation between native tree diversity and herbaceous IPS (r = 0.89). Similarly, the correlation between native tree diversity and woody IPS was positively correlated (r = 0.77). However, correlation between woody and herbaceous IPS was negative (r = -0.72).

3 Discussion

3.1 Invasive plant species richness patterns

We found the richness patterns of invasive plant species in Nepal to be unimodal along the elevation gradient, as reported for various groups of native plants (Bhattarai and Vetaas 2003; Bhattarai et al. 2004; Bhattarai and Vetaas 2006, Grau et al. 2007). The maximum number of IPS was found at the same elevation where maximum native tree richness is observed (Figure 1). The present study found that IPS richness was positively correlated with the total native plant species richness (Table 1). Cleland et al. (2004) found similar results, and their patterns were stronger at the larger scale as, generally, a larger area supports more species than a smaller area (Rosenzweig 1997). Area decreases along the elevation gradient (Figure 2a), and the species-area relationship is significant in a second-order polynomial model, indicating a uni-modal relationship. The observed mid-elevational peak in IPS cannot, however, be ascribed to the availability of larger area, as there is a reduction in area when moving upslope.

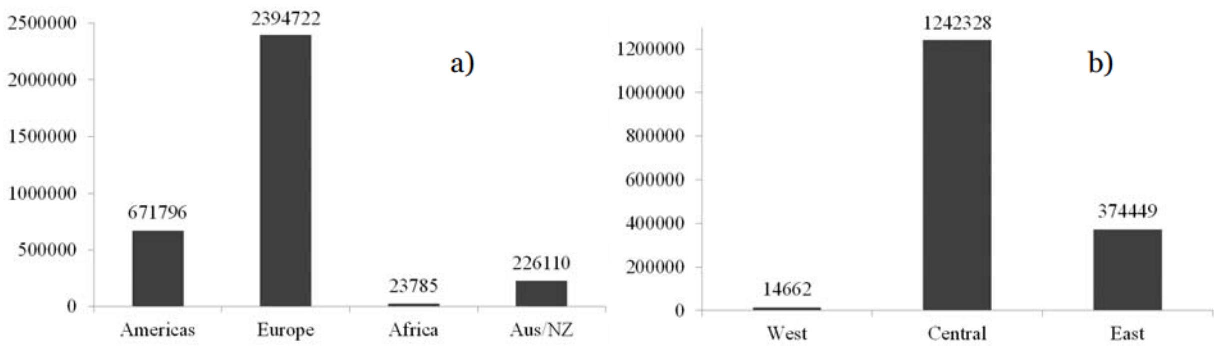

Figure 6 Bar diagrams showing the number of tourists visiting Nepal a) from different continents (Aus = Australia, NZ = New Zealand), and b) to the three phytogeographic regions (Western-, Central- and Eastern region) of Nepal, over a period from 1980 to 2005.

Table 1 Correlation between different biological and anthropogenic factors influencing occurrences of native and invasive plant species in the Nepalese Himalayas.

Variables	Invasive plants	Native plants	Area	Human population	Human density
Native plants	0.91				
Area	-0.81	-0.49			
Human population	0.63	0.89	-0.06		
Human density	0.96	0.98	-0.64	0.8	
Tourist numbers	0.73	0.95	-0.2	0.98	0.88

Among the three phytogeographic regions of Nepal, the western region comprises the largest area, followed by the central region and lastly the eastern region but the western region, however, contains the lowest species richness for both native species as well as for IPS (Figure 4). This suggests that the size of area alone couldn't explain the maximum native species richness, or the IPS richness. The explanation for maximum richness at mid-elevation might be due to a combination of biological, climatic and anthropogenic factors. Higher moisture levels and optimum energy increase photosynthesis, which leads to higher biological activity and ultimately an increase in species richness (O'Brien 1998). The maximum IPS at 1100 m a.s.l. may thus be due to optimum energy (potential evapotranspiration, PET= 1160 mm), and maximum moisture availability due to higher rainfall condition (1423 mm) at this elevation which could create suitable conditions for many of the IPS (Bhattarai and Vetaas 2003). The Rapoport's elevation rule is not supported by woody native species but it is supported by IPS, indicating that these species may have different responses and ecological requirements compared to native plant species.

3.2 Invasive species richness and anthropogenic factors

Knowledge on the early introduction of IPS in Nepal is poorly documented. The first report of an IPS is *Leersia hexandra* which was recorded in 1820. Five years later, *Chromolaena odorata* was reported as an invasive plant in Nepal. We assume that some IPS have been introduced deliberately as ornamentals (e.g. *Lantana camara, Eichhornia crassipes, Pistia stratiotes*) or as plants for soil establishment (e.g. *Ipomea carnea*). Many more have been introduced accidentally. Often, agricultural and forestry weeds (*Ageratina adenophora, Ageratun conyzoides, Mikania micrantha, Chromolaenao dorata*) have been introduced as contaminants in imported seed mixes of crops, forages and nurseries (Tiwari et al. 2005; NHPL 2011, 2012).

The majority of IPS to Nepal are of neo-tropical origin (South America) and have been introduced to Nepal via India (Tiwari et al. 2005). The land-linked connection, porous border, similarity in culture and ecological conditions with India favour the introduction of invasive species through both intentional and unintentional pathways. Anthropogenic factors like human migration, roadways, transport routes and agricultural practices may favour plant invasion (Liu et al. 2005). Some species might have been introduced to Nepal via machinery, agricultural equipment and vehicles. Another important means for dispersal of IPS is tourist's luggage, shoes and clothing as seeds are carried, knowingly or unknowingly, from the source of origin to be dispersed at the destination (Tiwari et al.2005; Kalusova et al. 2012). This is supported by the fact that the region visited by a high number of tourists showed relatively higher richness of IPS (Figure 6b). The higher local population numbers, in combination with the higher number of visiting tourists, may create more chances (deliberate, accidental or both) for the introduction of invasive plant species.

Human population density may be an important determinant of non-native plant distributions as shown by Hulme (2003). In our study, the elevation with highest IPS richness at 1100 m a.s.l. does experience high levels of anthropogenic disturbance. Our results are consistent with the already known fact that human activities have an important influence on the dispersal and establishment of exotic plants (Elton 1958; Hodkinson and Thompson 1997; Sax 2002; Liu et al. 2005). The richness of IPS correlated positively with human population size, native species numbers and the number of tourists (Table 1). The dispersal of many invasive plant species depends on the activity of human disturbances to establish as shown by Pyšek et al. (1998) and Byers (2002). Similarly, native species showed greater richness in the eastern and central regions of Nepal and showed lower richness in the western region. Thus, this study supports the 'high native diversity' hypothesis that predicts an area with higher native species diversity to be invaded by higher numbers of IPS. Furthermore, we suggest that native plant species richness and IPS richness are highly determined by both natural conditions and human disturbance levels. This is in congruence with a large survey of parks and conservation sites around the world that found a positive correlation between the number of native species and the number exotic species (Lonsdale 1999). A higher-resolution study of vegetation in the Rocky Mountains, the western deserts and the Great Plains of North America, also found that native and exotic species richness were positively correlated across sample areas and at several levels of sampling resolutions (Stohlgren et al. 2001).

Although 166 IPS are identified in Nepal (Tiwari et al. 2005), a large number of IPS are naturalized in Nepal as permanent denizens of the native flora. The IPS is conspicuous along roadsides, suggesting that road edges which bears more anthropogenic disturbance, act as microhabitats for many IPS. It is reasonable to presume that the majority of IPS have been introduced to Nepal via surrounding countries, particularly India. Roadways are the major means of transportation in Nepal and most disturbed roadsides are found to be invaded by *Ageratum adenophora, Lantana camara, Parthenium adenophorus* and *Bidens pilosa*. *Eichornia crassipes* dominates in marsh and swamp areas along roadsides and wetlands. *Mikania micrantha* is well established in the tropical part of eastern and central Nepal and has been causing serious problems in the Koshi Tappu Wildlife Reserve and Chitwan National Park.

The IPS are more abundant in fallow lands than in habitats where resource availability is less accessible. Xeric sites are less conducive to IPS seed germination or establishment, and hence exclude many invaders (Rodgers and Parker 2003). Similarly, Wiser et al. (1998) showed that alien invasions in the Southern Alps of New Zealand were more frequent in plots that were more fertile, more sheltered, and at lower elevations. Additionally, Harrison (1999) reported that alien species, common throughout most grasslands of California, were significantly less abundant within the nutrient-poor serpentine grasslands. The IPS invasions in Australia have also shown to be associated with more fertile soils. In these cases, the physically harsh habitats limited invasions because the environmental stress reduces the ability of species to utilize available resources (Davis et al. 2000). Both human disturbance and environmental stress affect invasions by changing resource availability. Consequently, we regard the interaction of these two factors to play an important role in the distribution of IPS in Nepal and elsewhere.

4 Conclusions

A total of 166 invasive plant species are registered in the Nepalese Himalayas, and these are distributed along the altitude range from 100 m a.s.l. up to 4300 m a.s.l. and have a humped shaped pattern of distribution along the elevation gradient, similar to that shown for other groups of plants. The maximum numbers of IPS were found at 1100 m a.s.l. and in areas with higher native richness, consequently supporting the hypothesis that high native species richness possibly facilitates the invasibility of the habitat to IPS. The IPS richness was positively correlated with anthropogenic factors such as human population size and density, and the number of visiting tourists, which indicate that the IPS may be influenced by population densities, human disturbance levels, transportation routes and the number of visiting tourists. Nepal is part of the Eastern Himalaya biodiversity hotspot and the country harbours dramatic gradients in elevation. This in turn may facilitate invasions. At the same time, the potential threats of IPS to biodiversity, ecosystem function, resource availability, national economy and human health is poorly understood. It is utterly important to enhance the knowledge of all aspects of IPS for the future biodiversity conservation and ecosystem management of this region.

Acknowledgements

First author would like to acknowledge to National Herbarium and Plant Laboratories, Department of Plant Resources for cooperation provided during preparation of manuscript. This work is part of the research project 'Legal frameworks for Conservation of Biodiversity and Ecosystem Services in the Himalayas (HIMALINES)' funded by the Norwegian Research Council (190153/V10) and Olaf Grolles Legat.

Electronic supplementary material: Supplementary material (One Appendix: Appendix 1) is available in the online version of this article at http://dx.doi.org/10.1007/s11629-013-2821-3.

References

Banergi ML (1963) Outline of Nepalphytogeography. Vegetation 11: 288-296. DOI: 10.1007/BF02855331

Bhattarai KR, Vetaas OR (2006) Can Rapoport's elevation rule explains the tree species richness along the Himalayan elevation gradient, Nepal? Divers Distributions12: 373-378. DOI: 10.1111/j.1366-9516.2006.00244.x

Bhattarai KR, Vetaas OR (2003) Variation in plant species richness of different life forms along a subtropical elevation gradient in the Himalayas, east Nepal. Global Ecology and Biogeography 12: 327-340 DOI: 10.1046/j.1466-822X.2003.00044.x

Bhattarai KR, Vetaas OR, Grytnes JA (2004) Fern species richness along a central Himalayan elevation gradient, Nepal. Journal of Biogeography 31:398-400. DOI: 10.1046/j.0305-0270.2003.01013.x

Bhowmik PC (2005) Characteristics, significant, human dimension of global invasive weeds. In: Inderjit (ed) Invasive Plants: Ecological Agricultural aspects. pp. 251-267.

Brown RL, Peet RK (2003) Diversity invasibility of southern Appalachian plant communities. Ecology 84: 32-39. DOI: 10.1890/0012-9658(2003)084[0032:DAIOSA]2.0.CO;2

Byers JE (2002) Impact of non-indigenous species enhanced by anthropogenic alteration of selection regimes. Oikos 97: 449-458. DOI: 10.1034/j.1600-0706.2002.970316.x

Central Bureau of Statistic (CBS) (2011) Statistical year book Nepal 2011. Central Bureau of Statistics, Kathmandu, Nepal.

Crawley MJ (1987) What makes a community invasible? In: Crawley MJ, Edwards PJ, Gray AJ (eds.) Colonization, succession, stability. Blackwell Scientific Publications, Oxford. pp. 429-454.

Crawley MJ (2002) Statistical computing: an introduction to data analysis using S-Plus. Wiley, Chichester.

Crawley MJ (1993) GLIM for ecologists. Blackwell Scientific Publications, Oxford.

Dark SJ (2004) The biogeography of invasive alien plants in California: an application of GIS spatial regression analysis. Divers Distributions 10:1-9. DOI: 10.1111/j.1472-4642.2004.00054.x

Davis MA, Grime JP, Thompson K (2000) Fluctuating resources in plant communities, a general theory of invasibility. Journal of Ecology 88: 528-534. DOI: 10.1046/j.1365-2745.2000.00473.

Department of Plant Resources (DPR) (2001) Flowering plants of Nepal. Department of Plant Resources, Kathmandu, Nepal.

Dobson AJ (1990) An introduction to generalized linear models. Chapman Hall, London.

Elton CS (1958) The ecology of invasions by animals plants.2nd edn. Methuen, London.

Ehrenfeld JG (2003) Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems 6: 503-523. DOI: 10.1007/s10021-002-0151-3

Grau O, Grytnes JA, Birks HJB (2007) A Comparison of altitudinal species richness patterns of bryophytes with other plant groups in Nepal, Central Himalaya. Journal of Biogeography 34: 1907-1915 DOI: 10.1111/j.1365-2699.2007.01745.x

Grime JP (1977) Evidence for the existence of three primary strategies in plant its relevance to ecological evolutionary. American Naturalist 111: 1169-1194.DOI: 10.1086/283244

Hara H, Williams H J (1979) An enumeration of the flowering plants of Nepal, Vol II. British Museum Natural History, London.

Hara H, Chater AO, Williams HJ (1982) An enumeration of the flowering plants of Nepal, Vol. III. British Museum Natural History, London.

Hara H, Stearn WT, Williams HJ (1978) An enumeration of the flowering plants of Nepal, Vol. I. British Museum Natural History, London.

Harrison S (1999) Local regional diversity in a patchy landscape: Native, alien, endemic herbs on serpentine. Ecology 80:70-80.DOI:10.1890/0012-9658(1999)080[0070:LARDIA]2.0.CO;2

Heard M J, Sax DF, Bruno JF (2012) Dominance of non-native species increases overtime in a historically invaded strandline community. Divers Distributions18: 1232-1242

Higgins SI, Richardson DM (1998) Pine invasions in the southern hemisphere, modelling interactions between organism, environment, disturbance.PlantEcology135: 79-93. DOI: 10.1023/A:1009760512895

Hobbs RJ, Atkins L (1988) Effect of disturbance nutrient addition on native introduced annuals in plant communities in the Western Australian wheat belt. Australian Journal of Ecology 13: 171-179. DOI: 10.1111/j.1442-9993.1988.tb00966.x.

Hodkinson DJ, Thompson K (1997) Plant dispersal: the role of man. Journal of Applied Ecology 34: 1484-1496. DOI: 10.2307/2405264

Huenneke LF, Hamburg SP, Koide R, et al. (1990) Effects of soil resources on plant invasion community structure in California serpentine grassland. Ecology 71: 478-491. DOI: 10.2307/1940302

Hulme PS (2003) Biological invasions: winning the science battles but losing the conservation war? Oryx 37:178-193. DOI: 10.1017/S003060530300036X

Huston MA (1994) Biology diversity: the coexistence of species on changing landscapes. Cambridge University Press, Cambridge.

Huston MA (2004) Management strategies for plant invasions: manipulating productivity, disturbance, competition. Divers Distributions 10: 167-178. DOI: 10.1111/j.1366-9516.2004.00083.x

Kalusova V, Chytrý M, Kartesz JT, et al. (2013) Where do they come from where do they go? European natural habitats as donors of invasive alien plants globally. Divers Distributions 19(2)199-214. DOI: 10.1111/ddi.12008

Kennedy TA, Shahid N, Katherine MH, et al. (2002) Biodiversity as a barrier to ecological invasion. Nature 417: 636-8. DOI: 10.1038/nature00776

Kühn I, Brenburg M, KlotzS (2004) Why do alien plant species that reproduce in natural habitats occur more frequently? Divers Distributions 10(5-6): 417-425. DOI: 10.1111/j.1366-9516.2004.00110.x

Kunwar RP (2003) Invasive alien plants Eupatorium: Biodiversity and Livelihood. Himalayan Journal of Sciences 1(2): 129-133. DOI: 10.3126/hjs.v1i2.213

Larson DL, Erson PJ, Newton W (2001) Alien invasions in mixed-grass prairie: Effects of vegetation type anthropogenic disturbances. Ecological Applications 11:128-41.

Liu J, Liang SC, Liu FH, et al. (2005) Invasive alien plant species in China: regional distribution patterns. Divers Distributions 11(4): 341-347. DOI: 10.1111/j.1366-9516.2005.00162.x

Lonsdale WM (1999) Global patterns of plant invasions the concept of invasibility. Ecology 80: 1522-1536.

National Herbarium and Plant laboratories (NHPL 2011) *Catalogue of Nepalese Flowering Plants II*. (Ed) Keshav Raj Rajbhanadari , Khem Raj Bhattarai and Sushim R. Baral. National Herbarium and Plant Laboratories, Godawari, Lalitpur, Nepal. pp. 209.

National Herbarium and Plant laboratories (NHPL 2012) Catalogue of Nepalese Flowering Plants III. (Ed) Keshav Raj Rajbhanadari , Khem Raj Bhattarai and Sushim R. Baral. National Herbarium and Plant Laboratories, Godawari, Lalitpur, Nepal. pp. 255.

Press JR, Shrestha KK, Sutton DA (2000) Annotated checklist of the flowering plants of Nepal. The Natural History Museum, London.

Pyšek P, Jarošík V, Kušera T (2002) Patterns of invasion in temperate nature reserves. Biological Conservation 104: 13-24.DOI: 10.1016/S0006-3207(01)00150-1

Rapoport EH (1975) Areografía: estrateg IPSgeograficas des lasespecies. Fondo de Cultura Económica, Mexico City.

Rapoport EH (1982) Areography: geographical strategies of species. Trans. B. Drausal. Vol. 1. Pergamon, New York.

Ricciardi A, Steiner WWM, Mack RN, Simerloff D (2000) Towards a global information system for invasive species. Bioscience 50 (3): 239-44.

Richardson DM, Bond WJ (1991) Determinants of plant distribution, evidence from pine invasions. The American Naturalist 137: 639-668. DOI: 10.3375/043.031.0102

Rodgers JC, Parker KC (2003) Distribution of alien plant species in relation to human disturbance on the Georgia Sea Isles. Divers Distributions 9(5): 385-398. DOI: 10.1046/j.1472-4642.2003.00036.x

Rosenzweig ML (1997) Species diversity in space time.2nd edn, Cambridge University Press, Cambridge.

Saure HI, Vandvik V, Hassel K, Vetaas OR (2012) Effects of invasion by introduced versus native conifers on coastal heath land vegetation. Journal of Vegetation Science 24(4):744-754. DOI: 10.1111/jvs.12010

Sax DF (2002) Native naturalized plant diversity are positively correlated in scrub communities of California Chile. Divers Distributions 8(4): 193-210. DOI: 10.1046/j.1472-4642.2002.00147.x

Sekaar KC (2012) Invasive Alien Plants of Indian Himalayan Region. Diversity and Implication. American Journal of Plant Sciences 3: 177-184. DOI: 10.4236/ajps.2012.32021

Shea K, Chesson P (2002) Community ecology theory as a framework for biological invasions. Trends in Ecology & Evolution 17: 170-176.

Smith MD, Knapp AK (1999) Exotic plant species in a C4-dominated grasslands: invisibility, disturbance community structure. Oecologia120:605-612.

Stern WT (1960) Allium Milula in the central Eastern Himalaya. Bulletin of the British Museum (Natural History) 2: 159-191.

Stevens GC (1992) The elevational gradient in altitudinal range, an extension of Rapoport's latitudinal rule to altitude. The American Naturalist 140: 893-911.DOI: 10.1086/285447

Stohlgren TJ, Otsuki Y, Villa CA, et al. (2001) Patterns of plant invasions: a case example in native species hotspots rare habitats. Biological Invasions 3: 37-50. DOI: 10.1023/A:1011451417418

Tiwari S, Adhikari B, Siwakoti M, Subedi K (2005) An inventory assessment of invasive alien plant species of Nepal, IUCN-The World Conservation Union, Nepal. Viii+ pp. 116.

Vetaas OR, Grytnes, JA. (2002) Distribution of vascular plants species richness and endemic richness along the Himalayan elevation gradient in Nepal. Global Ecology and Biogeography 11: 291-301. DOI: 10.1046/j.1466-822X.2002.00297.x

Weber E (2003) Invasive plant species of the world.A reference guide to environmental weeds. CABI Publishing, Wallingford. pp. 548.

Wiser SK, Allen RB, Clinton PW, PlattKH (1998) Community structure forest invasion byan exotic herb over 23 years. Ecology 79:2071-2081. DOI: 10.1890/0012-9658(1998)079[2071:CSAFIB]2.0.CO;2