



The impact of invasive *Hyptis suaveolens* on the floristic composition of the periurban ecosystems of Chandigarh, northwestern India



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ABSTRACT

We investigated the impact of invasive *Hyptis suaveolens* on the natural vegetation and soil of the periurban ecosystems of Chandigarh (Northwestern India), in terms of declines in species number, importance value index (IVI), richness, diversity, evenness, and changes in soil pH, conductivity and organic matter. The number of species declined by 46–52% in the areas massively invaded by *H. suaveolens*. The richness, diversity, dominance and evenness of species were severely reduced in the invaded areas compared to uninvaded areas. The reasons for this strong impact may be attributed to the vigorous growth of the weed in the invaded areas. Invaded areas were characterized by high cover of the exotic species. Several economically important species like *Justicia adhatoda*, *Anisomeles indica*, *Carissa carandas*, *Dioscorea deltoidea*, *Murraya koenigii* and *Paspalidium flavidum* were conspicuously absent in the invaded areas, though present in the uninvaded areas. Absence of these species in the areas invaded by *H. suaveolens* may pose socio-economic problems for the local people. Further, alterations were also noticed in the pH, conductivity, organic carbon and organic matter of the soil of invaded areas. Based on these observations, it was concluded that invasion of *H. suaveolens* has a marked influence on the vegetation of periurban ecosystems, and causes depletion of several economically important species. The present study calls for an immediate action for the management of this noxious alien weed.

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1. Introduction

Biological invasion is the second largest threat to biodiversity after habitat destruction (Holzmueller and Jose, 2009). Invasive alien species decrease species diversity, alter ecosystem functioning, lead to homogenization of biota and have severe socio-economic implications (Cushman and Gaffney, 2010). Though not all introduced species are harmful, a few of them spread fast in the introduced areas, acquire invasive character and harm the native ecosystems (Pyšek et al., 2012). Several plants were introduced to different parts of the world for their economic and aesthetic value (Hulme et al., 2013). Notwithstanding, globalization, climate change and increasing anthropogenic activities have further contributed to their spread (Mack, 2000). Plant invasion has become a hot topic for ecological research in the past few decades (Nuñez

and Pauchard, 2010). Depending upon the opportunities available, invasive plants invade a variety of ecosystems including forest, agriculture, urban and periurban areas. Owing to urban sprawling, periurban areas are fast becoming susceptible to the invasive alien plants due to human disturbance, habitat loss, and migration of invasive species from urban landscape, consequently resulting in reduced biodiversity and loss of ecosystem services provided by the native species (Duguay et al., 2007; Niinemets and Peñuelas, 2008; Dolan et al., 2015; Martin et al., 2016). Periurban areas, however, are important as these serve as green belts around human habitation, have habitat heterogeneity, possess high species richness of indigenous species and provide numerous ecosystem services (McKinney, 2008; Bernholt et al., 2009; Huang et al., 2011). Their protection from the invasive plants therefore is important, though not much has been done in this direction.

Hyptis suaveolens (L.) Poit. (pignut or bushmint; Lamiaceae; Fig. 1), a pantropical, aromatic herb with a tendency to be perennial, is a fast emerging invasive plant posing detrimental effects on the native biodiversity and replacing the vulnerable or threatened species (Padalia et al., 2014). In India, the weed has been reported

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Fig. 1. Pictures showing a) an area invaded by *H. suaveolens*, and b) a flowering shoot of the plant.

from Vindhyan region, North-East India, Deccan Peninsula and Andaman and Nicobar Islands (Anonymous, 1959) and Telangana region (Suthari et al., 2016). It grows luxuriantly during the months of July till November, and rail tracks, roadsides or foothills of open forests, forest clearings and wastelands are its typical habitats (Verma and Mishra, 1992; Mudgal et al., 1997). There is, however, hardly any systematic study showing the impact of *H. suaveolens* on the native/local vegetation of the invaded areas except that of Sharma et al. (2009) who reported significant alteration in the species diversity in the dry deciduous forests of Vindhyan region due to invasion of *H. suaveolens*. Nevertheless, the weed possesses immense potential to spread to other parts, especially to areas with warm and wet climate, as predicted by the species distribution models taking various climatic and non-climatic variables into consideration (Padalia et al., 2014). Chandigarh, a modern Indian city situated in the foothills of Shiwalik range of Northwestern Himalayas, possesses favourable climate for this species. It is a well-designed city marked by periurban areas with open green spaces. However, due to urban sprawl and expansion of satellite towns, these periurban areas around Chandigarh are degrading fast, thereby paving a way for invasive alien species like *H. suaveolens*. The weed can be seen forming monocultures at the expense of local plants (Fig. 1). However, no study has been conducted to assess and quantify the ecological impact of *H. suaveolens* in periurban areas. In order to fulfill the knowledge gap, we conducted specific studies to determine the effect of *H. suaveolens* invasion on the natural vegetation, and on soil of the periurban ecosystems in terms of species number, richness, diversity, evenness, and also the pH, conductivity and soil organic matter.

2. Materials and methods

2.1. Study site

The present study was conducted in periurban areas on the outskirts of city Chandigarh (Site I: 30°45'32.62" N; 76°44'51.01" E to 30°46'00.14" N; 76°49'08.47" E; Site II: 30°41'51.72" N; 76°49'02.77" E to 30°44'32.10" N; 76°51'01.99" E and altitude 321 m) in Northwestern India (Fig. 2). It is situated in the foothills of Shiwaliks and experiences cold dry winter, hot summer and sub-tropical monsoon (~1110 mm average annual precipitation) (Chandigarh Administration, 2017). The city is well-planned and has extensive greens mainly contributed by its tree cover. The open vacant areas around the city harbor vegetation composed of common local weeds, grasses and forbs. Besides these, it also serves as an important sink for extra water at the time of monsoon season. Expansion of urban areas or suburbs has disturbed these periurban areas that otherwise provided important

ecosystem services such as fodder, food, medicine and habitat for various plants and animals beneficial to the local inhabitants. Unfortunately, due to unorganized development and anthropogenic pressure, these periurban areas have become home for invasive species like *H. suaveolens*. However, its impact on the local vegetation is yet to be ascertained. For this, two massively infested sites (with IVI of *H. suaveolens* >60%) referred to as site I and II were selected and each site was further divided into uninvaded (control) or *H. suaveolens* invaded areas (Fig. 2). The coordinates of the selected sites are: Site I: Uninvaded: 30°45'58.55" N; 76°46'57.29" E to 30°46'09.18" N; 76°49'13.63" E; Invaded: 30°45'34.91" N; 76°44'51.09" E to 30°46'25.31" N; 76°46'25.31" E; Site II: Uninvaded: 30°42'07.13" N; 76°49'25.35" E to 30°43'36.01" N; 76°51'33.56" E; Invaded: 30°43'10.14" N; 76°49'25.47" E to 30°44'41.21" N; 76°50'46.60" E.

2.2. Data collection

A quadrat-based study was conducted in the two selected study sites (Site I and Site II) during the post-rainy season (from September–November). At each study site, 10 quadrats of 1 m² were laid randomly in the uninvaded and invaded areas of site I and II making a total number of quadrat as 40, which was sufficient for vegetation analyses (Squiers and Wistendahl, 1976; Barbour et al., 1987). Collected data was fed in MS Excel sheet and plant samples were identified through Herbarium of the Department of Botany, Panjab University, Chandigarh, India. The voucher specimens were deposited, and voucher numbers of all the plants including *H. suaveolens* have been given in Table 1. The soil samples were also collected from the top 15 cm soil after removing litter or humus, from both the sites. Five replicates were taken for each sample. The soil samples were dried, sieved through 2 mm mesh after gentle grinding and were stored in polythene bags for further analysis (Batish et al., 2007). The above-ground biomass of *H. suaveolens* plants was determined by chopping the aboveground parts of the plants from both the study sites. The dry biomass was determined by oven drying the plant samples for 72 h at 65 °C (Kurupparachchi et al., 2016).

2.3. Data analysis

Different parameters like density, frequency and dominance of the vegetation of both the sites were calculated in MS Excel using various formulae as per Kent and Coker (1992). Importance value indices (IVIs) were calculated for each plant species using the formula:

$$\text{Importancevalueindex(IVI)} = \text{R.Den.} + \text{R.F.} + \text{R.D.} (\text{Philips, 1959}).$$

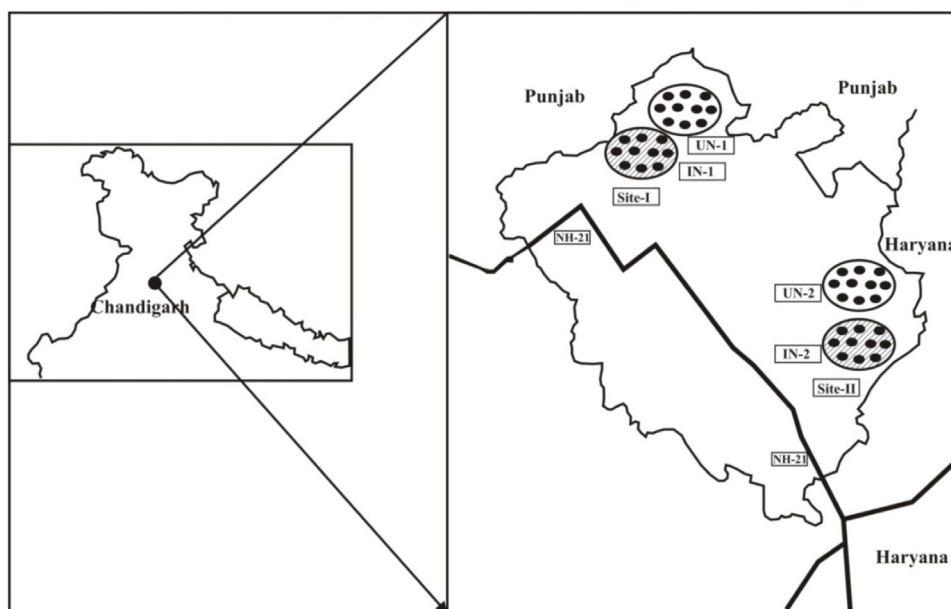


Fig. 2. Map showing the location of study site (site I and II). UN: Uninvaded area; IN: Invaded area.

Table 1
The list of plant species found in the study sites I and II with Importance value index (IVI).

S. No.	Plant Species/Family	Vouchernumber	Status	Habit	Growth Form	IVI			
						Site I		Site II	
						UN	IN	UN	IN
1	<i>Abutilon indicum</i> (L.) Sweet; MLV ^a	PAN21082	N	S	A/P	7.9	2.4	10.1	–
2	<i>Achyranthes aspera</i> L. AMA	PAN21083	E	H	A	5.6	–	–	–
3	<i>Andrographis paniculata</i> (Burm.f.) Nees ACA	PAN 21085	N	H	A	10.2	7.3	–	–
4	<i>Anisomeles indica</i> (L.) Kuntze LAM	PAN 21086	N	H	A	10.3	–	7.9	–
5	<i>Artemisia scoparia</i> Waldst. & Kitam. AST	PAN 21087	E	H	A	12.0	9.7	12.5	14.2
6	<i>Barleria cristata</i> L. ACA	PAN 21088	N	S	A	6.0	–	7.3	–
7	<i>Bauhinia vahlii</i> Wight & Arn. CSL	PAN 21089	N	L	P	8.4	–	6.0	4.5
8	<i>Boerhavia diffusa</i> L NYC	PAN 21090	N	H	A	6.1	2.4	10.0	5.1
9	<i>Carissa carandas</i> L. APO	PAN 21091	N	S	P	2.1	–	12.9	–
10	<i>Chenopodium album</i> L. AMA	PAN 21093	E	H	A	6.2	–	–	–
11	<i>Coccinia grandis</i> (L.) Voigt CUC	PAN 21094	N	CL	P	4.7	8.3	6.4	8.9
12	<i>Corchorus trilocularis</i> L. MLV	PAN 21095	E	H	A	9.6	12.2	10.6	–
13	<i>Crotalaria albida</i> Roth FAB	PAN 21096	N	S	A/P	6.8	9.7	20.1	–
14	<i>Cyanthillium cinereum</i> (L.) H.Rob. AST	PAN 21115	E	H	P	5.9	2.4	–	–
15	<i>Dichanthium annulatum</i> (Forssk.) Stapf. POA	PAN 21097	N	H	P	5.9	–	–	–
16	<i>Dicliptera bupleuroides</i> Nees ACA	PAN 21098	N	H	P	–	–	5.9	–
17	<i>Dioscorea deltoidea</i> Wall. ex Griseb. DSC	PAN 21099	N	CL	A	3.5	–	–	–
18	<i>Euphorbia hirta</i> L. EUP	PAN 21100	E	H	A	7.5	7.6	12.8	–
19	<i>Hyptis suaveolens</i> (L.) Poit. LAM	PAN 21101	E	H	A	4.0	197.9	3.8	212.8
20	<i>Ipomoea cairica</i> (L.) Sweet CNV	PAN 21102	E	CL	A	6.2	–	8.6	–
21	<i>Justicia adhatoda</i> L. ACA	PAN 21084	N	S	P	25.6	–	20.0	–
22	<i>Murraya koenigii</i> (L.) Spreng. RUT	PAN 21103	N	S	P	11.8	–	7.4	–
23	<i>Paspalidium flavidum</i> (Retz.) A. Camus POA	PAN 21104	N	H	P	10.4	–	–	–
24	<i>Phyllanthus amarus</i> Schumach. & Thonn PLL	PAN 21105	N	H	A	7.1	10.2	8.5	4.8
25	<i>Physalis lagascae</i> Roem & Schult. SOL	PAN 21106	E	H	P	4.7	–	7.4	13.5
26	<i>Senna occidentalis</i> (L.) Link FAB	PAN 21092	E	S	A	31.5	12.7	29.9	4.5
27	<i>Setaria viridis</i> (L.) P.Beauv. POA	PAN 21107	E	H	A	7.9	2.4	–	–
28	<i>Sida acuta</i> Burm.f. MLV	PAN 21108	E	H	P	9.1	2.4	24.5	9.0
29	<i>S. cordifolia</i> L. MLV	PAN 21109	N	H	P	6.3	–	–	–
30	<i>S. rhombifolia</i> L. MLV	PAN 21110	E	H	A	–	–	18.7	9.0
31	<i>Solanum americanum</i> Mill. SOL	PAN 21111	E	H	P	–	–	7.94	4.5
32	<i>Tephrosia purpurea</i> (L.) Pers. FAB	PAN 21112	N	H	A/P	8.4	–	–	–
33	<i>Triumfetta rhomboidea</i> Jacq. MLV	PAN 21113	E	H	A	14.4	4.9	14.9	9.4
34	<i>Urena lobata</i> L. MLV	PAN 21114	E	H	A	7.4	–	–	–
35	<i>Xanthium strumarium</i> L. AST	PAN 21116	E	H	A	23.1	2.4	14.7	–
36	<i>Ziziphus</i> sp. RHM	PAN 21117	N	S	P	3.6	4.9	11.0	–

E=Exotic, N=Native, H=Herb, S=Shrub, CL:Climber, L:Liana, P=Perennial, A=Annual, UN=Uninvaded, IN=Invaded.

^a Three letter acronym for the family name as per Weber (1982) and Brasher and Snow (2004).

where, R.Den.=Relative density, R.F.=Relative Frequency, and R.D.=Relative Dominance.

Dominance = Basalarea \times density

where, Basal area = πr^2 ($\pi = 3.14$ is constant and r = basal radius of plant stem).

Ecological Indices were calculated as per the formulae given by Ludwig and Reynold (1988).

i) Shannon Index (H' ; Shannon and Weaver, 1963).

$$H' = - \sum_{i=1}^s p_i \ln p_i$$

ii) Simpson's Index (λ) calculated as per formula given by Simpson (1949).

$$\lambda = \sum_{i=1}^s (n_i/N)^2$$

iii) Margalef's Richness Index (R) was estimated as per Margalef (1958).

$$(R) = \frac{S - 1}{\text{Log}N}$$

iv) Evenness Index (E) was calculated as per Hill (1973).

$$E = H' / \ln S$$

In the above equations, p_i = the proportion of individuals belonging to i^{th} species, and \ln = the natural log, S = the number of species, n_i = number of individuals of i^{th} species, and N = total number of individuals of all the species.

2.4. Soil analysis

The soil samples were analyzed for pH (using Ecoscan CON 5, Eutech Instruments Pvt. Ltd., Singapore), electrical conductivity (EC; using Ecoscan pH 5, Eutech Instruments Pvt. Ltd., Singapore), and organic carbon (OC) and organic matter (OM) content (Walkley and Black, 1934). The data were subjected to cluster analysis to generate a dendrogram for similarity of the invaded and uninvaded area of site I and II. Average values were used from four replicate in each site (site I and site II) for each parameters of invaded and uninvaded area. Values of each parameter were entered in PAST software ver. 2.17 (Hammer et al., 2001). Euclidean distance is calculated in past software by using the formula given below.

$$d_{jk} = \sqrt{\sum_i (x_{ji} - x_{ki})^2}$$

where, d is the Euclidean distance and i , j and k are the sample units. In Unweighted pair-group average (UPGMA) the clusters were joined based on the average distance between all members in the two groups in hierarchical clustering to generate the dendrogram.

3. Results

The overall floristic survey of the vegetation of study area (collectively for both site I and II) depicts the presence of 36 species belonging to 34 genera and 18 families. Among these 18 families, Malvaceae predominated with 7 species, closely followed by Acanthaceae (4), Asteraceae, Fabaceae and Poaceae (3 each) and Lamiaceae, Solanaceae and Amaranthaceae (2 each). The rest of the families (10) were represented by one species each (Table 1). The recorded species belonged to different life forms; which included

24 herbs, 8 shrubs, 3 climbers and 1 liana (Table 1). Further, the vegetation was mixture of annuals, perennials or some annual species showing tendency to be perennial (Table 1). Of the recorded 36 species, the proportion of native species was slightly higher than that of the exotic species and these constituted ~53% of the total.

The number of species in the invaded site I and II were 17 and 12 compared to 33 and 25 in the uninvaded sites, indicating a 48–52% reduction (Fig. 3). Some of the prominent native species like *Justicia adhatoda*, *Barleria cristata*, *Carissa carandas*, *Dicliptera bupleuroides*, *Murraya koenigii*, *Paspalidium flavidum*, *Anisomeles indica*, *Dichanthium annulatum*, *Dioscorea deltoidea* and *Sida cordifolia* were conspicuously absent (Table 1). The results indicate dominance by one or a few species in the invaded areas (of both the sites) compared to their respective uninvaded areas. Incidentally, the highest IVI values in both the invaded sites were of *H. suaveolens*; it was ~198 (66%) and 213 (71%) in the site I and site II, respectively. This indicated that *H. suaveolens* was the most dominant species of the invaded areas. The higher IVI of *H. suaveolens* may be attributed to the greater height and biomass in the invaded areas compared to the uninvaded areas of both the sites (Table 2). The above ground biomass of *H. suaveolens* was more by ~152% and ~138% (significant at $p \leq 0.01$) in the invaded areas of site I and site II, respectively. *Hyptis suaveolens* plants were taller (by 43% in site I and 67% in site II) in the invaded areas compared to those in the uninvaded areas, though the difference was statistically insignificant (Table 2).

The Margalef's richness index (R) also decreased in the invaded areas and the reduction was ~43% and ~55%, respectively, at site I and II. The Shannon index (H') declined by ~79% and ~86% in the invaded areas at site I and II, respectively, compared to uninvaded areas (Fig. 3). A decline of ~73% and ~81% was noticed in the evenness index (E) of species found in the invaded areas of both the sites (Fig. 3). The Simpson index (λ), on the other hand, increased by 19 and 14 time in the invaded areas of site I and II, respectively, over the respective uninvaded sites (Fig. 3). Further, both the invaded sites had higher percentage of exotic species over the native ones, whereas in the uninvaded areas, there was a higher proportion of the native species (pie charts shown in Fig. 3 in reference to Table 1).

The soil analysis of the study area indicates significant differences in the values of pH, EC, OC and OM between invaded and uninvaded areas of both the sites. The values of OC and OM were almost the same in the uninvaded areas of both the sites. Compared to these, an increase in the amount of OC (>3 times) and OM (>2.5 times) was noticed in the invaded areas compared to the uninvaded ones (Fig. 4). The soil pH of the invaded sites was towards acidic side compared to the near neutral or slightly alkaline soil of the uninvaded sites (Fig. 4). The EC, on the other hand, increased (~1.3 times) in the areas invaded by *H. suaveolens* compared to the uninvaded areas (Fig. 4).

4. Discussion

It is clear from the results that *H. suaveolens* imposes profound impact on the vegetation of the area upon invasion. The species number, richness, diversity and evenness are severely reduced in the areas where *H. suaveolens* invaded. Many other reports have also shown that invasive plants reduce/replace the resident species of native communities (Alvarez and Cushman, 2002; Levine et al., 2003; Hulme and Bremner, 2006; Mitchell et al., 2006). On the other hand, the dominance of *H. suaveolens* was much more pronounced in the invaded areas as indicated by its higher IVI values. The greater influence of *H. suaveolens* is also reflected by its higher biomass (average dry weight ~423 g/plant) in the invaded area compared to the uninvaded area (average dry weight ~173 g/plant). Likewise, plants were also higher (average height ~2.74 m per plant) in the

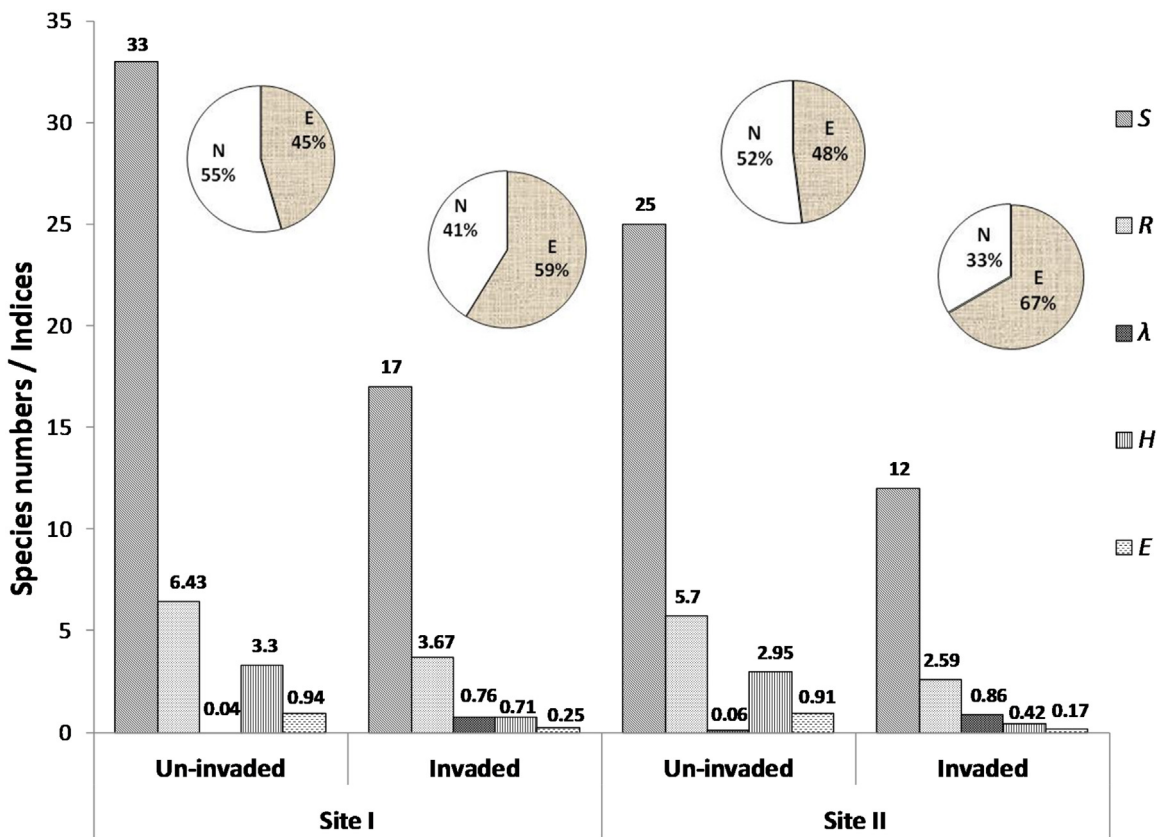


Fig. 3. Measures of species number (S), Margalef's index of richness (R), Shannon's index of diversity (H), Simpson's index of dominance (λ) and index of evenness (E) in *H. suaveolens* invaded and uninvaded areas of both the study sites around Chandigarh, India. Pie charts indicate percentage of native species (N) and exotic species (E).

Table 2
Height and aboveground biomass of *H. suaveolens* in the invaded and uninvaded areas of site I and II.

Area	Height (m)		Above ground biomass (g/plant)	
	Site I	Site II	Site I	Site II
Uninvaded area	1.70 ± 0.64	1.83 ± 0.72	185.0 ± 12.50a	160.2 ± 9.50
Invaded area	2.44 ± 0.30	3.05 ± 0.42	465.2 ± 10.25**	380.5 ± 7.65**

** Means significant at $p \leq 0.01$ from uninvaded areas.

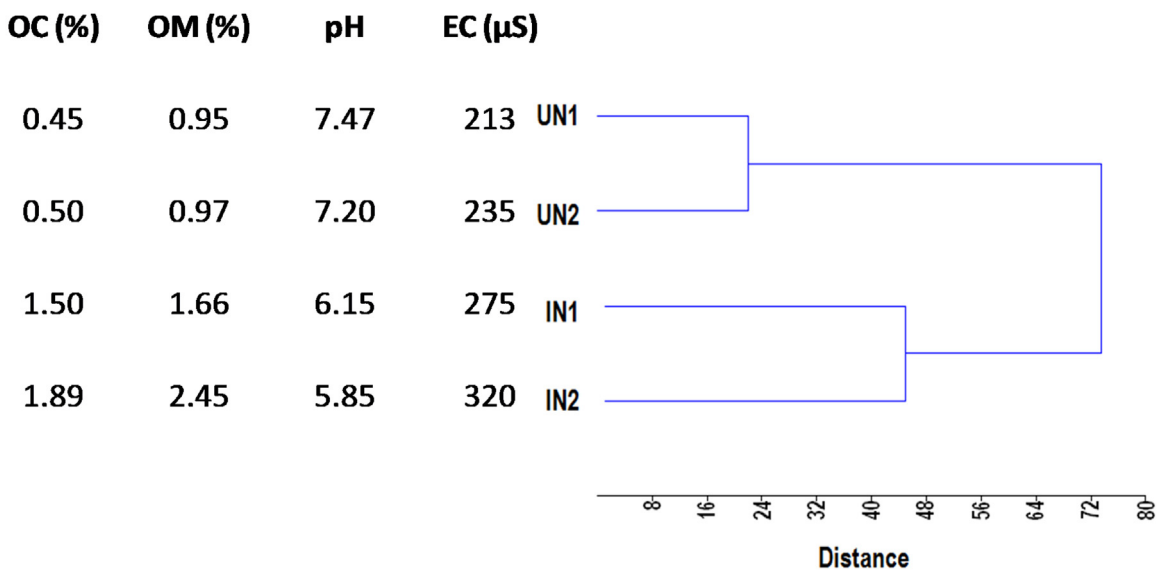


Fig. 4. Comparison between the soil properties of invaded and uninvaded area of site I and II. Here, OC=organic carbon, OM=organic matter, EC=electrical conductivity, UN1 = uninvaded area in site I, UN2 = uninvaded area in site II, IN1 = invaded area in site I, IN2 = invaded area in site II. Cluster analysis based on Euclidean distance shows the similarity of invaded and uninvaded areas from site I and II.

invaded areas than in the uninvaded ones (average height ~1.80 m per plant). Both biomass and height vis-à-vis IVI value may account for the lower number of species recorded in the areas invaded by *H. suaveolens*. Our observations are corroborated by those of Pyšek and Pyšek (1995) who pointed out that the dominance of an invasive species (having more height or biomass) determines its impact. Hejda et al. (2009) also indicated that cover and height of the invading species are the important determinants of species decline in the invaded area. Invasive species with vigorous growth and taller size have stronger impact on the resident communities. *Hyptis suaveolens* is also an aggressive invader. Its rapid spread may be facilitated by factors such as production of large numbers (>2000 m⁻²) of small seeds and high adaptability (Raizada, 2006). The seeds also exhibit dimorphism that helps them germinate in a wide range of temperature conditions and provide greater viability (Tothill et al., 1982). In addition to sexual reproduction, *H. suaveolens* also reproduces through perennating roots that survive during unfavorable conditions (Raizada, 2006). The weed forms monocultures by releasing phytotoxic chemicals that suppress the growth of other plant species in its close vicinity (Mominul Islam et al., 2014).

In our study, the differences in some physico-chemical properties of soil collected from the *H. suaveolens* invaded or uninvaded areas of the two sites were also observed. The similarity between the two invaded or uninvaded areas of the two selected sites was reflected by cluster analysis. The contents of OC and OM were higher in *H. suaveolens* invaded areas compared to the uninvaded areas. This might be due to its higher biomass in the invaded sites. The present study corroborates earlier reports that high amount of aboveground biomass in the invaded area result in enhanced OC and OM in the soil (Vitousek and Walker, 1989; Koutika et al., 2007; Liao et al., 2009). Some other studies have also shown that invasive plants alter the soil chemical constituents by producing higher biomass or by releasing allelochemicals (D'Antonio, 1993; Kourtev et al., 1998).

Most invasive plants are unpalatable or may even be toxic, and hence livestock do not relish them. According to the residents of the study area, *H. suaveolens* was also found to be unpalatable and livestock avoided eating such plants. The unpalatable nature of the weed may be attributed to the presence of various phytochemicals including essential oil in its aerial parts (Mominul Islam and Kato-Noguchi, 2013; Chatri et al., 2014). Jayakumar and Ganesh (2012) pointed that the presence of compounds like (2*E*)-1-(2-hydroxy phenyl) pent-2-en-1-one and 1-[(3-hydroxy-5,5-dimethyl cyclohex-3-en-1yl) oxy]-hexan-3-one in *H. suaveolens* provide antifeedant properties to the plant making it unpalatable. The presence of alkaloids, glycosides, tannins and saponins in different parts of the plant may also contribute in this direction (Shaikat et al., 2012). Further, the absence of useful species like *Abutilon indicum*, *Justicia adhatoda*, *Anisomeles indica*, *Barleria cristata*, *Carissa carandas*, *Dioscorea deltoidea*, *Murraya koenigii* and *Paspalidium flavidum* in the invaded areas may also affect the local people as these species are known to provide various ecosystem services (Upreti et al., 2012; Jaryan et al., 2013).

5. Conclusions

The present study demonstrated that invasion of *H. suaveolens* impose detrimental impact on the vegetation of the study sites in terms of reduced number of species, diversity, richness and evenness. Consequently, it causes socio-economic implications for the local people such as depleted grazing area for livestock and loss of useful plant species used by the local inhabitants. This calls for early efforts for the management of this species. However, prior to this, the studies on the mechanism of its spread and quantification

of socio-economic implications are required in order to control this weed.

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References

- Chandigarh Administration, 2017. Know Chandigarh, The Official Website of Chandigarh, Available online at http://chandigarh.gov.in/knowchd_general.htm (Accessed on March 1, 2017).
- Alvarez, M.E., Cushman, J.H., 2002. Community-level consequences of a plant invasion: effects on three habitats in coastal California. *Ecol. Appl.* 12, 1434–1444.
- Anonymous, 1959. *The Wealth of India*, vol. 5. CSIR, New Delhi, pp. 159.
- Barbour, M.G., Burk, J.H., Pitts, W.D., 1987. *Method of sampling the plant community*. In: *Terrestrial Plant Ecology*. Benjamin/Cummings Publishing Co, Menlo Park, CA.
- Batish, D.R., Lavanya, K., Singh, H.P., Kohli, R.K., 2007. Phenolic allelochemicals released by *Chenopodium murale* affect the growth, nodulation and macromolecule content in chickpea and pea. *Plant Growth Regul.* 51, 119–128.
- Bernholt, H., Kehlenbeck, K., Gebauer, J., Buerkert, A., 2009. Plant species richness and diversity in urban and peri-urban gardens of Niamey, Niger. *Agroforest. Syst.* 77, 159–179.
- Brasher, J.W., Snow, N., 2004. *An Online Compilation: Weber's System of Three-letter Plant Family Acronyms*. University of Northern Colorado Herbarium Website: <http://www.unco.edu/biology/herbarium/>.
- Chatri, M., Baktiar, A., Mansyurdin, Adnadi, P., 2014. Chemical components of essential oils of the leaves of *Hyptis suaveolens* (L.)Poir. from Indonesia. *AJRC* 2, 30–38.
- Cushman, J.H., Gaffney, K.A., 2010. Community-level consequences of invasion: impacts of exotic clonal plants on riparian vegetation. *Biol. Invasions* 12, 2765–2776.
- D'Antonio, C.M., 1993. Mechanisms controlling invasion of coastal plant communities by the alien succulent *Carpobrotus edulis*. *Ecology* 74, 83–95.
- Dolan, R.W., Stephens, J.D., Moore, M.E., 2015. Changes in plant species composition and structure in two peri-urban nature preserves over 10 years. *Am. Midl. Nat.* 174, 33–48.
- Duguay, S., Eigenbrod, F., Fahrig, L., 2007. Effects of surrounding urbanization on non-native flora in small forest patches. *Landsc. Ecol.* 22, 589–599.
- Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. *PAST: Paleontological statistics software package for education and data analysis*. *Palaeontol. Electron.* 4 (1), 1–9.
- Hejda, M., Pyšek, P., Jarosík, V., 2009. Impact of invasive plants on the species richness, diversity and composition of invaded communities. *J. Ecol.* 97, 393–403.
- Hill, M.O., 1973. Diversity and evenness: a unifying notation and its consequences. *Ecology* 54, 427–432.
- Holzmueller, E.J., Jose, S., 2009. Invasive plant conundrum: what makes the aliens so successful? *J. Trop. Agric.* 47, 18–29.
- Huang, S.-L., Chen, Y.-H., Kuo, F.-Y., Wang, S.-H., 2011. Emergy-based evaluation of peri-urban ecosystem services. *Ecol. Complex.* 8, 38–50.
- Hulme, P.E., Bremner, E.T., 2006. Assessing the impact of *Impatiens glandulifera* on riparian habitats: partitioning diversity components following species removal. *J. Appl. Ecol.* 43, 43–50.
- Hulme, P.E., Pyšek, P., Jarošík, V., Perg, J., Schaffner, U., Vila, M., 2013. Bias and error in understanding plant invasion impacts. *Trends Ecol. Evol.* 28, 212–218.
- Jaryan, V., Uniyal, S.K., Kumar, A., Gupta, R.C., Parkash, O., Singh, R.D., 2013. Distribution characteristics of *Sapium sebiferum* (L.) Roxb.—an invasive tree species in Himachal Pradesh, Western Himalaya. *Proc. Indian Nat. Sci. Acad.* 79, 215–234.
- Jayakumar, S.V., Ganesh, S.M.K., 2012. New enolic type bioactive constituents from *Hyptis suaveolens* (L.) Poit. *Asian J. Plant Sci. Res.* 2, 403–408.
- Kent, M., Coker, P., 1992. *Vegetation Description and Analysis. A Practical Approach*. John Wiley and Sons, New York, pp. 363.
- Kourtev, P.S., Ehrenfeld, J.G., Huang, W.Z., 1998. Effects of exotic plant species on soil properties in hardwood forests of New Jersey. *Water Air Soil Poll.* 105, 493–501.
- Koutika, L.S., Vanderhoeven, S., Chapuis-Lardy, L., Dassonville, N., Meerts, P., 2007. Assessment of changes in soil organic matter after invasion by exotic plant species. *Biol. Fert. Soils* 44, 331–341.
- Kurupparachchi, J., Senevirate, G., Madurapperuma, B., 2016. Carbon sequestration in Tropical forest stands: its control by plant, soil and climatic factors. *Open J. For.* 6, 59–71.
- Levine, J.M., Vila, M., D'Antonio, C.M., Dukes, J.S., Grigulis, K., Lavorel, S., 2003. Mechanisms underlying the impacts of exotic plant invasions. *Proc. R. Soc. Lond. B* 270, 775–781.
- Liao, Q.L., Zhang, X.H., Li, Z.P., Pan, G.X., Smith, P., Jin, Y., Wu, X.M., 2009. Increase in soil organic carbon stock over the last two decades in China's Jiangsu Province. *Glob. Change Biol.* 15, 861–875.

- Ludwig, J.A., Reynold, J.F., 1988. *Statistical Ecology: a Primer on Methods and Computing*. John Wiley, New York.
- Mack, R.N., 2000. Cultivation fosters plant naturalization by reducing environmental stochasticity. *Biol. Invasions* 2, 111–122.
- Margalef, R., 1958. *Perspective in Ecological Theory*. University of Chicago Press, Chicago.
- Martin, P., Le Gal, E., Choy, D.L., 2016. Effect of social and institutional fragmentation on collective action in peri-urban settings. In: Maheshwari, B., Singh, V.P., Thoradeniya, B. (Eds.), *Balanced Urban Development: Options and Strategies for Liveable Cities*. Volume 72 of the Series Water Science and Technology Library. Springer, USA, pp. 465–480.
- McKinney, M.L., 2008. Effects of urbanization on species richness: a review of plants and animals. *Urban Ecosyst.* 11, 161–176.
- Mitchell, C.E., Agrawal, A.A., Bever, J.D., Gilbert, G.S., Hufbauer, R.A., Klironomos, J.N., Maron, J.L., Morris, W.F., Parker, I.M., Power, A.G., Seabloom, E.W., Torchin, M.E., Vazquez, D.P., 2006. Biotic interactions and plant invasions. *Ecol. Lett.* 9, 726–740.
- Mominul Islam, A.K.M., Kato-Noguchi, H., 2013. Plant growth inhibitory activity of medicinal plant *H. suaveolens*: could allelopathy be a cause? *Emir. J. Food Agric.* 25, 692–701.
- Mominul Islam, A.K.M., Ohno, O., Suenaga, K., Kato-Noguchi, H., 2014. *Suaveolic Acid: a potent phytotoxic substance of Hyptis suaveolens*. *Sci. World J.* 2014, 1–6.
- Mudgal, V., Khanna, K.K., Hazra, P.K., 1997. *Flora of Madhya Pradesh II*. Bot. Surv. India, 403–404.
- Niinemets, U., Peñuelas, J., 2008. Gardening and urban landscaping: significant players in global change. *Trends Plant Sci.* 13, 60–65.
- Núñez, M.A., Pauchard, A., 2010. Biological invasions in developing and developed countries: does one model fit all? *Biol. Invasions* 12, 707–714.
- Padalia, H., Srivastava, V., Kushwaha, S.P.S., 2014. Modeling potential invasion range of alien invasive species, *Hyptis suaveolens* (L.) Poit. in India: comparison of MaxEnt and GARP. *Ecol. Inform.* 22, 36–43.
- Philips, E.A., 1959. *Methods of Vegetation Study*. Henry Holt and Co. Inc., New York, pp. 318.
- Pyšek, P., Pyšek, A., 1995. Invasion by *Heracleum mantegazzianum* in different habitats in the Czech Republic. *J. Veg. Sci.* 6, 711–718.
- Pyšek, P., Jarošík, V., Hulme, P.E., Pergl, J., Hejda, M., Schaffner, U., Vilà, M., 2012. A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species traits and environment. *Glob. Chang Biol.* 18, 1725–1737.
- Raizada, R., 2006. Ecological and vegetative characteristics of a potent invader, *Hyptis suaveolens* Poit. from India. *Lyonia* 11, 115–120.
- Shaikat, M.Z.H., Hossain, M.T., Azam, M.G., 2012. Phytochemical screening and anti-diarrhoeal activity of *Hyptis suaveolens*. *Int. J. Appl. Res. Nat. Prod.* 5, 1–4.
- Shannon, C.E., Weaver, W., 1963. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, IL, USA, pp. 31–35.
- Sharma, G.P., Raizada, P., Raghubanshi, A.S., 2009. *Hyptis suaveolens*: an emerging invader of Vindhyan plateau, India. *Weed Biol. Manage.* 9, 185–191.
- Simpson, E.H., 1949. Measurement of diversity. *Nature* 163, 688.
- Squiers, E.R., Wistendahl, W.A., 1976. Sample unit selection for studies of herbaceous oldfield vegetation. *Ohio J. Sci.* 76, 185–188.
- Suthari, S., Kandagatla, R., Geetha, S., Ragan, A., Raju, V.S., 2016. Intrusion of devil weed *Chromolaena odorata*, an exotic invasive, into Kinnerasani and Eturnagarm Wildlife Sanctuaries, Telangana, India. *J. Threat. Taxa* 8, 8538–8540.
- Tothill, J.C., Mott, J.J., Gillard, P., 1982. Pasture weeds of the tropics and subtropics with special reference to Australia. In: Holzner, W., Numata, M. (Eds.), *Biology and Ecology of Weeds*. St Lucia, Qld., Australia, pp. 403–427.
- Updety, Y., Poudel, R.C., Shrestha, K.K., Rajbhandary, S., Tiwari, N.N., Shrestha, U.B., Asselin, H., 2012. Diversity of use and local knowledge of wild edible plant resources in Nepal. *J. Ethnobiol. Ethnomed.* 8, 1–16.
- Verma, B.K., Mishra, B.K., 1992. *Flora of Allahabad District U.P., India*. Bishen Singh Mahendra Pal Singh Publishers, Dehradun, India, pp. 530.
- Vitousek, P.M., Walker, L.R., 1989. Biological invasion by *Myrica faya*. Hawai'i: plant demography, nitrogen-fixation, ecosystem effects. *Ecol. Monogr.* 59, 247–265.
- Walkley, A., Black, I.A., 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 37, 29–38.
- Weber, W.A., 1982. Mnemonic three-letter acronyms for the families of vascular plants. *Taxon* 31, 74–88.