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PLANT INVASION: DYNAMICS AND HABITAT INVASION CAPACITY OF INVASIVE SPECIES IN WESTERN INDIAN HIMALAYA

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Abstract – Understanding the factors that intensify the invasion patterns across the geographic ranges is an important challenge in the effort to conserve biodiversity. In the present study we tried to establish a correlation between the exotic invasive richness with different habitat types. To achieve the goal we used Importance value Index for biodiversity assessment and established linear regression alongwith spearman's rank correlation to testify the significant relationship between chosen habitat types and dependent variables, including exotic species richness and cover. Invasive cover from all three habitats was positively correlated with the invasive species number but negatively correlated with the total species richness and the native richness. Invasive species richness, however, was neither correlated with native richness nor the total species richness. In riparian areas a significant positive correlation was observed between invasive species richness and areas away from direct water sources than areas near water sources. Our results highlight that riparian areas despite having high native richness are more prone to plant invasion than forest periphery and highway roadsides. However, areas with increased feral cattle activity alongwith scattered cattle dung from all three habitats were also found promoting plant invasions. Our result from riparian areas thus rebuff the widespread hypothesis (rich biodiversity less invasion) proposing that migration and establishment of invasive species are likely to be based primarily on changes in propagule pressure, availability of nutrients and light and not exclusively on habitat richness.

Keywords: Plant invasion, invasion dynamics, habitat suitability, propagule pressure, local and global adaptation, environmental variability, Importance Value Index, Spearman's rank correlation

Introduction

Invasion of alien flora in native ecosystems is considered as one of the biggest threats to biodiversity and ecosystem services globally (Head & Muir, 2004; Pimental, 2005; de Lange & van Wilgen, 2010; Mandal & Joshi, 2014c). There are many factors which determine and define the invasibility (Richardson et al., 2011) of a plant (Alpert et al., 2000), including, (a) those resulting from the move to a new geographic region and (b) those inherent to the growth characteristics of the species. Additional complexity can be added by, for example, splitting the geographic barrier into two components, by adding a reproductive barrier or/and by splitting the biotic barrier into components, a better geographic distribution of invasive weeds is required to predict the amplitude of its invasion. Many factors are responsible for the plant invasion and also triggers many questions related to plant invasion. One such critical question in the study of plant invasions is what factors determine invasibility of a community. Elton (1958) hypothesized that sites with high species diversity are less invasible than sites with lower species diversity. Some experimental studies have supported this hypothesis (Knops et al., 1999; Dukes, 2002; Kennedy et al., 2002) but others have not (Levine, 2000; Foster et al. 2002). Comparisons across sites typically find positive, rather than negative, correlations between native species richness and invasive species richness (Wiser et al., 1998; Lonsdale, 1999; Stohlgren et al., 1999b, 2003; Brown & Peet, 2003). However, Fridley et al. (2004) determined that native and

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exotic species richness at different scales is similar to a null model which assumes no interactions between native and exotic species. Disturbance is also hypothesized to increase invasibility (Hobbs & Huenneke, 1992) with support from manipulative (Gentle & Duggin, 1997) and comparative studies (Parker et al., 1993; Anderson, 1999; Vujnovic et al., 2002). However, higher disturbance has also been found to be associated with lower invasibility in some manipulative (Smith & Knapp, 1999) and non manipulative studies (Stohlgren et al., 1999a). While the scope of invasion ecology has continued to expand (incorporating, for example, evolutionary factors and enemy release), its fundamental emphasis on early successional and disturbance adapted species has remained unchallenged, leaving important questions about invasions in intact communities particularly forests and riparian areas are largely unaddressed. Are forests effectively immune to invasion, even by exotic plants with late successional life history traits, especially shade tolerance? Are late successional plants essentially non–invasive, suggesting a fundamental trade off between invasive and competitive life history traits? What is the status of riparian areas in preventing plant invasion? Although they are relatively few, some recent studies have begun to address these questions (Gilbert & Lechowicz, 2005; Martin & Marks, 2006; Mandal & Joshi, 2014b) and offer evidence that important subset of different habitat invasives is neither dependent on disturbance nor restricted to early successional life history strategies. Some found that forest understories will be more prone to invasion than forest canopies, as most do not appear saturated in terms of either biomass or species diversity (Gilbert & Lechowicz, 2005). Patterns of forest invasions will potentially be influenced by the species richness of the native community, as theory predicts that species rich communities should be more resistant to invasion (Levine & D'Antonio, 1999). Tropical and subtropical dry forests are increasingly being invaded by alien plant species such as *Lantana camara* L. (henceforth lantana) and *Chromolaena odorata* (henceforth chromolaena), they are most wide spread, ubiquitous invasive species in the world ranging from tropical to subtropical and warm temperate regions of the world and also encroached most of the areas under community and reserve forestlands of western Himalaya (Cronk & Fuller, 1995; Richardson & Rejmánek, 2011; Mandal & Joshi, 2014a). The generally suppressive effect of invasives on a wide range of native species is attested by several studies (Gentle & Duggin, 1998; Day et al., 2003) and a multitude of field observations. Some workers have suggested that riparian and roadsides are favourable areas contributing in exotic plant invasion due to high moisture content and propagule pressure through dispersal of water (Hood & Naiman, 2000; Holmes et al., 2008). This important aspect of how the different habitat types are being invaved by exotic plants is often neglected in India, and even the little amount of work done on invasive plant species in Indian subcontinent has focused mainly on a handful of species, with *Lantana camara*, *Chromolaena odorata*, *Parthenium hysterophorus*, *Mikania micrantha*, *Ipomoea carnea*, *Prosopis juliflora* and *Ageratum conyzoides* being the subject of almost half of these studies without habitat level invasion interaction. Lantana which is the most dominating invasive species in India possiblly introduced here as an ornamental plant brought to the Calcutta Botanical Gardens in 1809 (Thakur et al., 1992; Kannan et al., 2013). By the time lantana was introduced into the old world tropics it had already been in cultivation as a garden ornamental in Europe since the mid to late seventeenth century (Day et al., 2003; Kannan et al., 2013). Plants that were introduced from Europe were thus likely to have been a complex of hybrids, which then hybridised further in their introduced environments (Day et al., 2003). This may be what underlies lantana's wide ecological amplitude both in India and elsewhere (Vardien et al., 2012). It is true that India is suffering from the impacts of invasive alien species and according to a recent report by Khuroo et al. (2012) the alien flora of India accounts for 1599 species, belonging to 842 genera in 161 families and constituting 8.5% of the total vascular flora found in the country. Exact distribution and current location of potentially dominant invasive species are very essential to carry out further research programs, although making detection of such cryptic invaders is complicated as the captured spectral information cannot be directly attributable to these species, thus the prediction of their distribution is difficult. Some workers have suggested potentially successful ecological niche modelling techniques such as Genetic Algorithm for Rule set Prediction (GARP), Maximum Entropy (Maxent), FloraMap, Biomapper and Climex to map the invasion distribution of this weed from western Himalaya (Priyanka & Joshi, 2013) (Fig. 1). After the successful identification of exact location and distribution patterns of invasive species, the next challenge shall be finding the factors responsible for their growth and how they choose their ideal habitat? Some researchers in this regard have suggested that climatic changes are associated with the growth of alien species and decide many physical features of their growth (Zhang et al., 2014). The work of Gooden et al. (2009) showed a strong negative association between invasive species abundance and total species richness of the resident native plant community, validating widespread perceptions that invasion in natural ecosystems is detrimental to species diversity.

Large scale deforestation mostly due to agricultural clearance, urban township construction and widening of highways had almost completely transformed the originally forested landscapes into barren lands in Doon valley, here the intensive cultivation was not confined to fertile lowlands but also occurred in the upland areas, even at the highest areas of

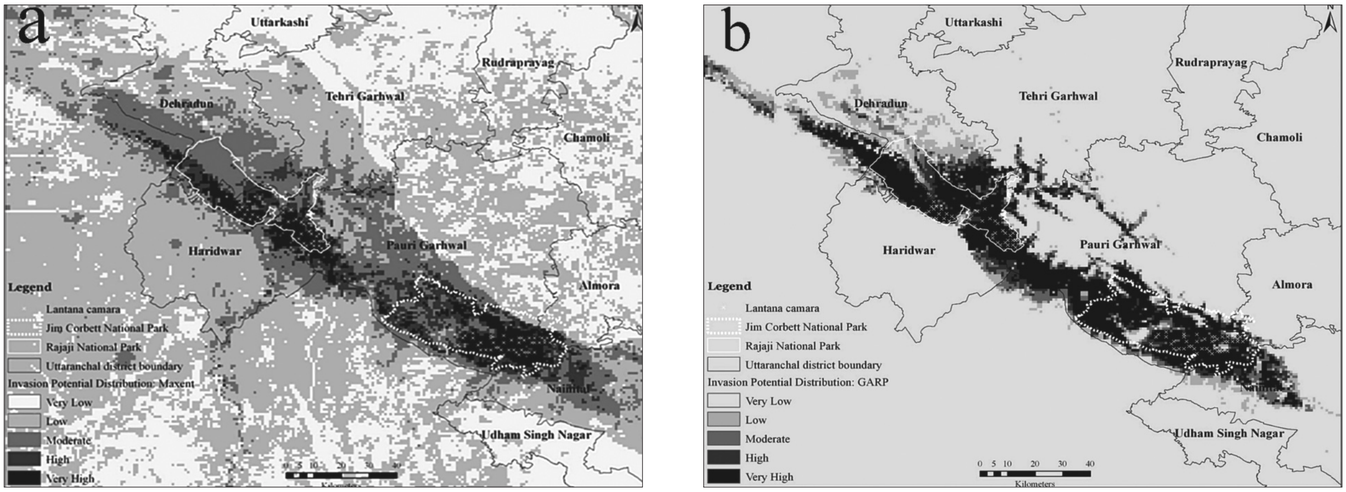

Figure 1. Potential invasion distribution of *Lantana camara* L. from Doon valley (Dehradun), India.

the valley. Forest recovery by natural succession in Doon valley is slow, largely as a result of many factors such as continuous deforestation and anthropogenic forest fires. These fires can either be lit deliberately by rural dwellers for weeding, burning garbage and creating footpaths, or accidentally during traditional worshipping rites by significant visitors. Therefore, in the light of previous evidence and facts from the available literature the present study aim to address the following questions 1. What is the total floristic diversity of Doon valley with emphasis to invasive plants as it was not measured recently? 2. What are the associate plant species (native and alien) frequently growing with each other from three habitat types chosen for this study such as forest periphery, highway roadsides and riparian areas? 3. What are the preferred habitats for the growth of invasive alien species? 4. What is the relationship between the chosen habitat types and the dependent variables, including exotic species richness and cover? To achieve the goal linear regression and Spearman's rank correlation was used for testifying the significant relationship between dependant and independent variables. To facilitate comparison between habitats also to calculate the frequency and abundance of the exotic species in order to find out the preferred habitat for aggressive invaders, we investigated and recorded plant species from all chosen habitats during field surveys and quantified the data on a four point scale according to their relative abundance and Importance Value Index (IVI).

Materials and methods

Description of study sites

The present study was carried out in the Doon valley, also known as Dehradun (part of western Himalaya, India). The Doon valley is surrounded by hills and has a varied range of subtropical deciduous forests mainly dominated by *Shorea robusta*, *Syzygium* spp., *Terminalia* spp., *Ehretia* spp., and *Litsea* spp. It is a saucer shaped valley about 20km wide and 80km long with a geographical area of about 2100km^2 and is lying between $29^0 55'$ and $30^0 30'$ N, $77^0 35'$ and $78^0 24'$ E (Fig. 2). Doon valley falls under the sub tropical to temperate climate due to its variable elevation. The average maxmum temperature of Doon valley was 27.65^0C and the average minimum temperature was 13.8^0C with average maxima in June (40^0C) and average minima in January (1.80^0C). The area receives an average annual rainfall of 2025.43 mm with most of the annual rainfall occurring from June to September. We selected nine study sites and divided them into three habitat types such as forest periphery (Jhajra, Asarori and Thano) Highway roadsides (Dehradun – Shimla highway, Dehradun – New Delhi highway and Dehradun – Nainital highway) and riparian areas (Sahastradhara, Maldevta, Asarori) giving equal distribution of three sites each habitat. Rigorous field surveys were conducted and appropriate quadrates were laid down to collect plant species. In forest peripheries and riparian areas we laid 10 quadrats each of 1m×1m for herbs, 5m×5m for shrubs and 10m×10m for tree species, along roadsides we covered 10 km area of 3 major highways linking 3 major cities of the country and laid 10 quadrats each highway of 100m×5m giving a gap of 1000m. In order to make a better estimation of the percentage cover, each sampling plot was further divided into 10 smaller subplots of size 5m×10m for estimation. The total percentage cover of each sampling plot was obtained by adding up all 10 measurements from each sub plot. In riparian areas, to collect diversified result on invasiveness we created two types of plots (1) plots near water sources (near water plots) and (2) plots 50m > away from the water source (water away plots). We took 1000m^2 areas in forest peripheries and divided after every 10m^2 appropriate intervals to lay down the quadrats. The number and size of quadrat is discussed above.

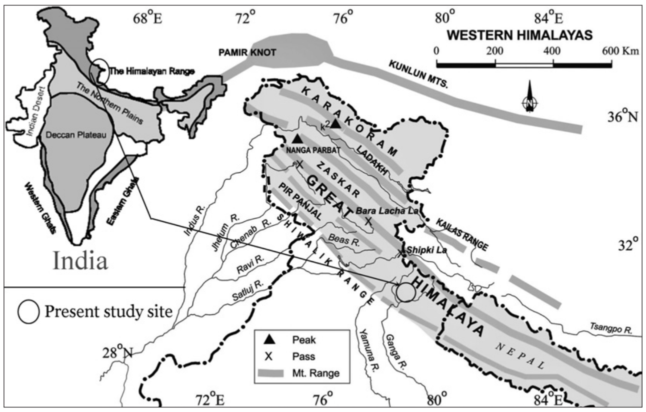

Figure 2. Present study location in western Indian Himalaya.

The dominance of the plant species was determined by the Importance Value Index (IVI) species. Vegetation composition was evaluated by analyzing the frequency, density, abundance and IVI according to Mishra (1968); Curtis & McIntosh (1951) also used by numerous workers for biodiversity assessment (Mandal & Joshi, 2014b; Mandal & Joshi, 2014c; Ram et al., 2013; Moktan & Das, 2013; Singh et al., 2011). The formulae are described as:

$$\text{Frequency} = \frac{\text{Total number of quadrats in which the species occurred}}{\text{Total number of quadrats studied}} \text{x100}$$

$$\text{Relative Frequency (\%)} = \frac{\text{Frequency of a species}}{\text{Frequency of a species}} \text{x100}$$

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

$$\text{Relative Density (\%)} = \frac{\text{Number of individuals of a species}}{\text{Number of individuals of all the species}} \text{x100}$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats in which the species occurred}}$$

$$\text{Relative Dominance (\%)} = \frac{\text{Basal area of a species}}{\text{Basal area of all the species}} \text{x100}$$

Importance Value Index (IVI) = Relative Frequency + Relative Density + Relative Dominance

Basal cover is considered as the portion of ground surface occupied by a species (Greig–Smith, 1964). Basal area measurement was calculated by using following formula:

Total Basal Cover (TBC) = Mean basal area of a species × density of that species

$$\text{Mean Basal Area (MBA)} = \frac{C^2}{4 \times 3.14}$$

Where C = average circumference of one individual of that species and MBA is expressed as cm^{-2} herb^{-1} (Mishra, 1968).

Biodiversity Measurement

Simpson's index (D) is a measure of diversity, which takes into account both species richness, and an evenness of abundance among the species present. In essence it measures the probability that two individuals randomly selected from an area will belong to the same species. The formula for calculating D is presented as:

$$D = \frac{\sum n_i (n_i - 1)}{N(N-1)}$$

Where n_i = the total number of organisms of each individual species.

N = the total number of organisms of all species

Simpson's Index of Diversity (SID)

The formula is: SID = 1–D

The higher the SID, the more diverse your sample will be

Shannon Diversity Index (H′)

$$H' = -\sum_{i=1}^{S} (P_i * \ln P_i)$$

Where:

H = the Shannon diversity index

P_i = fraction of the entire population made up of species

S = numbers of species encountered

∑ = sum from species 1 to species S

The power to which the base e (e = 2.718281828.......) must be raised to obtain a number is called the natural logarithm (*ln*) of the number.

Habitat Diversity

Beta (β) diversity measures the turnover in species composition along transects and is particularly applicable to the study of environmental gradients. It represents differences in species composition between very different areas or environments and the rapidity of change of those habitats. It is calculated by the formula given by Whittaker (1975).

$$\beta_w = \frac{S}{\alpha - 1}$$

Where,

Where S = the total number of species and α = the average species richness of the samples (not the alpha diversity).

Measuring the correlation between variables – Spearman's rank correlation

We wish to measure and test the significance of the correlation between two variables. Observations are correlated when a change in the value of one variable is reflected in a change in the value of the second. Three different habitats are chosen in this study to see the level of invasion in strategically different habitats. Therefore, as an example, we laid quadrats in each habitat dividing the habitat into many parts ranging from 0–100m distance from the main points i.e., in forest periphery, the distance of periphery and intact forest from the roads was measured and given different levels from 0–100 m towards the forest from entrance and quadrats were laid at an interval of 5m, the same was followed for the highway roadsides and the riparian areas. The data calculated was the abundance of associated invasive species of lantana (as this is the dominant invasive species in all habitats) from all three habitats according to the above mentioned categories. The working hypothesis is that majority of invasive species grow in open areas with more light and water availability also other natural resources include inorganic and organic nutrients. Spearman's rank correlation was calculated as:

$$R = 1 - \frac{6S}{n^3 - n}$$

Where n is the number of paired samples, which is 20 in our case, and S is the sum of the squared difference in the ranks.

Regression analysis

For the different habitat surveys, linear regression was used to test for any significant relationship between habitat types and the dependent variables, including exotic species richness and cover. Pearson correlation was used to test for any significant relationship between other independent variables. To facilitate comparison between habitats, the exotic species recorded in different habitats surveys were quantified on a four point scale according to their relative abundance and IVI.

Field Survey

Intensive floristic surveys were conducted covering most of the habitat types between 1500–3200m. Field identification of flowering plants was done with the help of regional floras, research papers and reports (Collett, 1921; Nayar & Sastry, 1990; Rau, 1981; Polunin & Stainton, 1984; Chaudhery & Wadhwa, 1984; Aswal & Mehrotra, 1985). A set of duplicate specimens were collected for less known and doubtful species and preserved at DAV (PG) College, Dehradun Herbaria. All the species were later verified by comparing the specimens housed at the Herbaria of Forest Research Institute, Dehradun and Botanical Survey of India (North circle), Dehradun, India.

Results

Total 341 plant species were recorded from all three habitat types. Out of 341 plant species 72 were trees and belonging to 28 families having maximum contribution from Euphorbiaceae (8) followed by Mimosaceae (6), Moraceae (6) and Caesalpiniaceae (6). We counted 68 Shrub species from all three habitats belonging to 32 families, of which maximum contribution was from Fabaceae (8) followed by Verbenaceae (7), Acanthaceae, Lamiaceae, Rutaceae and Solanaceae were represented by 4 shrubs each. The maximum plant species were recorded as herbs (201) belonging to 45 families, of which, family Poaceae was the dominant being represented by 33 herbs followed by Asteraceae (26), Cyperaceae (20), Lamiaceae (14), Scrophulariaceae (11) and Acanthaceae (10) (Figs. 3a, b, c). The understory of all the habitats was found to be fully occupied by variety of invasive species such as *Alternanthera ficcoides*, *Alternanthera pungens*, *Antigonon leptopus*, *Apium leptophyllum*, *Aristolochia littoralis*, *Bauhinia galpinii*, *Bougainvillea spectabilis*, *Calliandra haematocephala*, *Calotropis procera*, *Cassia obtusifolia*, *Cassia occidentalis*, *Euphorbia cotinifolia*, *Euphorbia prostrata*, *Lantana* *camara*, *Chromolaena odorata*, *Ageratum conyzoides*, *Opuntia stricta*, *Parthenium hysterophorus* and *Ricinus communis*. Along roadsides the population of lantana was prominent and frequently found giving shelter to a parasite invasive plant *Cuscuta reflexa*. However, lantana population and other invasive species were occasionally found in places 50m away from the main roadsides. *Calotropis procera* patches were all over the roadsides along with dense population of *Ageratum conyzoides* and *Parthenium hysterophorus* and even 50m away from the main highway roads.

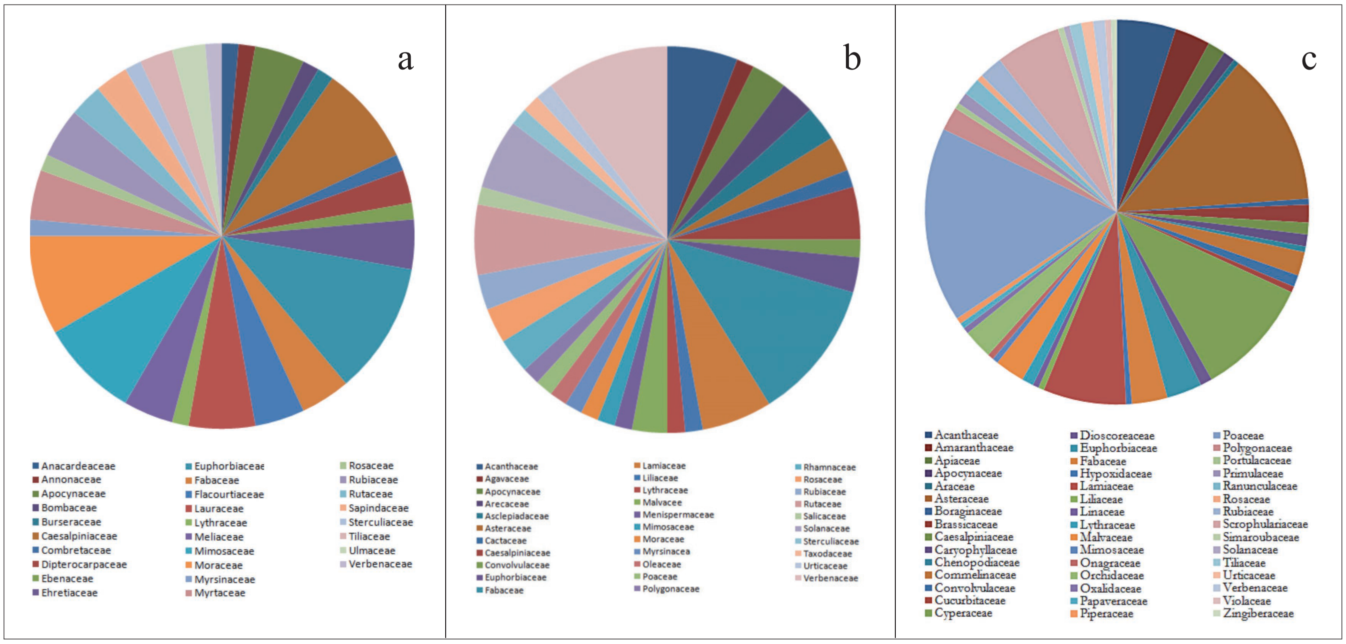

Figure 3. Desrciption of total plant species identified and collected from the study locations (a) Tree species; (b) Shrubs; (c) herbs.

The understorey of forest peripheries were found fully occupied by lantana and other invasive species such as *Cassia occidentalis*, *Cassia obtusifolia*, *Cassia hirsuta*, *Cleome gynandra*, *Mimosa pudica*, *Murraya koenigii* and *Chromolaena odorata*. The forest underground was occasionally occupied by *Ageratum conyzoides* and *Parthenium hysterophorus*. All three forests investigated in this study were of deciduous subtropical type with *Shorea robusta*, *Mallotus philippensis*, *Toona ciliata*, *Acacia catechu*, *Albizia lebbeck*, *Ehretia laevis* and *Dalbergia sissoo* as dominant tree species. The mean vegetation community structure of these forests was 77% foliage cover and mean tree height was of 26.67m. Crown separation ratio was 0.38 and percentage crown cover was 88.7%.

The riparian areas were no better than the other two habitats and were infested by variety of invasive species including lantana, chromolaena, *Opuntia dillenii*, *Cyperus difformis*, *Cyperus iria*, *Datura innoxia*, *Datura metel*, *Echinops echinatus*, *Eichhornia crassipes*, *Leucaena leucocephala*, *Mimosa pigra* and *Argemone mexicana*. In riparian areas the lantana patches and clusters were more common than individual plants, also it was noticed that clusters were not alone and most of them were often found growing with *Opuntia dillenii* and *Parthenium hysterophorus* without any faltering, where native species were finding it difficult to grow with the aggressive colonizer lantana. There were no significant differences in species richness between near water plots and water away plots in the riparian areas ($P > 0.418$) but a significant difference was noticed in the cover of invasive species ($P > 0.005$). Mean evenness was 0.649 in near water plots and 0.792 in water away plots ($F = 5.261$, d.f. = 1, 33, $P = 0.019$). Mean absolute and relative cover in near water areas was < 20%, and there were on average <6 invasive species/near water plots. Mean cover of invasive species in near water plots was 23.5% with a maximum of 48.5% while the mean cover of invasive species range in water away plots was from 55.32% to 87.98%. Plots with relatively high numbers of invasive species had a propensity to occur most frequently at lower elevations, in areas of low to moderate slope, and a high proportion of short shrub species. Most of the located invasions were found in completely exposed areas and a few could be found in partially exposed areas. All the invasions were recorded either in areas recently disturbed by animal trampling or grazing, or in areas with cattle dung. For most of the invasions recorded, no surrounding vegetation was higher than the invading species. Only a few individuals, including lantana, chromolaena, *Opuntia dillenii*, *Cyperus difformis*, *Cassia occidentalis*, *Cassia tora*, *Chamaesyce hirta, Parthenium hysterophorus* and *Corchorus trilocularis* could be found in areas slightly shaded by planted trees nearby. The most abundant invading species were, lantana and chromolaena which were the only species invading both near water and water away plots also cattle-grazed sites, they were even found to invade the farthest from the nearest path (up to 100 m and above).

As per IVI values lantana, chromolaena, *Ageratum conyzoides*, *Parthenium hysterophorus* and *Urena lobata* were common in all three habitats however; chromolaena was abundant in riparian areas but found to be growing more often in the forest periphery at comparatively higher altitudes also occasionally discrete distribution was observed along roadsides en route to high altitudes. This argues that the growth of chromolaena with low IVI value was still restricted to the high altitudes with fewer disturbances; on the other hand lantana and other invasive species were growing in all types of habitat showing extensive amplitude for their growth. The forest peripheries and the riparian areas were also infested by a variety of invasive bamboo species and climbers such as *Bambusa glaucescens*, *Bambusa guadua*, *Bambusa longispiculata*, *Bambusa vulgaris*, *Cephalostachyum pergracile*, *Clerodendrum splendense*, *Clerodendrum ugandense*, *Dendrocalamus membranaceus*, *Pereskia grandiflorus* and *Pereskia aculeata*. Lantana was dominant in all three habitats yet the growth of this shrub underneath or near vicinity of bamboo tree clusters were constrained as no lantana (individual or clusters) was recorded from there. This observation justifies the photophilous (light requiring) nature of lantana and identifies its further growth possibilities only in open forest canopies and exposed areas, also provide new opportunity for the successful management of lantana from the forests by planting more bamboo clusters keeping in mind the economic importance of bamboos. Majority of invasive species counted from these three habitats were found showing flowering and fruiting seasonally i.e., during particular months except few like *Lantana camara*, *Ipomoea carnea*, and *Tribulus lanuginosus* as they did round the year. Of all three habitats the frequency and abundance of invasive species were found high in highway roads and riparian areas, invasive cover in forest periphery was lesser than these two habitats, however, the narrow pavements created in forest peripheries for human and animal movements were found more infested than the intact forest peripheries without pavements and unscathed riparian areas. During our sample collection we surveyed two planted Eucalypt forests along roadsides on Dehradun – Nainital and Dehradun – New Delhi highway. The amplitude of plant invasion in these planted forests were utterly different from the natural forests we had visited previously; only five invasive species were recorded so far from these planted forests such as *Alternanthera tenella*, *Bidens pilosa*, *Blumea eriantha*, *Cassia alata* and *Cassia hirsuta*. We did not observe any presence of lantana, chromolaena, *Parthenium hysterophorus* and *Ageratum conyzoides* from these forests, these results were unexpected as the planted Eucalypt forests were located on one side of highway to which there were fallow lands on the other side and were heavily invaded by these above mentioned invasive species. The mean vegetation community structure of these two Eucalypt forest was 37% foliage cover and mean tree height was of 20.45m. Crown separation ratio was 0.21 and percentage crown cover was 68.7%. The reason for this unexpected result may be due to high competition they were likely to get from Eucalypt trees (another invasive competitor) or may be the non availability of nutrients and depleted hydrological cycle due to Eucalypt invasion as literature suggests, the exact reasons are unknown and need further research.The number of invasive species along roadsides were found to be decreased significantly with altitude (R^2 =0.861, P =0.005) and towards closed canopy dense forest from their peripheries (R^2 =0.892, P =0.005). The invasive species richness was recorded high immediately alongside the highway roads, water away plots in riparian areas and fragmented forest peripheries (R^2 =0.871, P =0.005; R^2 =0.782, P =0.005; R^2 =0.853, P =0.005 respectively). However, there was no significant linear relationship between invasive cover and altitude (R^2 =0.312, P =0.100). The invasive cover from all three habitats was positively correlated with the number of invasive species (r =0.812, P =0.020) but negatively correlated with the total species richness (r = –0.639, P =0.024) and the native richness (r = –0.790, P =0.003). Invasive species richness, however, was neither correlated with native richness (r = –0.483, P =0.219) nor the total species richness (r = –0.211, P =0.642). Roadside construction works on all three highways were reported within the study area during our sampling times, also the roads were bit scrappy at many places with scattered cattle dung alongside roads. However, it is not possible to say if there is any significant correlation between well constructed roads and plant invasion or plant invasion with fragmented roads and cattle dung. Spearman's rank correlation results suggest that there is a negative correlation between the lantana density (as this is more prevalent in the valley) and the distance towards deep forests from peripheries, also from the main highway roads towards the nearby fallow lands (R = –0.533, and R = –0.587 respectively). Contrary to this a significant positive correlation was observed between the lantana density and distance away from the water source in riparian areas (R =0.959) (Fig. 4).

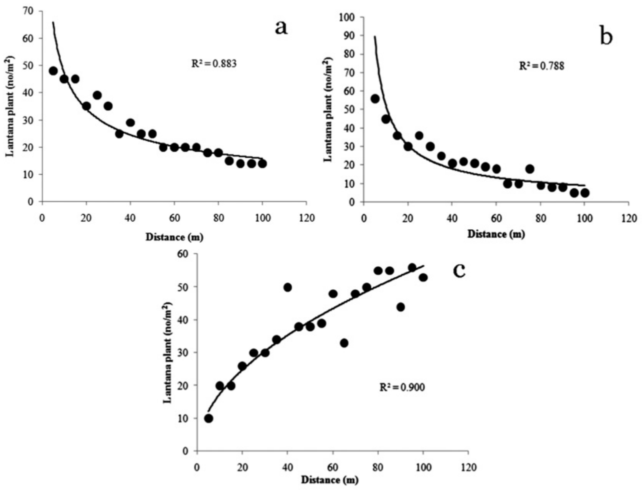

Figure 4. Spearman's rank correlation between *Lantana camara* L. population and distance from main habitat (a) forest periphery, (b) Highway roadsides (c) Riparian areas.

The regression data revealed more continuous and detailed information on the suitable habitat use and in particular the roadside areas used by the aggressive colonizers. Damp areas in the close vicinity of the roads were the preferred habitat of lantana and chromolaena also the grown up plants did use the road as a dispersal corridor. Since lantana was more prevalent in all three habitats we counted the total plant species from the lantana infested area and nearby places where lantana was absent. The results of this study show that plots infested by lantana had lower native plant species richness also wherever they had occurred, the total coverage were very less. The average mean number of plant species observed in the lantana infested plots (avg. 9.5) was significantly lower (P=0.0210) than for non lantana infested plots (avg. 17.9). The angiospermic weed species richness was higher in lantana infested plots (avg. 7.6) than non infested plots (avg. 3.7), and was significantly different (p = 0.005). Lantana infested plots did include a mean value of 7.7 native species per plot while non lantana infested plots contained mean value of 15.8 native plants per plot. However, the lantana infested plots had more no. of invasive species (14.3) than the non lantana infested plots (7.6). Under storey native species diversity was found negatively correlated with coverage of lantana (r^2= –0.463). Total under storey species richness also had a weak negative correlation with lantana cover (r^2= –0.403). However, Total species richness was found very strongly correlated with indigenous plant species richness (r^2 =0.927) also the invasive species richness was positively correlated with lantana cover (r^2 =0.893). The results revealed that the α-diversity (Species Richness) was maximum (55) for forest peripheries, followed by riparian areas (30) and highway roadside (20). Beta Diversity (β) was recorded maximum for riparian areas (1.55) followed by forest peripheries (1.33) and highway roadsides (1.20). The highest Concentration of Dominance (Cd) was recorded for the riparian habitat (0.038) while the lowest was recorded for forest periphery (0.021). Both Shannon diversity index and evenness was highest for forest peripheries (3.831, 0.974 respectively).

Discussion

The vegetation assessments from Doon valley reveal a satisfactory count of both native and non native species. Total 341 species including trees, shrubs and herbs were recorded from all three habitats chosen for this study. During the field survey profuse growth of invasive species in all three habitats was noticed with lantana, chromolaena, *Parthenium hysterophorus*, *Ageratum conyzoides*, *Cassia alata*, *Urena lobata*, *Opuntia stricta*, *Ipomoea carnea*, *Bambusa longispiculata*, and *Bambusa vulgaris* as some of the dominant invasive species. The three strategically studied habitats for this study allowed us to magnify the impact of invasive species on vegetation structure also helped revealing the role of habitat on growth status of some aggressive and noxious weed in the valley. The role of different habitat features in invasion establishment of exotic plants is well documented in previous studies (Fine, 2002; Hill et al., 2005; Alston & Richardson, 2006; Herr et al., 2007). Forest peripheries in our study acted as a corridor for the growth of invasive species and numerous non native species were recorded from these peripheries, some of them with more abundance and coverage is shown in (Table 1). A significantly decreased count of invasive species was recorded from low to high altitude along roadsides and also from the margins of forests towards dense intact forests. Our results also showed a widespread distribution of invasive species alongside well constructed highways, forest margins and the strategically established plots away from water sources in riparian areas.

All three habitats showed positive correlation between the invasive cover and the number of invasive species, but negatively correlated with the total species richness and native species richness. Contrary to the above mentioned results the invasive species richness was found correlated with neither native richness nor the total species richness. Our findings are in line with some of the previous works (Kuussaari et al., 2008; Jauni & Hyvönen, 2010; Jauni et al., 2012) where they used different habitat types, environmental variables and disturbance types to obtain a similar result in different geographic regions of Finland. Roadsides and forest trails are human disturbed corridors constructing

Table 1. Calculation of Importance Value Index [IVI] of associate species from different forest peripheries (Tree species are not counted).

Name of plant species	Family	Growth Pattern	Mean % Cover (C_2)	Freq. (C_4)	Rel. Dom. (C_3) ($C_2/\Sigma C_2$)	Rel. freq. (C_5) [$C_4/\Sigma C_4$]	Importance Value Index (C_6) [C3+C5+C8]	Density	Relative Density C8
Adenostemma lavenia (L.) Kuntze	Asteraceae	Shrub	7.4	100	2.92	4.55	7.64	0.29	0.17
Adhatoda zeylanica L.	Acanthaceae	Shrub	10.1	100	3.99	4.55	8.77	0.4	0.23
Ageratum conyzoides L.	Asteraceae	Herb	22.5	100	8.89	4.55	26.39	22.5	12.95
Calamus tenuis Roxb.	Arecaceae	Shrub	9.7	70	3.83	3.18	7.23	0.39	0.22
Callicarpa macrophylla Vahl.	Verbenaceae	Shrub	13.2	100	5.22	4.55	10.07	0.53	0.30
Clerodendrum viscosum Vent.	Verbenaceae	Shrub	8	80	3.16	3.57	6.91	0.32	0.18
Curculigo orchioides Gaertn.	Hypoxidaceae	Herb	6.3	90	2.49	4.02	10.13	6.3	3.62
Cyperus iria L.	Cyperaceae	Sedge	10.6	100	4.18	4.55	14.83	10.6	6.10
Desmodium parviflorum Baker	Leguminosae	Herb	3.7	80	1.46	3.57	7.16	3.7	2.13
Diplazium esculentum Retz.	Athyriaceae	Fern	10.9	100	4.31	4.55	15.13	10.9	6.27
Eclipta prostrata L.	Asteraceae	Herb	7.6	100	3	4.55	11.92	7.6	4.37
Chromolaena odorata King and Rob.	Asteraceae	Herb	11	100	4.35	4.55	15.11	10.8	6.21
Evolvulus nummularius L.	Convolvulaceae	Herb	8.6	100	3.4	4.55	12.90	8.6	4.95
Floscopa scandens Lour.	Commelinaceae	Herb	7.5	100	2.96	4.55	11.83	7.5	4.32
Kyllinga monocephala Rottb.	Cyperaceae	Sedge	8.6	100	3.4	4.55	12.90	8.6	4.95
Lantana camara L.	Verbenaceae	Shrub	28.4	100	11.23	4.55	16.73	1.656	0.95
Mimosa pudica L.	Fabaceae	Shrub	2.5	50	0.99	2.23	4.66	2.5	1.44
Murraya koenigii (L) Spreng	Rutaceae	Shrub	4.4	70	1.74	3.18	5.02	0.18	0.10
Oplismenus compositus L.	Poaceae	Grass	9.2	100	3.64	4.55	13.48	9.2	5.29
Parthenium hyesterophorus L.	Asteraceae	Herb	41	100	16.21	4.55	44.06	40.5	23.30
Perilla frutescens L.	Lamiaceae	Herb	2.5	60	0.99	2.69	5.12	2.5	1.44
Pollygonum hydropiper L.	Polygonaceae	Herb	6.9	90	2.73	4.02	10.72	6.9	3.97
Sida cordifolia L.	Malvaceae	Herb	6.5	100	2.57	4.55	10.86	6.5	3.74
Urena lobata L.	Malvaceae	Shrub	4.8	100	1.89	4.55	9.20	4.8	2.76
Zizyphus mauritiana Lam.	Rhamnaceae	Shrub	1.1	50	0.43	2.23	2.68	0.04	0.02

disturbances through the pressure of usage and create open spaces to facilitate primary and secondary level of invasion, this effectively fragment natural areas and change forest structure, allows light availability through canopy and increase competitive advantage of invasive species (Yates et al., 2004). Lantana, an opportunistic plant and a noxious invasive species as mentioned earlier had shown a profuse growth in all three habitats. Our results on the basis of Spearman's rank correlation from riparian areas showed a significant positive correlation between invasive species richness (especially lantana) and areas away from the direct water sources (R =0.959). This can be explained by the fact that increased flooding, sedimentation and debris deposition are very common in riparian areas, when they combine with multiple impacts, favour the invaders. Our results were supported by the facts and findings that flooding can restrain the growth of resident vegetation and create canopy gaps that allow photophilous invaders to establish more aggressively (Lindig–Cisneros & Zedler, 2001, 2002a). Concurrently water inflow and sediments add nutrients from sediments, and increase the growth of opportunistic plants (Kercher & Zedler, 2004). Opportunities begin each time natural or human caused disturbances either introduce or free up resources (Davis et al., 2000).

Continuous and detailed information on how invasive species use the suitable habitat was revealed by the regression data, especially the roadside areas used by these aggressive colonizers. We found that damp areas in the close vicinity of the roads were the preferred habitat of lantana and chromolaena, and these grown up plants did use the road as a dispersal corridor. The mean cover of lantana was twice greater in places adjacent to the well constructed highway roads than to nearby paved roads and places away from the roads (Table 2) however, the cover of chromolaena was found twice greater in places away from main highways than in places adjacent to highway roads. The exact reason is unknown why the lantana population was high adjacent to the well constructed roadsides which were majorly used by four wheel vehicles and less from the place away from the roads, but in the light of previously done work we can justify it with the fact that elevated CO_2 favours the exotic invaders to propagate faster and indeed, some research has highlighted several cases in which invasive species were found being favoured by the elevated CO_2 (Moore, 2004). Gelbard and Belnap (2003) also advocated that road improvement significantly affect exotic species cover in both roadside edges and adjacent interior communities also significantly alter native and exotic species richness. Ziska (2003) also found an average stimulation of biomass for six invasive species of 46% in response to a doubling of CO_2.

The alteration of vegetation structure in different habitats and land use system as examined and observed in this study is well supported by the findings of Jackson et al. (2007) and Reynolds et al. (2007) in which they mentioned how changes

Table 2. Calculation of Importance Value Index [IVI] of associate species from highway roadsides (Tree species are not counted).

Name of plant species	Family	Growth Pattern	Mean % Cover (C_2)	Freq. (C_4)	Rel. Dom. (C_3) ($C_2/\Sigma C_2$)	Rel. freq. (C_5) [$C_4/\Sigma C_4$]	Importance Value Index (C_6) [C3+C5+C8]	Density	Relative Density C8
Achyranthes aspera L.	Amaranthaceae	Herb	8.9	100	4.33	5.43	16.95	8.9	7.19
Achyranthes aspera L.	Amaranthaceae	Herb	8.9	100	4.33	5.43	16.95	8.9	7.19
Adhatoda zeylanica L.	Acanthaceae	Shrub	21.5	100	10.46	5.43	16.58	0.86	0.69
Aerva sanguinolenta L.	Amaranthaceae	Herb	1.3	50	0.63	2.72	4.40	1.3	1.05
Ageratum conyzoides L.	Asteraceae	Herb	26	100	12.65	5.43	38.67	25.5	20.59
Alternanthera sessilis (L.) R. Br. ex DC.	Amaranthaceae	Herb	7.4	100	3.6	5.43	15.00	7.4	5.97
Calotropis procera (Aiton) W.T.	Asclepiadaceae	Shrub	1	40	0.49	1.81	2.33	0.04	0.03
Cassia mimosoides L.	Fabaceae	Herb	3.7	100	1.8	5.43	10.22	3.7	2.99
Cassia occidentalis L.	Caesalpiniaceae	Shrub	9	100	4.38	5.43	10.10	0.36	0.29
Cyperus iria L.	Cyperaceae	Sedge	6.3	100	3.06	5.43	13.58	6.3	5.09
Chromolaena odorata King and Robinson	Asteraceae	Herb	1.3	40	0.63	1.81	3.49	1.3	1.05
Ipomoea carnea Jacq.	Convolvulaceae	Shrub	2.5	60	1.22	3.26	4.56	0.1	0.08
Justicia simplex (D. Don)T. Yamaz	Acanthaceae	Herb	0.8	50	0.39	2.72	3.76	0.8	0.65
Lantana camara L.	Verbenaceae	Shrub	29	100	14.11	5.43	21.00	1.81	1.46
Parthenium hysterophorus L.	Asteraceae	Herb	38.4	100	18.69	5.43	55.12	38.4	31.00
Argemone mexicana L.	Papaveraceae	Herb	1.5	40	0.73	1.81	3.75	1.5	1.21
Physalis minima L.	Solanaceae	Herb	1.8	50	0.88	2.72	5.05	1.8	1.45
Polygonum multiflorum Thunb.	Polygonaceae	Shrub	19.2	100	9.34	5.43	15.39	0.77	0.62
Sida acuta Burm. f.	Malvaceae	Herb	7.9	100	3.84	5.43	15.65	7.9	6.38
Sida cordifolia L.	Malvaceae	Herb	5.3	100	2.58	5.43	12.29	5.3	4.28
Solanum hispidum Pers.	Solanaceae	Shrub	2	60	0.97	3.26	4.29	0.08	0.06
Urena lobata L.	Malvaceae	Herb	4.9	100	2.38	5.43	11.77	4.9	3.96
Xanthium indicum J. Koenig ex Roxb.	Asteraceae	Shrub	4.8	100	2.33	5.43	11.64	4.8	3.88
Zizyphus mauritiana Lam.	Rhamnaceae	Shrub	1	50	0.49	2.72	3.24	0.04	0.03

in land use patterns can cause vegetation change and alter ecosystem biogeochemistry thereby affecting ecosystem functioning directly or indirectly. Vegetation assessment through Importance Value Index (IVI) data revealed the distribution and abundance of invasive and native species in the present study and supported by the previous findings (Mandal & Joshi 2014c; Ram et al., 2013; Moktan & Das 2013; Singh et al., 2011). Our results reveal that IVI of *Parthenium hysterophorus* with its coverage was high in both forest periphery and roadsides but in riparian areas the IVI and coverage of lantana and *Ageratum conyzoides* was maximum (Table 3). The successful invasion of *Parthenium hysterophorus* in these habitats suggest that this species possesses an enormous ability to grow and establish faster in almost all types of land use and soils, though less so in lateritic soil. Its seeds germinate throughout the year unaffected by light availability, temperature variations, and topography; these findings are also in agreement with Kohli et al. (2006) where they reviewed the invasion success of *Parthenium hysterophorus* with lantana and concluded moreover the same result. It is clear from the present result that lantana and *Parthenium hysterophorus* growth is not only limited to fallow lands and roadsides but it is also found encroaching the forest margins and intact forests even at high altitudes. A similar finding was observed by Kohli et al. (2004) where they found the high altitudinal hilly tracts being invaded rapidly by these invaders after becoming established in the lower and middle Himalayas.

The riparian sites were more species rich at the 1000 m^2 scale (45.9 ± 1.6) and diverse at the 100 m^2 scale (Simpson's index of alpha diversity 0.80 ± 0.01) than the forest peripheries (species richness 39.0 ± 3.1, P = 0.003 and alpha diversity 0.75 ± 0.02, P = 0.05). The forest peripheries were more species rich at the 1000 m^2 scale (55.6 ± 2.9) than the roadsides (49.0 ± 1.6) (P = 0.16). Even though the riparian areas were more rich and diverse in terms of species than the forest peripheries and highway roadsides, the overall relative abundances of plant species in each habitat was very similar (Simpson's measure of evenness, at the 100 m^2 scale, 0.55 ± 0.03 in the riparian areas, 0.53 ± 0.03 in the forest margins and 0.51 ± 0.04, P = 0.70). Some of the forest margins (Jhajra forest) tended to have a higher degree of invasion intensity (woody alien plants cover of 38.4 ± 3.6% for Jhajra forest periphery compared to 33.4 ± 4.8% of Asarori riparian areas, P = 0.32), possibly due to its position lower in the catchment, near to roads and high level of disturbance, hence a sink for upstream alien plant propagules, but overall alien invasion was found high in riparian areas. A similar result was also obtained by Upadhaya et al. (2006) from Indian context in which they suggested that disturbance enhances species richness and was well supported by the findings of Banda et al. (2006) from the forests of Tanzania. In other studies the species richness was found declined significantly with increasing lantana cover,

Table 3. Calculation of Importance Value Index [IVI] of associate species from riparian areas (Tree species are not counted).

Name of plant species	Family	Growth Pattern	Mean % Cover (C_2)	Freq. (C_4)	Rel. Dom. (C_3) ($C_2/\Sigma C_2$)	Rel. freq. (C_5) [$C_4/\Sigma C_4$]	Importance Value Index (C_6) [C3+C5+C8]	Density	Relative Density C8
Achyranthes aspera L.	Amaranthaceae	Herb	7.5	100	4.47	4.88	18.59	7.5	9.24
Adhatoda zeylanica L.	Acanthaceae	Shrub	16	100	9.53	4.88	15.20	0.64	0.79
Aerva sanguinolenta L.	Amaranthaceae	Herb	1.1	50	0.66	2.44	4.46	1.1	1.36
Ageratum conyzoides L.	Asteraceae	Herb	10.8	100	6.43	4.88	24.62	10.8	13.31
Alternanthera sessilis (L.) R. Br. DC.	Amaranthaceae	Herb	5.6	100	3.33	4.88	15.11	5.6	6.90
Cassia mimosoides L.	Fabaceae	Herb	5.4	100	3.22	4.88	14.75	5.4	6.65
Cassia occidentalis L.	Caesalpiniaceae	Shrub	9.6	100	5.72	4.88	11.07	0.38	0.47
Cyperus iria L.	Cyperaceae	Sedge	6.2	100	3.69	4.88	16.21	6.2	7.64
Chromolaena odorata King and Robin.	Asteraceae	Herb	10.4	100	6.19	4.88	23.89	10.4	12.82
Justicia simplex (D. Don) T. Y.	Acanthaceae	Herb	7.6	100	4.53	4.88	18.78	7.6	9.37
Lantana camara L.	Verbenaceae	Shrub	21.2	100	12.63	4.88	19.56	1.66	2.05
Murraya koinigii (L.) Spreng	Rutaceae	Shrub	11.1	100	6.61	4.88	12.03	0.44	0.54
Opuntia dillenii (Ker Gawl.) Haw.	Cactaceae	Shrub	17.8	100	10.6	4.88	16.35	0.71	0.87
Parthenium hysterophorus L.	Asteraceae	Herb	10.8	100	6.43	4.88	24.62	10.8	13.31
Phylanthus emblica L.	Euphorbiaceae	Shrub	0.4	30	0.24	1.46	1.72	0.02	0.02
Physalis minima L.	Solanaceae	Herb	1.4	70	0.83	3.41	5.97	1.4	1.73
Sida acuta Burm. f.	Malvaceae	Herb	3	100	1.79	4.88	10.37	3	3.70
Sida cordifolia L.	Malvaceae	Herb	3.3	100	1.97	4.88	10.92	3.3	4.07
Solanum nigrum	Solanaceae	Herb	2.2	80	1.31	3.9	7.92	2.2	2.71
Woodfordia fruticosa (L.) Kurtz.	Lythraceae	Shrub	0.8	40	0.48	1.95	2.47	0.03	0.04
Urena lobata L.	Malvaceae	Herb	1.4	60	0.83	2.93	5.49	1.4	1.73
Urtica dioica L.	Urticaceae	Shrub	8	80	4.67	3.9	8.96	0.32	0.39
Xanthium indicum J. Koenig ex Roxb.	Asteraceae	Shrub	5.8	100	3.45	4.88	8.61	0.23	0.28
Zizyphus jujuba Lam.	Rhamnaceae	Shrub	0.5	40	0.3	1.95	2.27	0.02	0.02

indicating that the threat of lantana is pervasive across all life forms in the recipient community also the impact of such studies have focussed on altered ecosystem functions, such as nutrient cycling and vegetation structure (Lamb, 1988; Bhatt et al., 1994; Islam et al., 2001; Ehrenfeld, 2003; Mandal & Joshi, 2014d).

For the present study it was hypothesized that higher plant species richness and/or diversity should enhance community resistance to alien plant invasions, in all three habitats. From the forest peripheries we found a negative correlation between the native and alien species richness, thus indicating that plant community in forest periphery regions may have been more resistant to the invasion of alien plants than the other two regions. Therefore, the hypothesis was not rejected for the forest periphery regions. On the other hand, in the riparian and roadside regions, there were positive correlations between the native and alien species richness, thus indicating that these plant communities may not have been as resistant to the invasion of alien plants. Therefore, the hypothesis was rejected for both the riparian and roadside regions. Upon considering the habitat ranges, the hypothesis at first glance was not rejected but the increase in total species richness with increasing invasion intensity in the riparian areas (which was more diverse than the forest periphery) indicated that it could have been more resistant to the invasion of alien plants than the forest periphery, but due to high propagule pressure and immense possibilities of nutrients they failed to resist against invasion. There is no second opinion that overstorey cover is the most important environmental feature influencing alien plant invasion in tropical forests, by increasing its richness with the decrease in overstorey cover. Gaps in the overstorey increase light availability, and allow shade intolerant alien plants to grow better. Despite the fact that light is an essential requirement for the growth of invasive plants like lantana and other shade intolerant alien species, we cannot neglect the fact that more nutrients are liberated in riparian areas due to sedimentation, and more CO_2 is released along roadsides, which favour dynamic growth of alien species in these two habitats. However, it is difficult to say whether the invasive species increase the soil nutrient or grow preferentially where soil composition is ideal. High alien species richness in riparian areas and highway roadsides than the forest peripheries are in line with the previous findings, where nutrient and water enriched sites received maximum exotic species than non nutrient enriched sites with an exotic coverage of 81.9% compared with 18.9% for native species (Lake & Leishman, 2004). We can't overlook the role of canopy gaps in alien plant richness and distribution apart from nutrient availability as it is well supported by several studies (Brothers & Spingarn, 1992; Parendes & Jones, 2000). Some studies have even shown that patterns of negative and positive correlations do not differ from predicted neutral models of no species interactions and that the relationship between exotic and native species richness depends on the area and/or number of individuals' sampled (Fridley et al., 2004; Herben et al., 2004).

Although the hypothesis which says that species richness makes communities more resistant to the establishment of exotic species, opposite to it sometimes diverse communities can also be invaded if the propagule pressure is high and nutrient availability is immense as revealed by the results of this study and supported by the results of Levine and D'Antonio (1999). Light availability though is still limiting the establishment of exotic plant species at least in the uplands, as almost all the located invasions from three habitats are confined to areas with complete exposure to sunlight. According to an interesting finding of this study we observed that all the invasions were recorded in areas with evidence of cattle activities, including heavily trampled vegetation and disturbed soil (exposure of bare soil) with cattle dung nearby, suggesting that cattle in their natural habitat in the uplands may facilitate invasions by creating disturbances such as clearing dense vegetation to allow exposure to sunlight and enriching soil with nutrients (by both cattle dung and re-exposing unused nutrients from soil). The overall results of this study suggest that several exotic plant species are able to establish themseves in the open areas of all three habitats including some upland areas away from roads and streams. Their abundance and ability to grow in any habitat can cause many observable impacts to the native species by reducing their richness. Some invasions in these habitats are found in areas heavily grazed by cattle, suggesting that habitats that are seldom or never grazed by cattle could still be free from exotic plant invasions if we effectively manage the feral cattle, on the other hand invasions in riparian areas by exotic plants despite having rich native species diversity would be a serious problem in near future requiring immediate and planned concern from policy makers and local authorities for effective managements.

CONCLUSIONS

Western Himalaya is severely affected by alien invasions, resulting in the transformation of large areas, as well as many negative impacts on the economy, in sectors such as health, agriculture, water supply and tourism (Negi & Hajra, 2007), also one of the biggest threats of alien plant invasions is to biodiversity (Randall, 1996). In the present study we basically worked on two hypotheses. These hypotheses stated that: 1) Higher plant species richness and/or diversity should enhance community resistance to alien plant invasions, in different habitats. 2) The lower the degree of alien plant invasion, the higher the understorey vegetation cover, which may result in reduced cover of exposed soil and litter, in all three habitats (Forest margins, riparian, roadsides). Following are the conclusion of the present study:

1. The result highlighted that the roadsides (only alien) and riparian plots were more species rich (Total and aliens) than the forest margins. Thus, roads and riparian areas could be additional contributing factor to the spread of alien plants and also needs to be taken into account in Doon valley clearing operations.

2. The invasion intensity was high in riparian areas justifying that only canopy gaps are not responsible for the invasions but availability of nutrients, moist soil, environmental gradients and high propagule pressure are also equally important and responsible in alien plant invasion. Therefore, a proper management of environmental gradients and propagule pressure is immediately required from the side of government and local authority, for which they should take appropriate measures so that riparian areas can be protected from invasion.

3. With increasing invasion intensity from roadsides and riparian areas, the cover of smaller growth forms (herbs) were found to be decreased due to the taller growing alien woody plants such as lantana, *Calotropis procera*, *Cassia obtusifolia*, shading out the herbaceous native vegetation but promoting the growth of invasive herbs. This is a serious threat to the valley's vegetation richness and surely needs immediate concern from the local authority.

4. A number of bamboo species were counted from forest peripheries such as *Bambusa glaucescens*, *Bambusa guadua*, *Bambusa longispiculata*, *Bambusa vulgaris*, surprisingly no lantana plant was recorded underneath these bamboo clusters or its near vicinity, this could be one of the reason that lantana and other shade intolerant alien species richness was less from forest peripheries. This is a great opportunity for the local authority to grow more bamboo clusters in riparian areas and highway roadsides so as to prevent the overgrowth of lantana and other aggressive invaders and manage the plant invasion.

5. The result also highlighted that exposed areas with light availability is still the suitable habitat for most exotic plant invasion but areas disturbed by cattle (domestic and feral) activities and having cattle dung around promoted plant invasion however, activities of undomesticated cattle are not limited only to open grasslands and shrublands as they can reach to high upland areas as well. The authorities can help eliminating these feral cattle with a proper management from the upland areas to prevent plant invasion.

6. All three habitats were found being occupied by many invasive species having potentials to dominate the local plant communities (i.e., that have the greatest invasion intensities) such as *Alternanthera ficcoides*, *Alternanthera pungens*, *Antigonon leptopus*, *Apium leptophyllum*, *Aristolochia littoralis*, *Bauhinia galpinii*, *Bougainvillea spectabilis*, *Calliandra haematocephala*, *Calotropis procera*, *Cassia obtusifolia*, *Cassia occidentalis*, *Euphorbia cotinifolia*, *Euphorbia prostrate* Some aggressive invaders like *Lantana camara*, *Chromolaena odorata*, *Ageratum conyzoides*, *Opuntia stricta* and *Parthenium hysterophorus* were found not being influenced by any of the environmental variables, and thus occurred in most of the plots. Therefore, these species are predicted to have highest invasion intensities in the entire Doon valley as they are not specific to a particular habitat.

The rapid multiplication capability and the wide range of adaptation of aliens are discernible, through their status of spatial distribution in the Doon valley and other parts of the Indian subcontinent is not fully revealed. The important ecosystem drivers or keystone species that facilitate recovery of forest, roadsides and riparian vegetations need to be identified. Future studies need to continue in order to determine even longer term effects of the invasion and subsequent clearing of alien plants from riparian and forest margins also during road construction appropriate measures need to be taken such as decreasing the soil depth of roadside edge, using crude and infertile soil for road filling so as to create a poor seedbed for exotic species, by preventing delebrate planting of roadside exotic species as roadside plantings of exotic species can increased the chances of invasions in adjacent habitats also by re–establishing native vegetation along roads after construction.

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