Do alien plant invasions cause biotic homogenization of terrestrial ecosystems in the Kashmir Valley, India?

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Abstract: Habitat characteristics and the species attributes that determine the rate of spread of alien plant species are likely to be pivotal in determining the extent of homogenization, particularly at regional level. In order to determine which habitats are more likely to be homogenized and which groups of alien plant species promote homogenization, we sampled seven sites of each of the three habitats namely forests, grasslands, and roadsides for presence-absence of plant species. We calculated a Jaccard similarity index separately for native, alien, and native + alien species. We used the average of Jaccard dissimilarity index (1- Jaccard index) of all paired localities as a measure of the mean overall beta diversity and mean beta diversity of alien and native species for each set of localities examined in an analysis. We used a homogenization index to quantify the homogenization or differentiation effect. For habitats, we found that biotic homogenization followed the order: roadsides > grasslands > forests. The various categories of plants varied in bringing about homogenization and the following order in respect of homogenization was recorded: invasive > naturalized > casual; perennial > annual/biennial; herbs > shrubs/subshrubs/lianas > trees. Beta diversity, based on alien species, was lower for roadsides; invasive, perennial and herbaceous alien plants, than their counterparts (i.e. grasslands, forests; casual, naturalized; annual/biennial and shrubs/sub-shrubs/lianas and trees alien plants, respectively). Our study clearly shows that extent of biotic homogenization depends upon habitat type, and alien plant species differ in their homogenization potential depending upon stage of invasion of alien species, life span and growth form. These observations assume significance in conservation biology to predict the impact of alien plant species on ecosystems.

Resumen: Las características del hábitat y los atributos de las especies que determinan la velocidad de propagación de las especies de plantas exóticas probablemente sonfundamentales en la determinación del grado de homogeneización, especialmente a nivel regional. Para determinar cuáles hábitats son más propensos a la homogeneización y qué grupos de especies de plantas exóticas promueven la homogeneización, muestreamos siete sitios de cada uno de tres hábitats (bosques, pastizales y bordes de camino)para determinar la presencia-ausencia de las especies de plantas. Calculamosun índice de similitud de Jaccard por separado para las especies nativas, las exóticas y el conjunto de nativas + exóticas. Utilizamos el índice promedio de disimilitud de Jaccard (1 - índice de Jaccard) de todas las localidades pareadas como una medida de la diversidad beta global promedio y de la diversidad beta promedio de las especies exóticas y nativas para cada conjunto de localidades examinadas en el análisis. Utilizamos un índice de homogeneización para cuantificar el efecto de homogeneización o diferenciación. Para los hábitats, encontramos que la homogeneización biótica siguió el siguiente orden: bordes de caminos > pastizales > bosques. Las diversas categorías de plantas variaron en lageneración de homogeneización, habiéndose registrado el siguiente orden con respecto a la homogeneización: invasoras > naturalizadas > ocasionales; perennes > anuales/bienales; hierbas > arbustos/subarbustos / lianas > árboles. La diversidad beta, con baseen las especies exóticas, fue

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menor en los bordes de caminosy para las plantas exóticas invasoras, perennes y herbáceas, que para sus contrapartes (es decir, pastizales, bosques; plantas exóticas casuales, naturalizadas; anuales/bienales y arbustos / subarbustos / lianas y árboles, respectivamente). Nuestro estudio muestra claramente que la magnitud de la homogeneización biótica depende del tipo de hábitat y que las especies de plantas exóticas difieren en su potencial de homogeneización en función de la etapa de la invasión, longevidad y forma de crecimiento. Estas observaciones adquieren un fuerte significado en la biología de la conservación en relación conla prediccióndel impacto de las especies de plantas exóticas en los ecosistemas.

Resumo: As características do habitat e os atributos de espécies que determinam a taxa de propagação de espécies de plantas exóticas são susceptíveis de ser fundamentais na determinação do grau de homogeneização, sobretudo a nível regional. A fim de determinar quais os habitats que são mais propensos a ser homogeneizados, e que grupos de espécies de plantas exóticas promovem a homogeneização, foram amostrados sete locais de cada um dos três habitats ou seja, florestas, pastagens e estradas para determinas a presença-ausência de espécies de plantas. Calculámos um índice de similaridade de Jaccard, separadamente para espécies nativas, exóticas e nativas + exóticas. Usou-se a média de índice de dissimilaridade de Jaccard (1 - índice de Jaccard) de todas as localidades emparelhados como uma medida da média global da beta diversidade e da média da beta diversidade de espécies exóticas e nativas para cada conjunto de localidades examinadas na análise. Utilizou-se um índice de homogeneização para quantificar o efeito de homogeneização ou de diferenciação. Para habitats, descobrimos que a homogeneização biótica seguiu a ordem seguinte: margens de estradas > pastagem > florestas. As diversas categorias de plantas variaram em concretizar a homogeneização e nesse aspeto registou-se a ordem seguinte em relação à homogeneização: invasivo > naturalizada > ocasional; perenes > anuais / bienais; ervas > arbustos / subarbustos / lianas > árvores. A diversidade beta, baseada em espécies exóticas, foi menor para estradas; plantas exóticas invasoras, perenes e herbáceas, do que os seus homólogos (ou seja, pastagens, florestas, casuais, naturalizadas; anuais / bienais e arbustos / subarbustos / lianas e árvores plantas exóticas, respectivamente). O nosso estudo mostra claramente que a extensão da homogeneização biótica depende tipo de habitat e as espécies de plantas exóticas diferem quanto ao seu potencial homogeneização dependendo do estádio de invasão de espécies exóticas, tempo de vida e forma de crescimento. Estas observações assumem importância na biologia da conservação para prever o impacto de espécies de plantas exóticas nos ecossistemas.

Introduction

Biotic homogenization is an important component of current global change and it results from the replacement of native species with alien species (Mckinney & Lockwood 1999). It has three components: taxonomic, functional and genetic homogenization (Olden *et al.* 2004). Although human mediated introduction of alien species increases species richness at regional level (i.e. α diversity increases) but this increase is typically at the expense of beta (ß) diversity (Whittaker 1972). Biotic homogenization is considered to be a complex process that encompasses aspects of invasion, extirpation and environmental modification.

Decrease in beta diversity is often considered to be synonymous with increase in the compositional similarity among communities (Olden & Rooney 2006; Whittaker 1972). Although alien and native species differ in increasing similarity among habitats but not many studies have been conducted at local scales (Lambdon *et al.* 2008). Beta diversity is most often quantified with similarity or dissimilarity metrics (Jurasinski *et al.* 2009) and among the many available metrics (Koleff *et al.* 2003; Wolda 1981). Jaccard's index has been the most frequently used in studies on biotic homogenization (Olden & Rooney 2006).

Several factors, such as dispersal abilities, residence time, life history traits and environ-
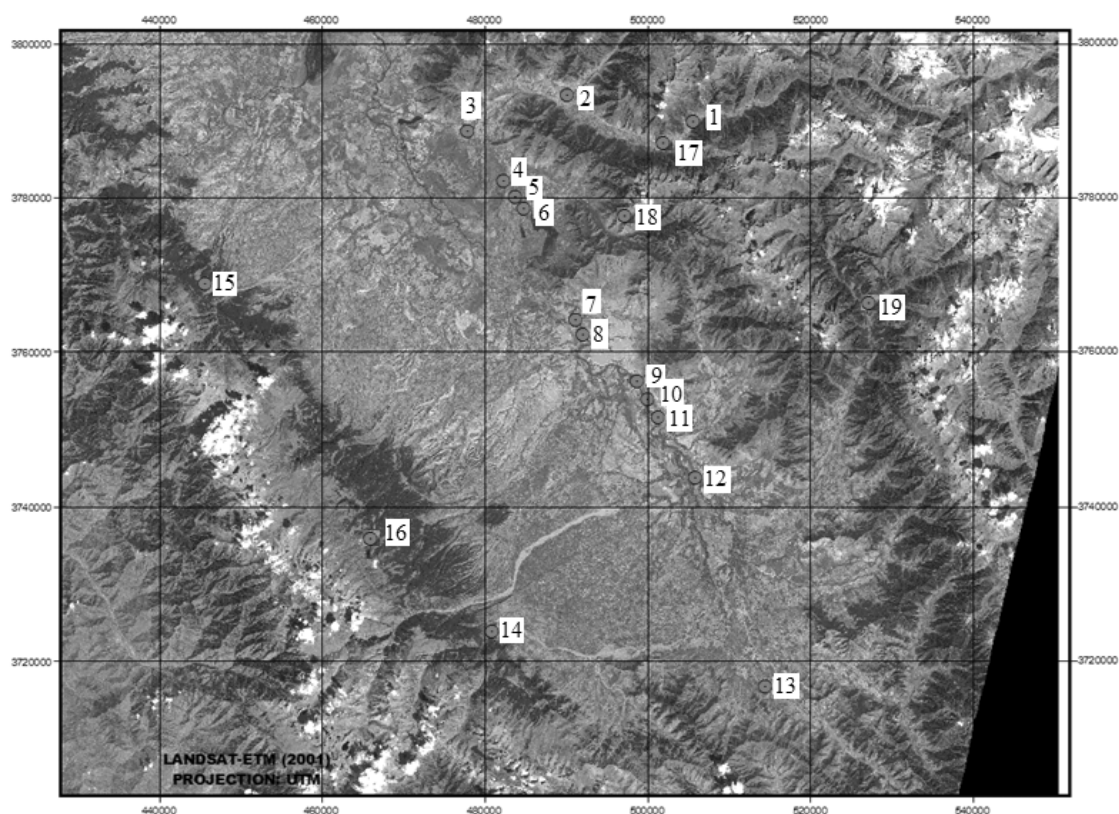
[1- Mammer, 2- Kangan, 3- Ganderbal, 4- Daren Nagbal, 5- Gulabbagh, 6- Zakoora, 7-
Pampore, 8- Galendar, 9- Lethpoora, 10 Barsoo, 11- Awantipoora, 12- Sangam, 13-
Qazigund, 14- Ahrbal, 15- Gulmarg, 16-Nilnag, 17-Prang, 18-Dachigam, 19-Pahalgam]

Fig. 1. Location of study sites.

mental tolerances of the introduced species, the environmental and biological attributes of the recipient communities, etc. are known to influence biotic homogenization (Blackburn & Duncan 2001; Kennard *et al.* 2005; Leprieur *et al.* 2008; Moyle & Marchetti 2006). Not withstanding the knowledge of the factors that influence biotic homogenization, nearly no detailed studies relating biotic homogenization to species traits and habitat characteristics have been carried out. Although, Qian & Guo (2010) recently have made an attempt to link biotic homogenization to habitat type, invasiveness, life cycle and growth form at continental scale, so far not many such studies have been carried out, particularly at local scale. In addition, the habitat type is considered to be an important predictor of extent of invasion (Chytrý *et al.* 2008a; 2008b) and different groups of alien plant species with different traits have been found to differ in their invasion potential (Cox 2004; Rejmánek & Richardson 1996). We hypothesize that disturbed habitats (roadsides in the present study), with high incidence of alien species due to high levels of anthropogenic disturbances, should be more homogenized than relatively less disturbed habitats, and alien species with desirable traits such as herbaceous growth form, perennial life span should promote homogenization greater than their counterparts (woody and perennial species, respectively). Thus present study is an attempt to evaluate (i) how is species turn-over (ß-diversity) influenced by alien plant invasions? (ii) which habitats are more likely to be homogenized and (iii) which groups of alien plant species promote homogenization?

Materials and methods

Area of study

The present study was carried out in the Kashmir Valley which is known worldwide for its

rich floristic and faunistic diversity. The region which lies between geographical coordinates of 32º 20´ to 34º 50´ North latitude and 73º 55´ to 75º35´ East longitude (Hussain 2002) is nestled in North-western Himalayan biodiversity hot spot. Alien flora of the region is comprised of 571 plant species, belonging to 352 genera in 104 families (Khuroo *et al.* 2007). The present investigation was restricted to the terrestrial communities, such as grasslands, forests and roadside habitats. In each of the habitats, seven study sites of the size of 100 x 100 m were identified and selected for sampling at 19 different locations (Fig. 1), and study sites of each habitat were selected atleast 2 kms from each other. In order to keep the disturbance levels relatively constant, all study sites (even forest sites) were selected close to the roadside or human settlements. Each study site was sampled thrice (representing three different seasons) during the year 2009 to compile a conspectus of the plant species growing in these habitats. This was done so as to collect flowering specimens of all the species as different species flower during different seasons. The plant specimens collected from various study sites were then identified using identified specimens of Kashmir University Herbarium.

Terminology used

The plant species collected from various study sites were categorized into native and alien species. Native geographical range of the plant species was obtained from all available sources, such as Khuroo *et al.* (2007), the specialized internet web pages (www.efloras.org; Germplasm Resources Information Network) and the recently published similar studies (Arianoutsou *et al.* 2010 a,b). The alien plant species were categorized into casual, naturalized and invasive species following Richardson *et al.* (2000) and Pyšek *et al.* (2004). With regard to habit, the species were classified into trees, shrubs, sub-shrubs, lianas, climbers and herbs. On the basis of life span, the species were classified into annuals, biennials and perennials.

Computation of biotic homogenization

For computation of biotic homogenization, each of the 21 study sites was compared with each of the remaining study sites, which resulted in a total of 210 site pairs {calculated as n (n-1)/2; Smart *et al.* (2006)}. For evaluation of floristic similarity, site-by-site matrices of similarity were constructed using Jaccard's index (J) which is a widely used

index in homogenization studies (Olden 2006). It computes binary values with the following algorithm:

$$J = \frac{a}{(a + b + c)}$$

where, J ranges from 0 to 1, a is the number of species shared between two sites and b and c are the numbers of species unique to either site (Legendre & Legendre 1998).

For each site pair, a Jaccard's similarity index (J) was calculated separately for native (J_{native}), for alien (J_{alien}), and for native plus alien (J_{total}) species. This was done to evaluate the differences in the extent of homogenization of the habitats and homogenization potential of alien species differing in stage of invasion (in which comparison between casual, naturalized, invasive species was made), life span (in which comparison between annual/ biennial and perennial species was made) and habit (in which comparison between herb, shrub/ sub-shrub / liana, tree species was made).

Since decrease in beta (ß) diversity is consi-dered to be an important measure of biotic homo-genization, and that decrease in ß diversity could be due to either native or alien species and/or combination of native and alien species, three types of ß diversity measures were calculated using Jaccard's dissimilarity index (1- Jaccard's index) (Lososova *et al.* 2012). This was done to evaluate the contribution of alien plant species in the decrease of ß diversity between any site pair. Average of Jaccard dissimilarity index (1 - J_{total} in case of overall ß diversity, 1 - J_{native} in case of ß diversity for native species and 1 - J_{alien} in case of ß diversity for alien species) of all paired sites was used as a measure of the mean overall beta diversity ($ß_O$), mean beta diversity of native species ($ß_N$) and mean beta diversity of alien species ($ß_A$) for each set of localities examined in an analysis. Site-by-site matrices were also constructed for ß diversity measures.

Homogenization index (H), which is J_{total}- J_{native} (Rahel 2000; Qian & Guo 2010), calculated for each of the four categories (i.e. habitat, stage of invasion, life span and habit) was subsequently used to quantify the effect of homogenization or differen-tiation. A positive H indicates a homogenization effect, whereas a negative H indicates a differen-tiation effect. H-values were divided into seven classes (Class I, H -0.2; Class II, -0.2 H < -0.1; Class III, -0.1 H < 0; Class IV, 0 H < 0.1; Class V, 0.1 H < 0.2; Class VI, 0.2 H < 0.3; Class VII; H 0.3) (Qian & Guo 2010) and the frequency distribution of values of homogenization indices in each of the

Table 1. Number of native and alien plant species recorded at different study sites.

Habitat	Site	Total number of species	Number of native species	Number of alien species
Roadsides	Zakoora (ZKR)	71	12	59
	Gulabbagh (GUR)	60	12	48
	Nagbal (NGR)	65	12	53
	Ganderbal (GDR)	64	21	43
	Lethpoora (LER)	62	13	49
	Sangam (SGR)	89	16	73
	Qazigund (QZR)	61	13	48
Grasslands	Pampore (PPG)	51	17	34
	Barsoo (BRG)	46	07	39
	Daren (NGG)	60	10	50
	Ganderbal (GDG)	70	23	47
	Kangan (KGG)	63	19	44
	Galendar (GAG)	79	17	62
	Awantipoora (AWG)	67	14	53
Forests	Ahrbal (AHF)	76	43	33
	Gulmarg (GUF)	66	40	26
	Mammar (MMF)	67	33	34
	Dachigam (DGF)	87	43	44
	Pahalgam (PHF)	47	20	27
	Prang (PGF)	61	28	33
	Nilnag (NGF)	44	18	26

seven H-classes were compared to discriminate homogenization and differentiation effects of different groups of species (Qian & Guo 2010). Since the value of H is negative in the first three classes (Class I, II and III), any observation in these classes indicates differentiation while that of the last four classes (Class IV, V, and VI) indicates homogenization. Besides this, high frequency of H in higher H classes indicates a higher degree of homogenization as H approaches 1 in higher H classes (Qian & Guo 2010).

We calculated confidence interval for mean values of β_O, β_A, β_N and then tested the significance of mean values using Howell's resampling programme. The significance of these mean values was tested by one way ANOVA at 5 % (0.05) probability. This one way ANOVA was done using Howell's resampling programme. First of all, the metric used to measure differences is the traditional F. While the program computed 1000 Fs, it also measured how many exceeded the obtained value of F (as given by Percent = > Fobt (P) in table 3) and if it turned out that only < 5 % (i.e., $P < 0.005$) of them possessed higher value, we rejected null hypothesis and concluded that there are significant differences between values. This

programme also computes effect size using following formula :

$$d = \sqrt{\frac{\Sigma\left(\mu_j - \mu\right)^2 / k}{\sigma_e^2}}$$

where the error term is simply MS_error from the traditional analysis of variance.

The purpose of providing effect size (d) is to give an index of how different the group means are. It is becoming much more common to publish effect size values, and the APA style manual encourages it. To discriminate the three habitats in terms of species composition, we also analyzed the species scores of the sites for the DCA using PC ORD-6. We analyzed the data in three different ways, firstly with all the species present, secondly with only native species and thirdly with only alien species.

Results

Species composition

A total of 339 species were recorded out of which 183 were alien and 156 were native (The complete list of species is available with the

Table 2. Confidence interval (95 %) for mean values of β_O, β_A, β_N (1000 resample replications).

Category	Sub-category	β_O				β_A				β_N			
		Mean	Lower CI	Upper CI	S.E	Mean	Lower CI	Upper CI	S.E	Mean	Lower CI	Upper CI	S.E
Habitat	Grasslands	0.742	0.714	0.771	0.013	0.721	0.690	0.755	0.016	0.788	0.745	0.825	0.019
	Forests	0.749	0.724	0.774	0.012	0.742	0.688	0.778	0.021	0.806	0.777	0.832	0.012
	Roadsides	0.649	0.617	0.676	0.014	0.624	0.589	0.653	0.015	0.755	0.721	0.788	0.016
Stage of invasion	Casual	0.955	0.929	0.974	0.011	-	-	-	-	-	-	-	-
	Naturalized	0.792	0.781	0.804	0.006	-	-	-	-	-	-	-	-
	Invasive	0.599	0.583	0.615	0.008	-	-	-	-	-	-	-	-
Life span	Annual/ Biennial	0.751	0.735	0.767	0.008	0.730	0.716	0.745	0.007	0.809	0.790	0.824	0.008
	Perennial	0.715	0.702	0.728	0.007	0.660	0.646	0.673	0.007	0.833	0.817	0.848	0.008
Growth form	Herbs	0.726	0.715	0.737	0.005	0.692	0.679	0.703	0.006	0.836	0.821	0.848	0.007
	Shrubs/Sub-shrubs/Liana	0.957	0.945	0.967	0.005	0.940	0.911	0.960	0.012	0.785	0.722	0.819	0.021
	Trees	0.979	0.969	0.987	0.004	1	--	-	-	0.409	0.305	0.503	0.045

Table 3. One way ANOVA for testing the significance of mean values of each category (1000 resamples). See materials and methods for (P) and (d).

Category	β_O			β_A			β_N		
	Obtained F	Percent => F_{obt} (P)	Effect size (d)	Obtained F	Percent => F_{obt} (P)	Effect size (d)	Obtained F	Percent => F_{obt} (P)	Effect size (d)
Habitat	13.011	0.023	0.643	11.473	0.011	0.603	2.683	0.071	0.292
Stage of invasion	11.2	0.012	0.143	-	-	-	-	-	-
Life span	11.490	0.040	0.165	13.46	0.02	0.357	4.040	0.047	0.104
Growth form	19.25	0.05	0.532	16.606	0.12	0.195	18.721	0.017	0.102

authors on request). The habitats showed differences with respect to number of native and alien species (Table 1). The average number of species per site was 67, 62 and 64 in roadside, grassland and forest habitats, respectively. The average number of native species per site was 14, 15 and 32, while average number of alien species per site was 53, 47 and in roadside, grassland and forest habitats respectively.

Beta diversity

Present study revealed that the beta diversity for aliens (β_A) was lower than the over all beta diversity (β_O). The average overall beta diversity as well as average of beta diversity for aliens (Table 2) were lowest for perennials followed by annuals/ biennials and were lowest for herbs followed by shrubs and trees. The beta diversity for habitats (β_A) was lowest for roadsides followed by grasslands and forests, while the β_O was lowest for roadsides, followed by forests and grasslands. Among habitats, the values of β_N were lowest for forests thus indicating that forests were more similar with respect to native species than alien species. For each of the trait categories evaluated for their effect on biotic homogenization it was observed that β_N was lowest for the group least effective in promoting homogenization i.e., it was lowest for trees among growth forms, for perennials among life cycle categories thereby indi-

Table 4. The lowest and the highest values of Homogenization Index (H) for each of the sub-category of habitat and plant groups.

Category	Sub-category	Lowest H	Highest H
Habitat	Grasslands	-0.0167	0.1007
	Forests	-0.0203	0.0035
	Roadsides	-0.0248	0.2491
Stage of invasion	Casual	-0.0258	0.0916
	Naturalized	-0.1326	0.1574
	Invasive	-0.0064	0.3208
Life span	Annual/Biennial	-0.1653	0.36
	Perennial	-0.1625	0.3542
Habit	Herbs	-0.0391	0.2508
	Shrubs/Sub-shrubs/Lianas	-0.5	0.5
	Trees	-0.75	-0.15

cating that biotic homogenization is largely caused by alien species. There were significant differences (P in most cases < 0.05) among mean values of β_O, β_A, β_N for each category (Tables 2 & 3).

Biotic homogenization

Homogenization indices ranged from -0.7778 to 0.875 (Table 4). Frequency distribution of H values among various classes for habitat categories revealed that roadsides were more homogenous in comparison to grasslands and forests (Fig. 2). In the case of roadsides, H was negative for one site pair and positive for 20 site pairs with maximum frequency of H in class V. In the case of grasslands, H was negative for 3 site pairs and positive for 18 site pairs with maximum frequency of H in class IV. In case of forests, H was negative for 5 site pairs and positive for 16 site pairs. Comparison of frequency distributions of H values among seven H classes for alien species revealed the following order of homogenization: invasive > naturalized > casual (Fig. 3). For casual species, H was negative for 8 site pairs and positive for 25 site pairs. For naturalized species, H was negative for 69 site pairs and positive for 141 site pairs with maximum frequency in class IV, and for invasive species, H was negative for 5 site pairs and positive for 205 site pairs with maximum frequency in class V. Perennial alien species promoted homogenization greater than annual/biennial alien species (Fig. 4). With respect to perennial species, H was negative for 30 site pairs and positive for 180 site pairs with maximum frequency in class V, while with respect to annual species, H was negative for 62 site pairs and positive for 148 site pairs with maximum frequency in class V. Homogenization for growth form

categories followed the following order: herbs > shrubs > trees (Fig. 5). Trees generally tended to have differentiation effect. With respect to herbaceous species, H was negative for 11 site pairs and positive for 199 site pairs, with maximum frequency in class IV. With respect to shrubs, H was negative for 26 site pairs and positive for 20 site pairs, with maximum frequency in class III. With respect to trees, H was negative for all the 22 site pairs which shared tree species. For each of the four comparisons, the distribution of H for roadsides, invasive, perennial and herbaceous plants tended to shift towards larger H-values, compared to forests, grasslands; casual, naturalized; annual/biennial; shrubs/sub-shrubs/liana, trees.

Habitat differences in extent of homogenization and the role of alien plant species in promoting biotic homogenization were further confirmed by DCA analysis with roadside sites being more similar than grasslands and forests (Fig. 6). In comparison to native species, DCA analysis reveals that the homogenization among roadside sites is promoted more by alien species (Figs. 7 & 8) consistent with the role of alien species in decreasing beta diversity among sites as established in the present study.

Discussion

Present study pointed out lower value of average beta diversity for alien plant species than average beta diversity based on all species. The lower beta diversity of alien plants is consistent with the homogenizing effect of these introduced species, particularly, among areas that are distant from one another (Qian & Ricklefs 2006). Because many alien species are closely associated with disturbed environments (Kumar & Mathur 2014)
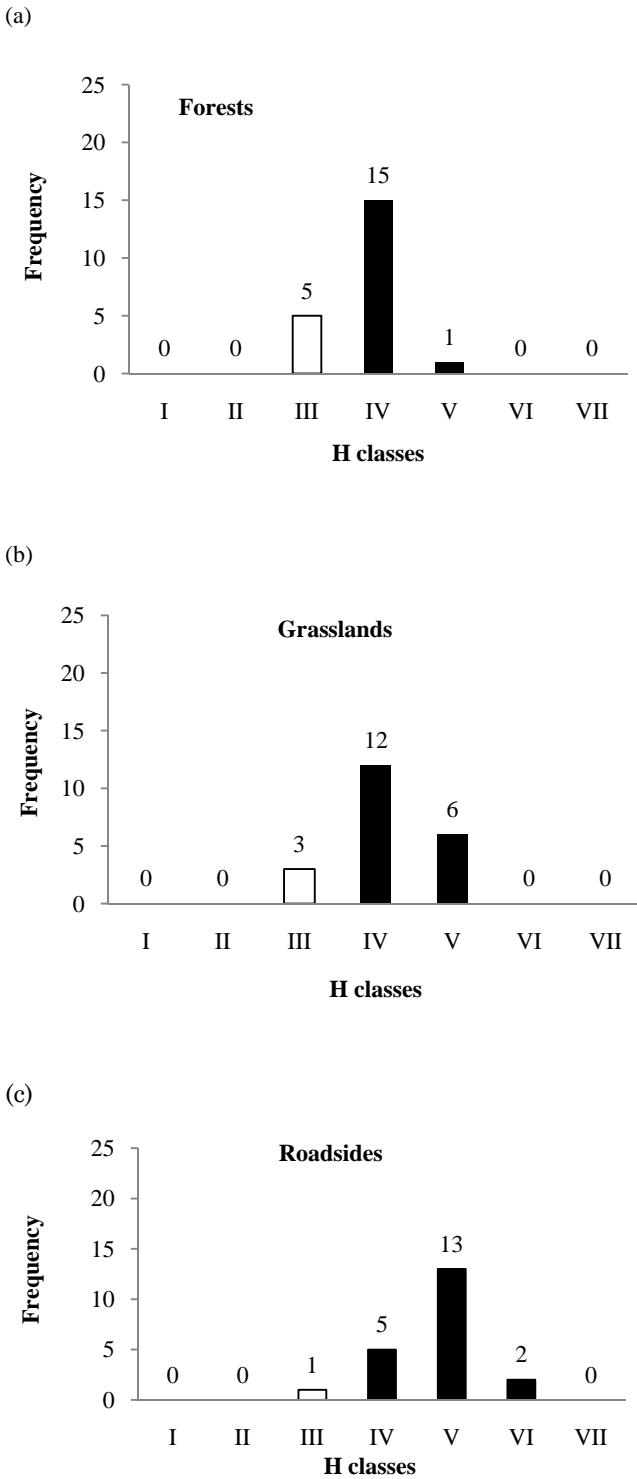
Fig. 2. Frequency distribution of homogenization indices in the seven H-classes according to habitat (Solid black-filled bars indicate positive H values, white-filled bars indicate negative H values. (a) Forests (b) Grasslands (c) Roadsides.
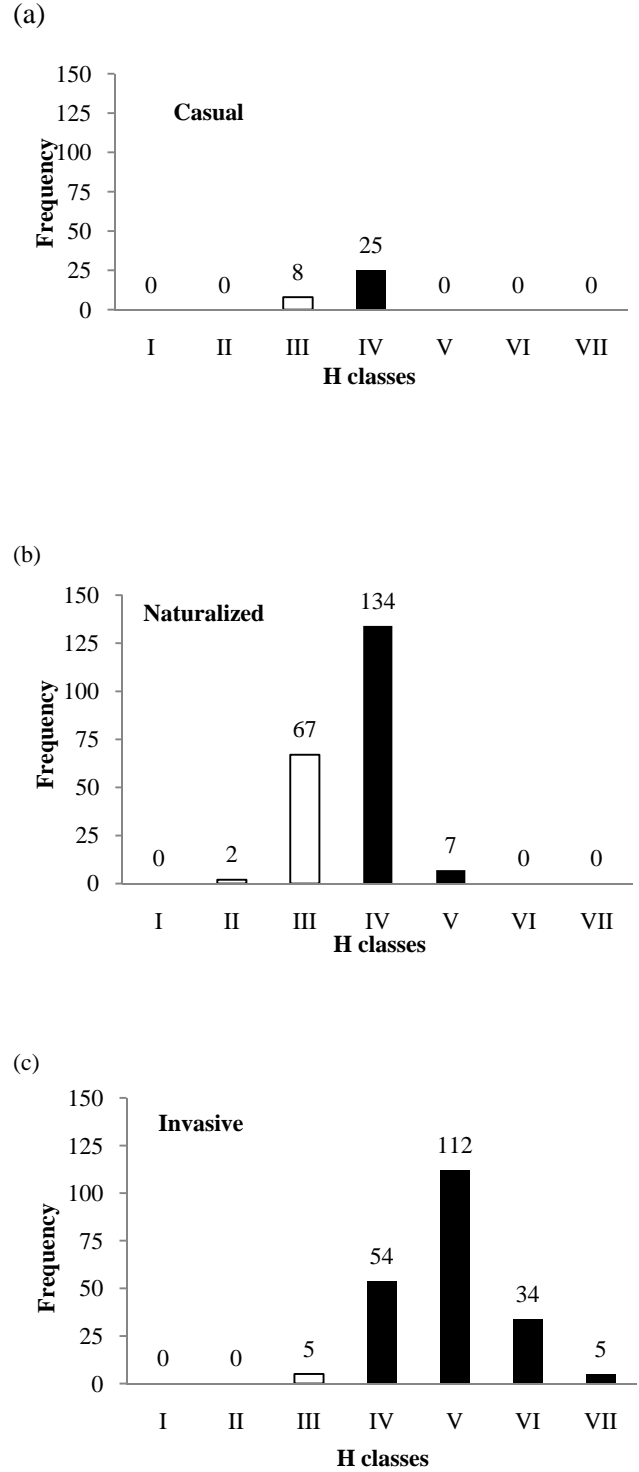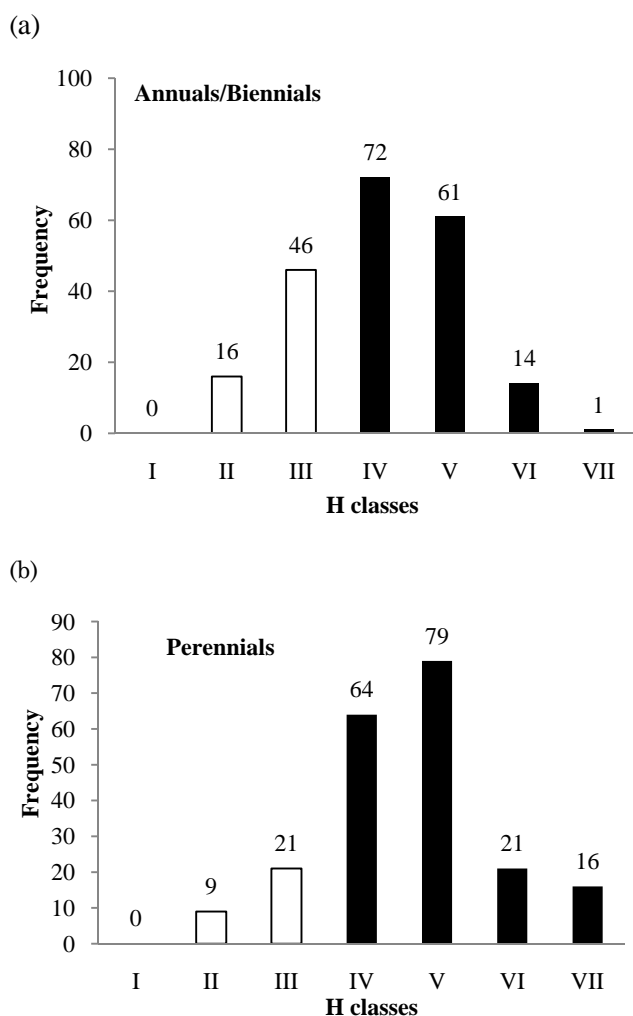
Fig. 3. Frequency distribution of homogenization indices in the seven H- classes according to stage of invasion (Solid black-filled bars indicate positive H values, white-filled bars indicate negative H values). (a) Casual (b) Naturalized (c) Invasive.

(a)

(b)

Fig. 4. Frequency distribution of homogenization indices in the seven H- classes according to life span (Solid black-filled bars indicate positive H values, white-filled bars indicate negative H values). (a) Annuals/Biennials (b) Perennials.

and may be excluded from intact habitats (e.g. Hector *et al.* 2001; Naeem *et al.* 2000), homogenization might reflect the creation of human-modified relatively uniform environment due to which exotic species have spread. Qian & Ricklefs (2006) also obtained lower values of beta diversity of exotic plants than beta diversity for native species.

Results of the present study revealed that roadsides were more homogenous in comparison to grasslands and forests. This homogeneity of road sides is due to their linear continuous structure and increased rate of spread of alien species along roads due to disturbance, altered soil conditions,
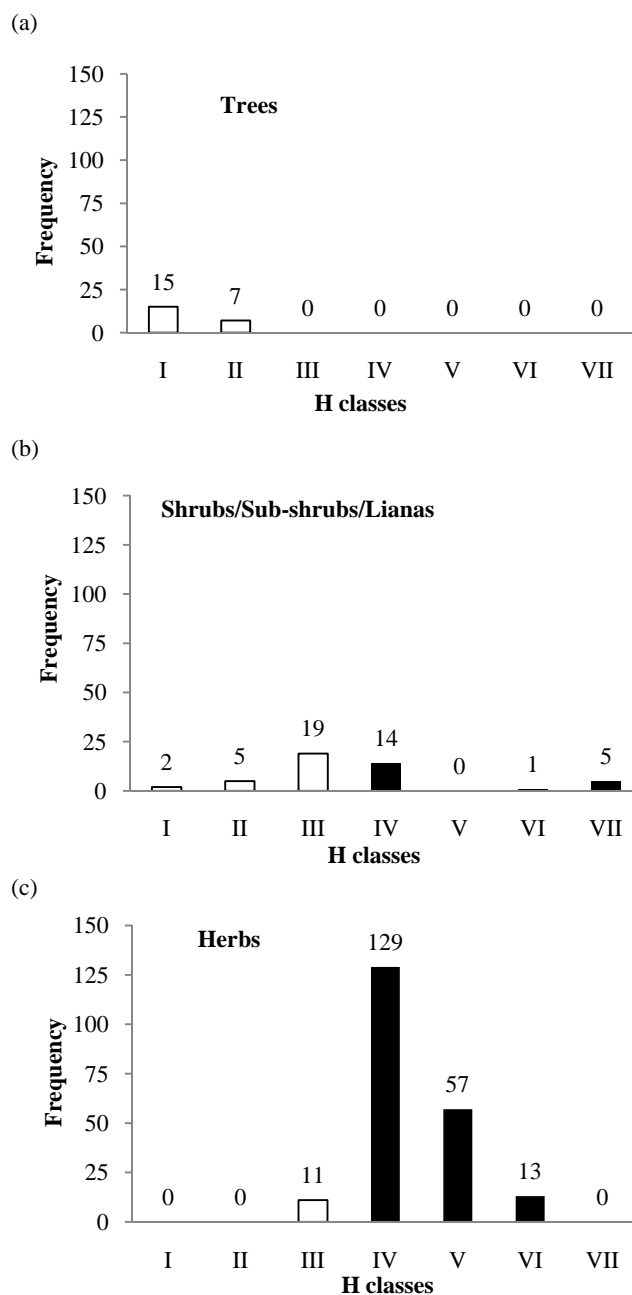
(a)

(b)

(c)

Fig. 5. Frequency distribution of homogenization indices in the seven H-classes according to habit (Solid black-filled bars indicate positive H values, white-filled bars indicate negative H values). (a) Trees (b) Shrubs/Sub-shrubs/ Lianas c) Herbs.

vehicular movement (von der Lippe & Kowarik 2007). Besides, many studies have reported that new alien plant species may first occur in roadsides (Gelbard & Belnap 2003; Parendes & Jones 2000; Tikka *et al.* 2001) and it is a well established fact that similar species invading different communities lead to the homogenization
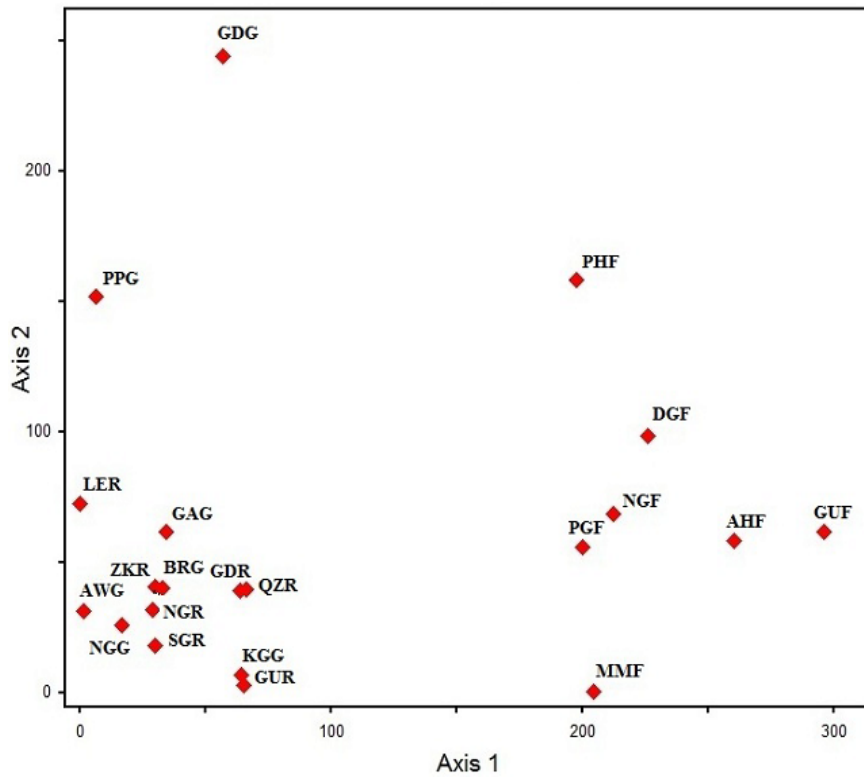
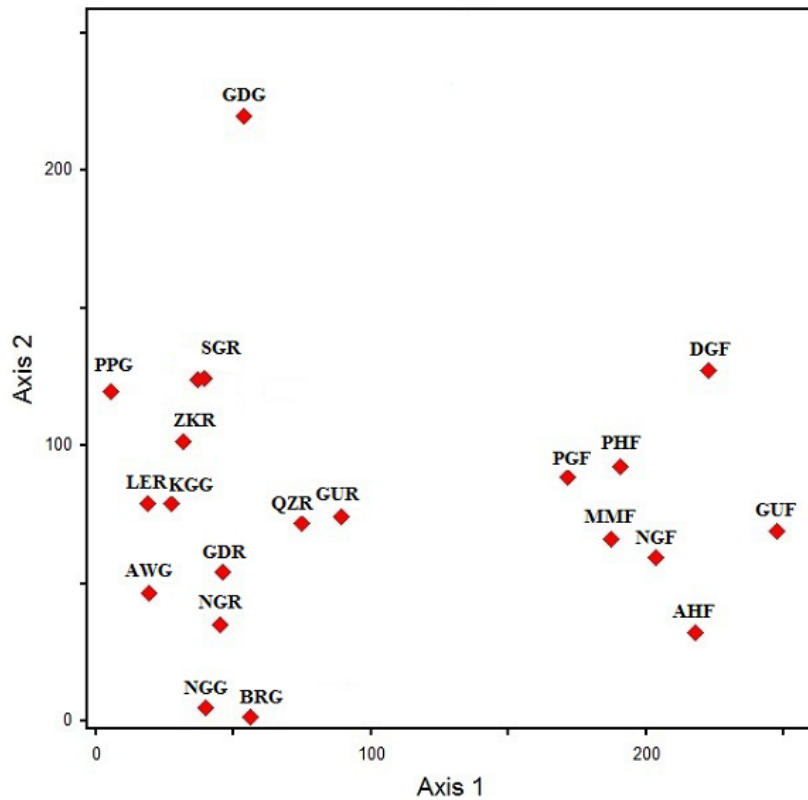**Fig. 6.** DCA axes I and II for site scores when all species included (for acronyms see Table 1).

Fig. 7. DCA axes I and II for site scores when only alien species included (for acronyms see Table 1).
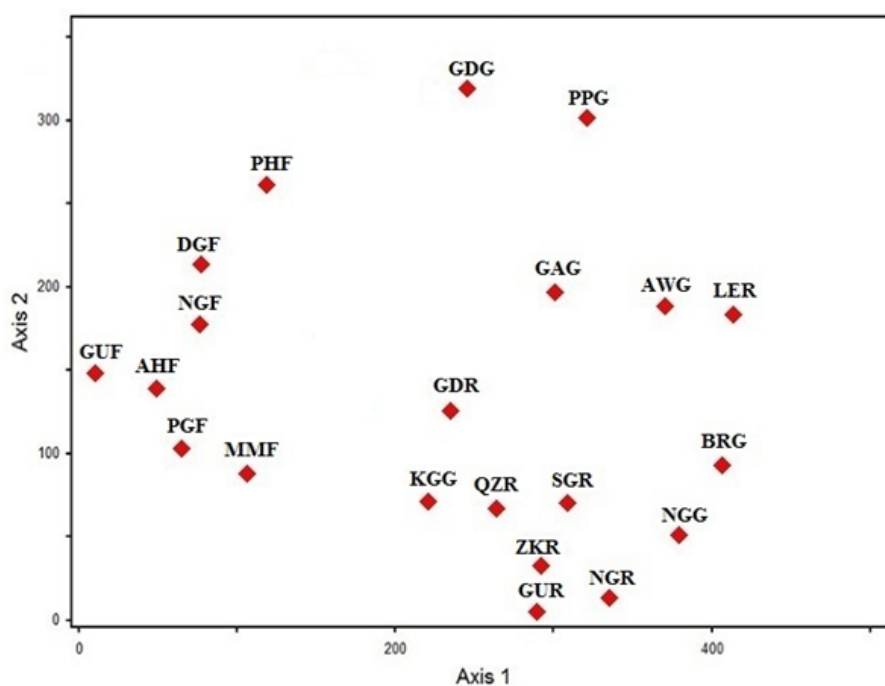
Fig. 8. DCA axes I and II for site scores when only native species included (for acronyms see Table 1).

of invaded communities (Olden & Poff 2003). Arévalo *et al.* (2010) have recently reported that road edges are more homogenous than interiors.

Present study also indicated that invasive species play a much greater role in promoting homogenization in comparison to naturalized and casual species. It is consistent with the findings of Qian & Guo (2010), who compared invasive species with non-invasive species and observed that invasive species have played a greater role than non-invasive species in homogenizing the flora of North America at the state/province level. Features such as greater genetic and phenotypic plasticity, multiple reproductive strategies, high growth rate, greater dispersal ability and greater ability to tolerate broader habitat conditions enable invasive species to spread faster and thus assume wider distributions (e.g. Devin & Beisel 2007; Goodwin *et al.* 1999; Gosper & Vivian-Smith 2009; Rejmánek & Richardson 1996), thus enabling invasive species to reorganize and homogenize the overall floras or faunas over larger areas.

It is also evident from the present results that perennial species promoted homogenization greater than annual/biennial species. Although the characteristics, such as production of small and higher numbers of seeds, greater genetic flexibility and evolutionary rates due to their shorter life spans enable annual/biennial plants to spread more

(Qian & Guo 2010), the greater role of perennial species in promoting homogenization observed in the present study is ascribed to their ability of clonal propagation (Fahrig *et al.* 1994). Besides, the ability of perennial plants to produce stolons and rhizomes from which new stems are produced at some distance from other connected stems has also been suggested as a means of coping with high disturbance rates (Bertness & Ellison 1987). It has also been reported that perennial plants increase their rate of spread after a disturbance (Bazaz 1983; Gibson 1989; Halpern 1988; Milchunas *et al.* 1988; Tappeiner *et al.* 1991). Qian & Guo (2010), who compared the state level floras of North America, reported that annual/biennial species promoted homogenization much greater than perennial species at continental scale. Results of the present study differ from findings of Qian & Guo (2010) probably due to differences in the scale at which the two studies are undertaken. Scale-dependence of homogenization has been highlighted by Olden & Poff (2003) also.

In terms of growth form, herbaceous species played greater role in promoting homogenization followed by shrubs and trees. This pattern is also consistent with the findings of Qian & Guo (2010). In comparison to woody species, herbaceous species are characterized by high growth rates, production of large number of small seeds and greater genetic

flexibility and evolutionary rates (Cox 2004; Rejmánek & Richardson 1996), which enable these species to spread more broadly and, over time eventually occupy larger geographical ranges than long-lived woody species.

Based on the present study, it could be safely concluded that biotic homogenization is related to habitat type (e.g. roadsides *versus* grasslands *versus* forests), stage of invasion and life-history traits, such as life span (e.g. annual/biennial *versus* perennial and herbaceous *versus* woody species).

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