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Impact of *Lantana camara* L. invasion on riparian vegetation of Nayar region in Garhwal Himalayas (Uttarakhand, India)

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***Lantana camara* L. (Verbenaceae), an exotic from tropical America, has invaded vast areas of forests surrounding Nayar River in Garhwal Himalayas (Uttarakhand, India). Several factors like high reproductive potential, absence of preferred predators, evergreen nature and sufficient moisture provided by river water favour extraordinary growth of *L. camara* in this area. In this study, the impact of *L. camara* invasion on basal area cover, density, frequency and abundance of various plant species was determined. Invasion was able to change the quality (composition, distribution) and quantity (growth in number and size) of different species in this region. The invasion was also found to have some relation with native-exotic nature and different plant habits (like tree and herbs) of local flora. As determined by various ecological indices, there was significant loss of species richness and diversity in invaded localities. In total, there was a 28.4% decrease in species richness of invaded localities. Excluding *L. camara*, nearly 63% loss of basal area of vegetation was recorded in the invaded localities compared to not invaded ones. There was also an impression that *L. camara* favoured exotics over endemic species in this riparian zone.**

Key words: Invasion, *Lantana camara*, riparian, species richness, species diversity, Garhwal Himalaya.

INTRODUCTION

There is a plethora of biological invasions across the blue planet in the 21st century. They affect ecological processes, which sooner or later contribute to the loss of biodiversity from native ecosystems (Vitousek, 1988; Baret et al., 2004; Lodge et al., 2006; Pauchard and Shea, 2006). After habitat destruction, this is the second most extensive threat to global biodiversity on continents, and second to none in the case of islands (Sharma et al., 2005a). Risk is not only restricted to biodiversity loss, as invasive alien species (IAS) also threaten the environment, economies, and human welfare (Lodge et al., 2006). Therefore global efforts are being made tocontrol these invaders.

In India, a large number of exotics are naturalized, affecting the distribution of native flora. A few among them have conspicuously altered the vegetation patterns of the country. Reddy (2008), reported 173 IAS from India, 80% introduced from the neotropics. The most prominent invasive species include *Ageratum conyzoides* L., *Chromolaena odorata* L., *Eupatorium adenophorum* Spreng, *Lantana camara* L., *Mikania micrantha* Kunth, *Mimosa invisa* (Mart.) Solms, *Parthenium hysterophorus* L. and *Prosopis juliflora* (Sw.) DC. among terrestrial plants, and *Eichhornia crassipes* (Mart.) Solms and *Pistia stratiotes* L., among aquatic IAS. All these species are principal threats to the native flora (Sharma et al., 2005b; Hajra and Negi, 2007). *P. hysterophorus* and *A. conyzoides*

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Abbreviations: IAS, Invasive alien species.

are mainly invaders of agroecosystems and pastures throughout India (Kohli et al., 2006; Javaid et al., 2009); *C. odorata* , *E. adenophorum*, *M. micrantha* are mainly invaders of forest, pastures and wastelands of Himalayan region, north-east and south-east India (Ramakrishnan, 1991; Kunwar, 2003; Muniappan et al., 2005). Specifically in the North-Western Himalayas, invasive plants such as *L. camara*, *P. hysterophorus* and *A. conyzoides* are the most problematic weeds (Kohli et al., 2004; Dogra et al., 2009a, b). Amongst these *L. camara* is considered as one of world's top 100 invasive species and top 10 worst weeds of the world (Sharma et al., 2005a; IUCN, 2009). It is a major invader of forests, pasture and wastelands throughout the India (Dobhal, 2010). The success of *L. camara* may be attributed to large number of fruits per plant (Kohli et al., 2006; Dobhal, 2010), its ability to grow under a wide range of climatic conditions (Day et al., 2003), allelochemicals released by roots in the soil inhibiting the growth of neighbouring plants (Ambika et al., 2003; Yadav et al., 2004), and possession of some feeding deterrents that probably render them less acceptable to generalist herbivores than non-invasive plants (Jogesh et al., 2008; Sharma et al., 2007). Its dominance in invaded areas and possession of poisonous components like triterpenes leads to forage scarcity and bad health or deaths of animal (Morton, 1994; Ghisalberti, 2000; Sharma et al., 2007). This species also possess ability to change socio-economic scenario of invaded regions. In India, its invasion is associated with estimated loss of US$ 924 million per year (Pimentel et al., 2000). This IAS also dominates traditional rain fed agriculture areas of mountainous Himalaya and the interest of the farmers towards agriculture is declining rapidly (Maikuri et al., 2001). These left out terraced agricultural fields, orchards and nurseries appears even more intensely dominated by this weed. Although it is well known that *L. camara* is a serious invader of various terrestrial ecosystems, there are few studies which emphasize the magnitude of the influence of this weed on the biodiversity of native ecosystems (Sharma et al., 2005a). For example, Sharma and Raghubanshi (2007) reported this invasive as being responsible for differential depletion of native trees. In Himalayas, this was found to be associated with marked decreased species density, frequency, abundance and basal area and biomass of other species of invaded community (Bhatt et al., 1994; Dobhal et al., 2009). The explicit impact of *L. camara* invasion in riparian zones is also not reported, particularly in India. To fill this gap, a study was conducted in the Pauri-Garhwal region of Uttarakhand, the Himalayan state in Northern India. Here, large areas surrounding the River Nayar are invaded by this weed. It was hypothesized that invasion of *L. camara* led to degradation of typical structure of valuable flora in this riparian ecosystem in terms of richness, diversity and native /exotic composition of species.

STUDY AREA

The study was conducted in the Pauri Garhwal (29°45´-30°15´N Latitude and 78°24´ -79°23´E Longitude), a district of Uttarakhand state, situated in Northern India. At an altitude of ≈ 600 m asl, running amid two ranges of lesser Himalaya (Dudhatoli - Pauri range in the north-east and Lansdowne - Mussoorie range in the south-west), Nayar is a major tributary of the River Ganges (Figure 1). The characteristic riparian vegetation of this region is dominated by *Acacia catechu* Willd. and *Dalbergia sissoo* Roxb. trees with associated shrubs and herbs such as *Carissa opaca* Stapf ex Haines, *Barleria cristata* L., *Cissampelos pareira* L., *Ichnocarpus frutescens* (L.) R. Br., *Justicia adhatoda* L., *Launaea acaulis* (Roxb.) Babcock ex Kerr., *Murraya koenigii* (L.) Spreng., *Sida cordata* (Burm. f.) Borss. Waalk., *Ziziphus mauritiana* Lam. There is heavy invasion of *L. camara* on both sides of the Nayar River.

METHODS

Data collection

The study area was divided into 3 sites; each covered a stretch of approximately 2.5 - 3 km along the river (Figure 1). At each site 4 quadrats, each measuring 4 × 4 m^2 were laid randomly in *L. camara* invaded localities. A corresponding "control quadrat" was laid in nearby non-invaded localities at ≥ 50 m away from each of these quadrats. In order not to miss any species, these studies were continued in four seasons namely spring (February to April), summer (May to July), monsoon (August to October) and winter (November-January). In this manner 96 quadrats were sampled during a year. In each quadrat, plants of each species were counted; basal area of each plant was calculated using a screw gauge for thin vegetation and vernier caliper or meter tape for thick stems. However, when there was high density of individuals of a particular herb species (e.g. grasses) and it was extremely difficult to separate each of them, the mean density of individual in 12 sub-quadrats was calculated. All these sub-quadrats were 100 cm^2 each and arranged in a random systemic design (Barbour et al., 1999) inside the larger quadrat measuring 1600 cm^2. This mean density when multiplied with total area of larger quadrat gave total number of individuals present inside. In other case when there were ≥100 individuals of a species in a quadrat, a mean basal area for randomly chosen 100 individual of that species from that specific quadrat was calculated and used as a representative basal area for that species in that particular quadrat.

Data analysis

The collected plants were identified to species level with the help of available floras Duthi (1911), Gaur (1999) and online annotated checklist of flora of Nepal available online at www.efloras.org. For comparison with type specimens, the herbarium of Botany Department, Panjab University and Botanical Survey of India (B.S.I.), Dehradun were also consulted. Species were characterized on the basis of their exotic-native status with the help of "flora of the District Garhwal North-West Himalaya" (Gaur, 1999) and "Germplasm Resources Information Network" (GRIN, 2008) an online database. Species were also categorised on the basis of their growth forms *viz.* climber, herb, shrub, tree and under-shrub.

Quantitative analysis of plants for per cent basal area,

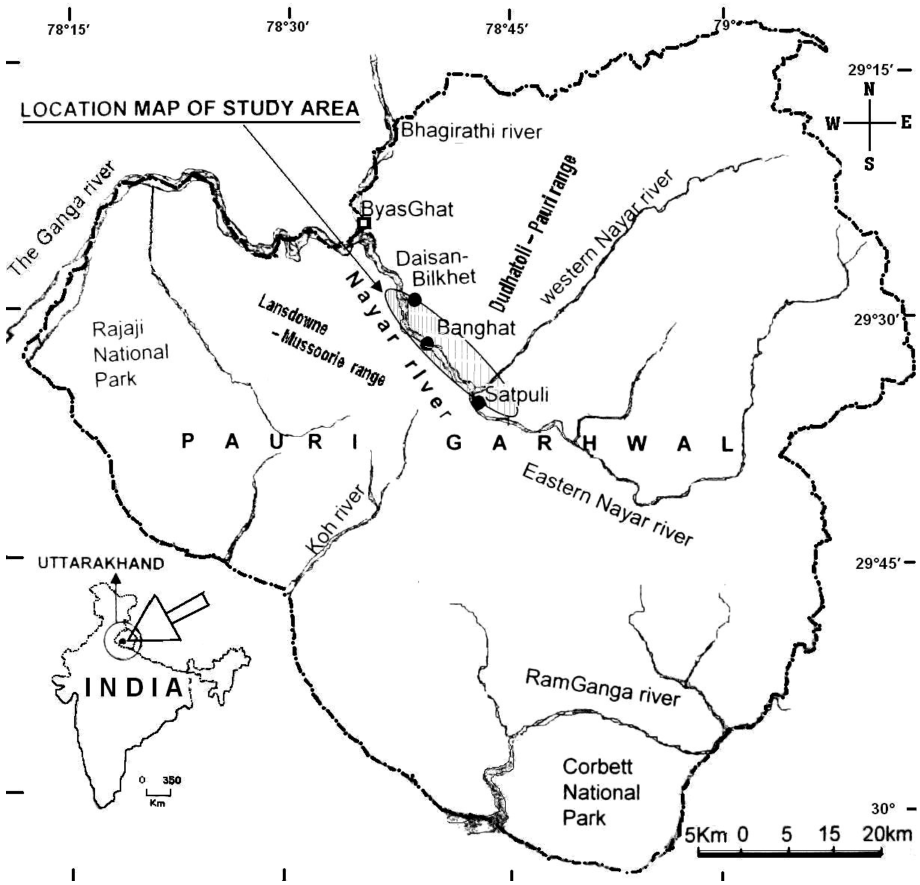

Figure 1. Location map of study area showing different sites of study.

abundance, density, frequency and importance value index (IVI) was done as per Misra (1968) and Ambasht (1990). Qualitative analysis in terms of richness, diversity and evenness indices was done using different methods. Species richness was calculated according to Margalef (1958), Menhinick (1964) and Peet (1974) as given in Sagar and Singh (1999). Diversity was calculated in terms of Fisher's diversity index α (Fisher et al., 1943), Shannon's index H' (Shannon and Weaver, 1963), Simpson's index λ (Simpson, 1949), Hill's number N_1 and N_2 (Hill, 1973), using Biodiversity Pro Version 2.0 (McAleece, 1997). Distribution of diversity was calculated in terms of Evenness number E_1 (Pielou, 1969) and E_2 (Sheldon, 1969) calculated per the method given in Sagar and Singh (1999), using the applicable ecological software package from Ludwig and Raynold (1988). Significance of difference between data was determined by Tukey-test using SPSS software.

RESULTS

A total of 89 plant species were recorded from the study area, of which 81 were found in non-invaded localities, 58 in *L. camara* invaded localities and 50 were common to both localities (Table 1).

There were 31 species (Table 1) found exclusively in non-invaded localities or absent from invaded localities. Standing out against these 31 sensitive species there were just 8 species, namely *Chloris dolichostachya*, *Jatropha curcas*, *Neyraudia arundinacea*, *Phyllanthus virgatus*, *Ricinus communis*, *Saccharum spontaneum*, *Sida acuta* and *Woodfordia fruticosa* which occurred exclusively in invaded areas, and may therefore be considered more resistant to *L. camara* invasion compared to all other species found in the study area. In comparison to non-invaded sites there was 28.4% reduction in species richness in invaded sites. Among species which were common to invaded and non-invaded localities *Cyanotis vaga*, *Phyllanthus urinaria*, *Boerhavia diffusa* and *Vallaris solanacea* were most severely influenced by invasion. Their IVI values in invaded localities were reduced respectively, to 25.1, 34.5, 43.0 and 15.7% of non-invaded localities. The other species demonstrating strong negative impacts of *L. camara* invasion were: *Oxalis corniculata* and *Murraya koenigii* throughout the year; *Cissampelos pareira* and *Launaea acaulis* during spring; *Gnaphalium hypoleucum, Geranium nepalens*, *Vallaris solanacea* and *Aerva sanguinolenta* during summer; and *Cyanotis cristata*, *Physalis minima*, *Dioscorea belophylla, Parthenium hysterophorus* and *Aerva sanguinolenta* during monsoon. The greatest number of species shows negative impacts during the winter, including *Mallotus philippensis*, *Aerva sanguinolenta, Securinega virosa, Ageratum conyzoides*, *Barleria cristata, Parthenium hysterophorus, Ipomoea*

Table 1. Inventory of plants in the study area in decreasing order of their IVI in *Lantana camara* invaded localities followed by species found exclusively in non-invaded localities.

S/No.	Botanical name (Family) and habit	Annual mean of importance value index		Native and exotic status* / native range
		Invaded localities	Non-invaded localities	
1.	*Lantana camara* L. (Verbenaceae) / S	89.43 ± 9.29	4.10 ± 1.08	E / Tropical America
2.	*Murraya koenigii* (L.) Spreng. (Rutaceae) / S	39.12 ± 12.18	65.08 ± 10.74	N / India, Asia
3.	*Ziziphus mauritiana* Lam. (Rhamnaceae) / S	18.94 ± 4.26	17.08 ± 2.97	N / India
4.	*Dalbargia sissoo* Roxb. (Fabaceae) / T	14.54 ± 2.77	14.99 ± 6.14	N / India, Pakistan, Afghanistan, Myanmar
5.	*Acacia catechu* Willd. (Mimosaceae) / T	14.05 ± 0.08	15.92 ± 3.69	N / India, Malaysia
6.	*Carissa opaca* Stapf ex Haines (Apocynaceae) / S	10.57 ± 1.73	10.47 ± 2.53	N / India, Pakistan, Sri-Lanka, Myanmar
7.	*Euphorbia hirta* L. (Euphorbiaceae) /H	8.64 ± 0.14	4.11 ± 2.09	N / Pantropics
8.	*Cassia occidentalis* L. (Caesalpiniaceae) / U-S	7.56 ± 3.92	3.03 ± 1.59	E / Tropical America
9.	*Parthenium hysterophorus* L. (Asteraceae) / H	6.98 ± 2.43	10.15 ± 5.77	E / Tropical America
10.	*Eragrostis tenella* (L.) P. Beauv. ex Roemer & Schultes (Poaceae) / H	6.23 ± 1.66	1.36 ± 0.46	N / India, Tropical and Temperate Asia, Africa
11.	*Ipomoea hederifolia* L. (Convolvulaceae) / C	6.16 ± 4.75	4.48 ± 3.82	E / America
12.	*Saccharum spontaneum* L. (Poaceae) / H	6.11 ± 4.87	- - - -	N / India, Pantropics
13.	*Oxalis corniculata* L. (Oxalidaceae) / H	5.03 ± 1.17	16.98 ± 8.03	O / Cosmopolitan
14.	*Corchorus aestuans* L. (Tilliaceae) / H	4.39 ± 5.07	2.35 ± 4.70	O / Neotropics (probably)
15.	*Ageratum conyzoides* L. (Asteraceae) / H	4.38± 1.24	8.15± 6.87	E / Tropical America
16.	*Aerva sanguinolenta* (L.) Blume (Amaranthaceae) /H	3.99 ± 2.09	6.82 ± 2.19	N / India, Bhutan, China, Myanmar, Malaysia, Nepal
17.	*Cissampelos pareira* L. (Manispermaceae) / C	3.82 ± 1.17	5.54 ± 1.29	E / America
18.	*Pyrus pashia* Buch. - Ham. ex D. Don (Rosaceae) / T	3.38 ± 0.50	1.02 ± 0.32	N / India, Bhutan, Myanmar
19.	*Ichnocarpus frutescens* (L.) R. Br. (Apocynaceae) / C	3.26 ± 0.61	1.71 ± 1.70	N / India, Sri-Lanka, Thailand, Indonesia
20.	*Celtis australis* L. (Ulmaceae) / T	3.16 ± 0.43	2.98 ± 0.84	E / Africa, South-Europe, Turkey
21.	*Launaea acaulis* (Roxb.) Babcock ex Kerr (Asteraceae) / H	2.57 ± 1.34	2.13 ± 0.46	N / India, Afghanistan, Pakistan
22.	*Phyllanthus virgatus* G. Forst. (Euphorbiaceae) / H	2.47 ± 1.70	- - - -	N / India, Sri-Lanka, China
23.	*Martynia annua* L. (Martyniaceae) / H	2.46 ± 2.84	1.91 ± 2.59	E / North America, Mexico
24.	*Sida cordata* (Burm. f.) Borss. Waalk. (Malvaceae) / H	2.45 ± 0.84	2.56 ± 1.53	E / America
25.	*Cassia tora* L. (Caesalpiniaceae) / U-S	2.28 ± 2.63	1.17 ± 1.19	E / South America
26.	*Neyraudia arundinacea* (L.) Henrard (Poaceae) / H	2.19 ± 2.12	- - - -	N / India, Tropical-Asia, Africa
27.	*Trichosanthes cordata* Roxb. (Cucurbitaceae) / C	1.80 ± 2.08	0.78 ± 1.56	N / India, Myanmar
28.	*Solanum incanum* L. (Solanaceae) / S	1.72 ± 1.17	2.21 ± 0.18	N / India, Africa
29.	*Capparis zeylanica* L. (Capparaceae) / S	1.69 ± 0.46	1.41 ± 0.34	N / India, Tropical and Temperate Asia
30.	*Boerhavia diffusa* L. (Nyctaginaceae) / H	1.38 ± 0.84	3.21 ± 5.95	O / Widely Naturalized
31.	*Securinega virosa* (Roxb. ex Willd.) Baillon (Euphorbiaceae) / S	1.24 ± 0.25	1.60 ± 0.49	N / India, Asia, Africa
32.	*Woodfordia fruticosa* (L.) Kurz (Lythraceae) / S	1.21 ± 0.23	- - - -	N / India, Burma, China, Africa
33.	*Triumfetta rhomboides* Jacq. (Tiliaceae) / U-S	1.12 ± 1.29	0.46 ± 0.93	N / India, China, Malaysia, Africa

Table 1 Contd.

34.	*Phyllanthus urinaria* L. (Euphorbiaceae) / H	1.09 ± 0.85	3.16 ± 5.98	N / Indian subcontinent, Indo-china, China, Japan
35.	*Vallaris solanacea* (Roth) Kuntze (Apocynaceae) / C	1.04 ± 0.71	6.64 ± 1.58	N / India, Tropical and Temperate Asia
36.	*Chloris dolichostachya* Lagasca (Poaceae) / H	1.01 ± 0.70	- - - -	N / India, Afghanistan, China, Myanmar, Sri-Lanka
37.	*Gnaphalium hypoleucum* DC. (Asteraceae) / H	1.00 ± 1.15	3.70 ± 6.48	N / Indian Himalayas Japan, China, Bhutan
38.	*Cyanotis cristata* (L.) D. Don (Commelinaceae) / H	0.93 ± 1.07	1.50 ± 2.66	N / India, Tropical Asia, Tropical Africa
39.	*Ipomea cairica* (L.) Sweet (Convolvulaceae) / C	0.91 ± 0.64	0.21 ± 0.43	E / Australia, America, New-Zealand
40.	*Jatropha curcas* L. (Euphorbiaceae) / S	0.91 ± 0.64	- - - -	E / Tropical America
41.	*Physalis minima* L. (Solanaceae) / H	0.86 ± 0.99	2.04 ± 2.39	E / Tropical America, Africa
42.	*Pupalia lappacea* (L.) Juss. (Amaranthaceae) / H	0.83 ± 1.66	0.55 ± 1.10	N / India, Pakistan, S.E. Asia, Africa, Madagascar
43.	*Cryptolepis buchananii* Roem. & Schult. (Asclepiadaceae) / C	0.72 ± 1.43	1.52 ± 0.55	N / India, China, Malaysia
44.	*Mallotus philippensis* (Lam.) Muell. Arg. (Euphorbiaceae) / T	0.71 ± 1.42	6.06 ± 1.67	E / Australia
45.	*Ampelocissus latifolia* (Roxb.) Planchon (Vitaceae) / C	0.67 ± 0.77	0.46± 0.91	N / India, Indian subcontinent
46.	*Holoptelea integrifolia* (Roxb.) Planch. (Ulmaceae) / T	0.66 ± 1.32	3.79 ± 0.59	N / India, Nepal, Myanmar, Sri-Lanka, Indo-China
47.	*Asparagus filicinus* Buch.-Ham. ex D. Don (Asparagaceae) / S	0.65 ± 0.48	1.05 ± 0.63	N / India, China, Indo-China, Myanmar
48.	*Geranium nepalense* Sweet (Geraniaceae) / H	0.61 ± 0.44	1.13 ± 1.34	N / India, Tropical and Temperate Asia
49.	*Cyanotis vaga* (Lour.) J. A. & J. H. Schult. (Commelinaceae) / H	0.46 ± 0.53	1.83 ± 3.65	N / India, Pakistan, Burma, Africa
50.	*Cypreus niveus* Retz. (Cyperaceae) / H	0.41 ± 0.48	0.15 ± 0.30	N / India, S. and S. E. Asia, Tropical Africa
51.	*Gomphrena globosa* L. (Amaranthaceae) / H	0.34 ± 0.39	0.11 ± 0.22	E / Tropical America
52.	*Dioscorea belophylla* (Prain) J.O. Voigt. ex Haines (Dioscoreaceae) / C	0.33 ± 0.39	0.89 ± 0.36	N / Indian Himalayas
53.	*Rhus parviflora* Roxb. (Anacardiaceae)	0.32 ± 0.64	0.16 ± 0.32	N / India, Nepal, Sri-Lanka
54.	*Peristrophe bicalyculata* (Retz.) Nees (Acanthaceae) / H	0.26 ± 0.52	0.29 ± 0.58	N / India, Nepal
55.	*Sida acuta* Burm. (Malvaceae) / H	0.26 ± 0.52	- - - -	E / Africa
56.	*Euphorbia helioscopia* L. (Euphorbiaceae) / H	0.26 ± 0.52	0.16 ± 0.31	E / Eurasia
57.	*Barleria cristata* L. (Acanthaceae) / U-S	0.24 ± 0.47	0.41 ± 0.81	N / India, Myanmar, Indo-China
58.	*Ricinus communis* L. (Euphorbiaceae) / S	0.22 ± 0.44	- - - -	E / Tropics, Africa
59.	*Abrus prectoris* L. (Fabaceae) / C	- - - -	0.97 ± 0.71	N / India, Old World Tropics
60.	*Anisomeles indica* (L.) Kuntze (Lamiaceae) / H	- - - -	0.65 ± 1.30	N / India, China, Malaysia
61.	*Arthraxon prionodes* (Steudel) Dandy (Poaceae) / H	- - - -	3.00 ± 6.00	N / India, Tropical and Temperate Asia, Africa
62.	*Asclepias curassavica* L. (Asclepiadacea) / H	- - - -	0.17 ± 0.34	E / Tropical America

Table 1. Contd.

63.	*Atylosia scarabaeoides* (L.) Benth. (Fabaceae) / H	- - - -	0.10 ± 0.21	N / India, China, Malaysia
64.	*Brachiaria reptans* (L.) Gardner & C. E. Hubbard (Poaceae) / H	- - - -	3.97 ± 4.65	N / India, Tropical and sub-tropical Asia, Africa
65.	*Butea monosperma* (Lam.) Kuntze (Fabaceae) / T	- - - -	12.62 ± 0.92	N / India, Nepal, Pakistan, Malaysia, Indo-China
66.	*Cannabis sativa* L. (Cannabaceae) / H	- - - -	0.37 ± 0.73	N / India, Central Asia
67.	*Cassia fistula* L. (Caesalpiniaceae) / T	- - - -	6.84 ± 0.55	N / India, Myanmar
68.	*Circium verutum* (D. Don) Sprengel (Asteraceae) / H	- - - -	0.41 ± 0.83	N / India, Pakistan, Afghanistan
69.	*Coccinia grandis* (L.) Voigt (Cucurbitaceae) / C	- - - -	0.54 ± 1.07	N / India, Tropical and Temperate Asia , Africa
70.	*Dioscorea bulbifera* L. (Dioscoreaceae) / C	- - - -	0.12 ± 0.24	N / Pantropics
71.	*Eupatorium adenophorum* Spreng. (Asteraceae) / S	- - - -	0.54 ± 0.37	E / North America, Mexico
72.	*Flacourtia indica* (Burm. F.) Merrill (Flacourtiaceae) / S	- - - -	0.12 ± 0.24	N / India, Tropical and Temperate Asia, Africa
73.	*Galium asparifolium* Wallich (Rubiaceae) / H	- - - -	0.98 ± 1.96	N / India, Myanmar, Sri-Lanka
74.	*Galium elegans* Wall. ex Roxb. (Rubiaceae) / H	- - - -	2.27 ± 4.54	N / India, Nepal, Bhutan, W. China
75.	*Gloriosa superba* L. (Liliaceae) / H	- - - -	0.21 ± 0.42	N / Tropical Asia, Africa
76.	*Grewia optiva* J. R. Drumm. ex Burret (Tiliaceae) / T	- - - -	0.56 ± 0.43	N / India, Nepal
77.	*Jasminum arborescens* Roxb. (Oleaceae) / C	- - - -	1.19 ± 2.38	N / India, Pakistan, Sri-Lanka
78.	*Justicia adhatoda* L. (Acanthaceae) / S	- - - -	3.21 ± 0.58	N / India, Indo-China
79.	*Lactuca dissecta* D. Don (Asteraceae) / H	- - - -	1.38 ± 2.75	N / India, Tropical and Temperate Asia
80.	*Malvastrum coromandelianum* (L.) Garcke (Malvaceae) / H	- - - -	0.61 ± 0.71	E / Southern USA, Mexico, Central America
81.	*Momordica dioica* Roxb. Ex Willd. (Cucurbitaceae) / C	- - - -	0.45 ± 0.89	N / India, Malaysia, Sri-Lanka
82.	*Naringi crenulata* (Roxb.) Nicolson (Rutaceae) / T	- - - -	2.07 ± 0.38	N / Indian subcontinent, China, Indo-China
83.	*Oenothera rosea* L'Herit. ex Aiton (Onagraceae) / H	- - - -	1.98 ± 3.95	E / America
84.	*Rhamnus virgatus* Roxb. (Rhamnaceae) / S	- - - -	0.20 ± 0.40	N / India, Temperate Asia
85.	*Saussurea candicans* (DC.) Sch. Bip. (Asteraceae) / H	- - - -	0.63 ± 1.26	N / India
86.	*Solanum nigrum* L. (Solanaceae) / H	- - - -	2.44 ± 1.31	E / Eurasia
87.	*Syzygium cumini* (L.) Skeels (Myrtaceae) / T	- - - -	0.40 ± 0.48	N / India, Tropical-Asia
88.	*Toona serrata* (Royle) M. Roemer (Meliaceae) / T	- - - -	0.78 ± 1.55	N / India, Myanmar
89.	*Urena lobata* L. (Malvaceae) / U-S	- - - -	0.71 ± 0.96	E / Australia

Given after family: C for climber, H for herb, S for shrub, T for tree and U-S for under-shrub; - - - - Species absent; *Status based on native and exotic status where; N, E and O stand for Native, Exotic and Obscure status respectively; ± is standard deviation.

hederifolia, *Holoptelea integrifolia* and *Sida cordata*. On the other hand, among species which were common to invaded and non-invaded localities, only a few species were growing more luxuriously in invaded localities.

Table 2. Mean number of plant species in terms of climber, herb, shrub, tree and under-shrub among species present in non-invaded, exclusively in non-invaded, commonly in invaded and non-invaded, in invaded and exclusively in invaded localities.

	Habit type	In non-invaded localities	In Invaded localities	Common in both localities	Exclusively in non-invaded localities	Exclusively in invaded localities
Number of species representing plant habit	Climber	9.33 ± 2.52	6.33 ± 0.58	5.67 ± 1.53	5.50 ± 0.71	1.00 ± 1.41
	Herb	24.67 ± 2.08**	13.00 ± 4.36	10.33 ± 4.73	14.33 ± 3.21**	2.67 ± 0.58
	Shrub	8.67 ± 2.08	8.33 ± 3.21	6.67 ± 2.08	2.00 ± 0.00	1.67 ± 1.15
	Tree	7.33 ± 2.31*	4.33 ± 0.58	4.33 ± 0.58	3.00 ± 1.73*	0
	Under-shrub	4.00 ± 1.00	2.67 ± 1.53	2.00 ± 1.00	2.00 ± 1.73	0.67 ± 0.58
Total species		54.00 ± 7.00*	34.33 ± 2.08	29.00 ± 2.65	25.00 ± 9.17*	5.33 ± 0.58

*Significantly different at level P < 0.05** and 0.1* from associated *L. camara* invaded localities, as estimated by t-test , ± is standard deviation.

Table 3. Percentage of sum of % basal area for all species, sum of frequency for all species, sum of density for all species, sum of abundance for all species in invaded compared with non-invaded localities during four seasons.

Season	Percentage against non-invaded localities			
	Sum of % basal area covered by all species	Sum of frequencies of all species	Sum of densities of all species	Sum of abundance of all species
Spring	83.15	70.29	66.25	52.88
Summer	74.45	89.64	75.25	88.30
Monsoon	73.04	62.98	45.22	75.96
Winter	78.42	56.84	49.81	51.75
Annual mean	77.27 ± 4.537	69.9 ± 14.2	59.1 ± 14	67.2 ± 17.9

These were *Martynia annua* and *Cassia tora* specifically during summer; *Euphorbia hirta* and *Cassia occidentalis* during summer as well as monsoon seasons; and *Eragrostis tenella* and *Pyrus pashia* throughout the year.

In terms of plant habit *L. camara* invasion seems to have maximum impact on herbs and trees. In comparison to 24.67 ± 2.08 herb species in non-invaded localities there were significantly less, 13.00 ± 4.36 species in *L. camara* invaded localities (Table 2). Similarly, compared to 7.33 ± 2.31 tree species in non-invaded localities there were significantly less (4.33 ± 0.58) species in *L. camara* invaded localities. The trend continued among those species which were exclusive to either invade or non-invaded localities. There were fewer herbaceous and no tree forms among species specific to invaded localities in comparison to species present specifically in non-invaded localities.

The values for invaded localities in terms of sum of per cent basal area (secondary growth of stem), sum of frequencies (probability of finding any species), sum of densities (overall density) and sum of abundance (local density) of all species were very low compared to non-invaded sites (Table 3).

The negative impact of *L. camara* on local flora is illustrated by the lower percentage values for invaded localities in terms of various parameters mentioned above varied with different seasons. The annual mean value of overall basal area of all plants from invaded localities was 77.27 ± 4.54% of non-invaded localities. It was lowest (73.04%) during winter and highest (83.15%) during spring. The sum of frequencies of all species in invaded localities was reduced to 69.9 ± 14.2% of non-invaded localities (Table 3).

Thus, with changing seasons there were some large fluctuations in impact of *L. camara* invasion on probability of finding any plant species. The maximum negative impact was found during winter season, when overall frequency of finding any species in invaded localities was reduced to just 56.84% compared to non-invaded localities. Relatively lesser negative impact was observed during summer, when frequency for invaded localities was 89.64% of non-invaded ones. Overall density of plant species in invaded localities was just 59.1 ± 14% of non-invaded localities; it was most negatively affected feature of plant distribution in invaded localities. The impact on density was most severe during monsoon followed by winter when overall density of plants in invaded localities was reduced to nearly half of corresponding non-invaded localities. Similarly, overall abundance of all species from invaded localities was very low; it was 67.2 ± 17.9% of non-invaded localities (Table 3).

Among all parameters mentioned above, overall value of basal area demonstrated a comparatively lesser impact of invasion. However, this was not the case if the

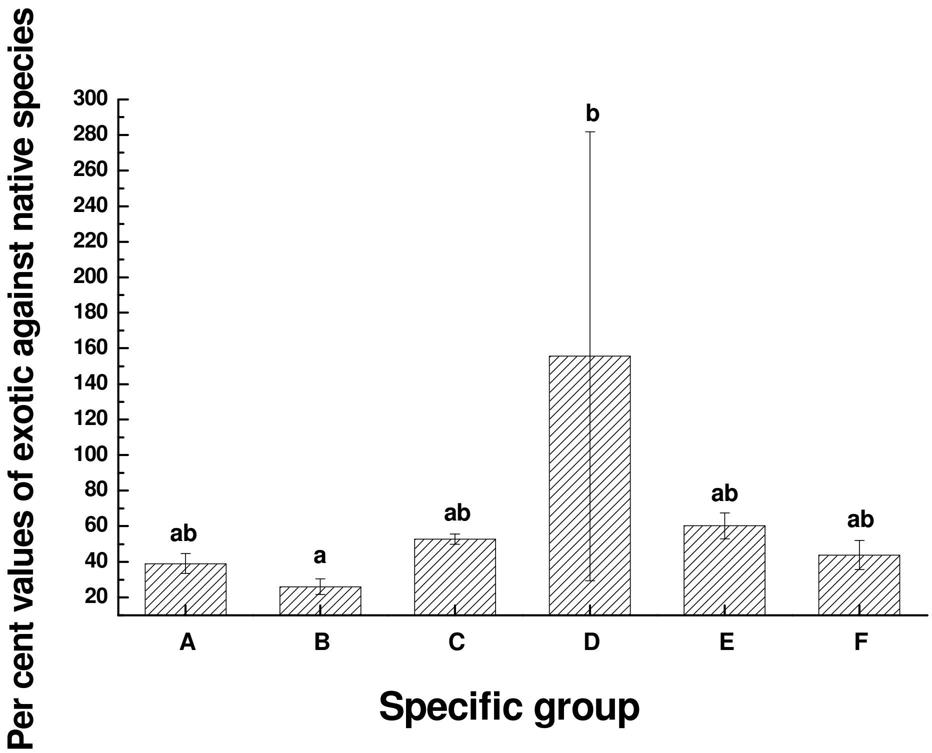

Figure 2. Percentage of exotics in relation to native species present in non-invaded (A), exclusively in non-invaded (B), commonly in invaded and non-invaded (C), exclusively in invaded (D), in invaded localities (E) and in whole area under study (F). Means denoted by different alphabets are significantly different at P < 0.1, as estimated by Tukey-test, ± is standard deviation.

basal area of *L. camara* is excluded from the analysis. In invaded localities *L. camara* had about 62.9 ± 0.86% contribution in total basal area of all species. Thus, although the total basal area of plants present in invaded localities was 77.27 ± 4.54% of non-invaded localities, this was mainly due to *L. camara*. The contribution of other plants was very low, that is, 37.42 ± 0.8% of non-invaded localities. Similarly, *L. camara* also had maximum (29.81 ± 3.1%) share in total IVI for invaded localities.

After incorporating data on the exotic and native status of each species found during the present study, *L. camara* was found to have some relation with exotic and native status of species. There were 27% exotics among the flora of Nayar irrespective of invaded or non-invaded localities. However, the percentage of exotics was found to vary when plants in this region were divided into different subsets on the basis of their presence and absence in invaded and non-invaded localities. It was 30, 19.35 and 50% among species common to invaded and non-invaded localities, species specific to non-invaded localities and species specific to *L. camara* invaded localities respectively.

During this survey the overall number of exotics was found to be 43.8 ± 8.1% of the native species (Figure 2). The exotic to native species ratio was particularly high (60.3 ± 7.2%) in the invaded localities, compared to (39 ± 9.6%) for non-invaded localities. The share of exotics among those species which were present exclusively in non-invaded localities was 26 ± 4.4% of native species. This was very low in comparison to overall per cent of exotics against natives. However, among those species which were restricted exclusively to *L. camara* invaded localities there were extremely high percentage (155.5 ± 126.2) of exotics in relation to native species. The exotic to native ratio were significantly different in case of species those were exclusive to non-invaded localities and those were restricted to invaded localities. Exotic species had 63.78% share in total basal area cover of invaded localities. It was extremely high in comparison to 3.55% for non-invaded localities. The percent share of exotics in overall frequency of occurrence of plant species in invaded localities (33.82%) was also higher compared to 26.83% for non-invaded localities (Figure 3). Exotics also constituted a higher percentage of total density of plants in invaded localities, although the trend was reversed in the case of abundance. The percentage of exotics in total IVI of invaded localities (44.38), that was nearly equal to per cent share (52.02) of non-invaded localities, also indicated that exotics were

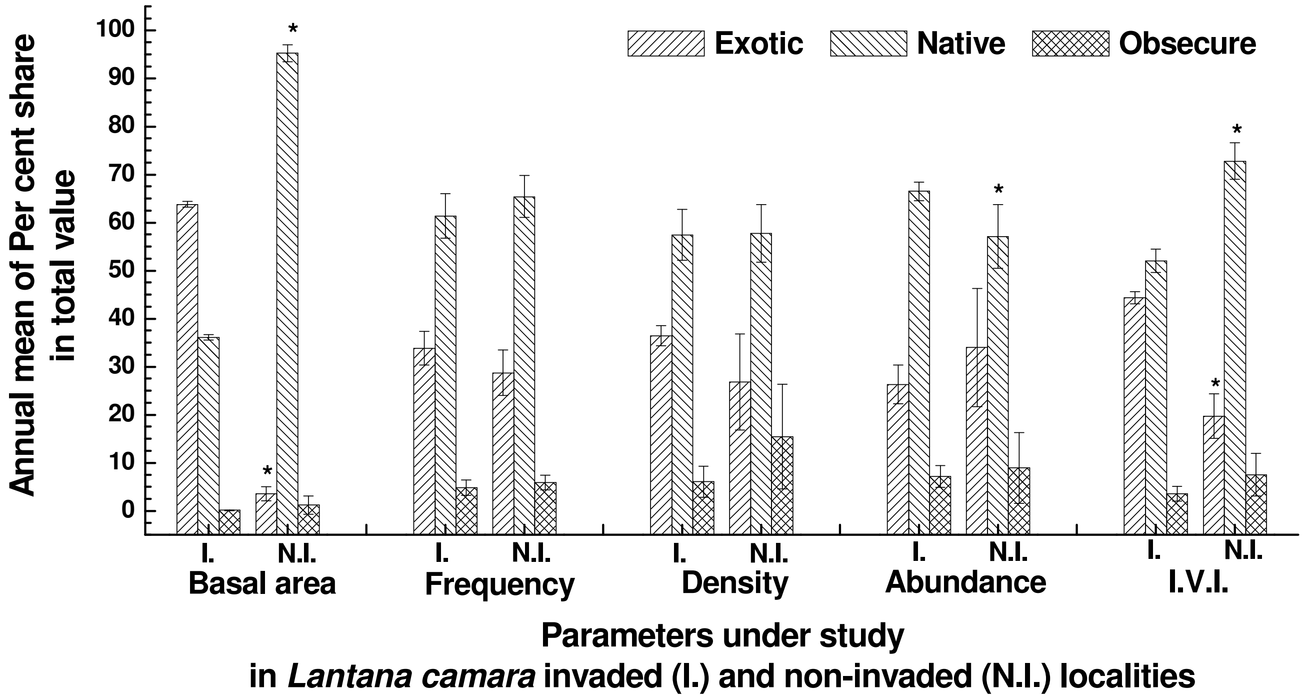

Figure 3. Percentage of species with exotic, native and obscure origin, in terms of basal area, frequency, density, abundance and IVI. Mean values for invaded localities with asterix (*) above bar are significantly different from corresponding non-invaded localities at $P < 0.05$, as estimated by Tukey-test, ± is standard deviation.

occupying very important places in *L. camara* invaded localities (Figure 3).

The species richness and diversity of invaded localities was very low in comparison to non-invaded localities. The difference was extremely high and significant in terms of species richness (Table 4). In terms of diversity, however, there was not a very large difference between the two compared localities. Despite this, the diversity of invaded localities was significantly lower than that of non-invaded localities in terms of Fisher's diversity index (α), Shannon's index (H'), and Hills number (N_1). The difference was neither very large and nor statistically significant in terms of Simpson's index (λ) and Hills number (N_2). Despite having lower values of diversity, the invaded localities had nearly equally even distribution of diversity (as shown by evenness E_1 and E_2) to that of non-invaded localities (Table 4).

DISCUSSION

L. camara has serious deleterious effect on some of endemic animal (Morton, 1994; Sharma et al., 2007) and plant species. It is also known to displace natural scrub communities as well as prevent natural regeneration of some tree species (Ambika et al., 2003; Sharma and Raghubanshi, 2006; Dobhal, 2010). In Shivalik hills in northwestern Himalayan range of India, it was observed that the diversity, evenness and richness of the native species were drastically reduced in the forest invaded by the exotics (Dogra et al., 2009a,b). Similar patterns were observed in the case of riparian forests along the Nayar River, where a decrease of nearly 30% in species richness was recorded in *L. camara* invaded localities. Compared to non-invaded localities there were significantly fewer herb and tree species in *L. camara* invaded localities. Specially, there were no tree species among species found exclusively in invaded localities. Plant species with specific root and shoot distribution habits in relation to *L. camara* may come across different level of resource competition and allelopathic inhibition offered by this invasive (Dobhal et al., 2010). This could also be a plausible reason for observed variation in impact of *L. camara* invasion on different life forms.

Anthropogenic and natural disturbances act together to facilitate the introduction and spread of exotic species in riparian zones. Further, the availability of moisture and the dispersal of propagules by water may increase invasibility of riparian zones (Hood and Naiman, 2000; Pysek and Prach, 1994). In riparian zones between hill slopes, such as in Nayar region where more than 25% of total species were exotics, there can be concentrated energy and material flow during flooding and other geomorphic disturbances and riparian forest communities

Table 4. Values of different parameters associated with richness and diversity in *L. camara* invaded and non-invaded localities.

Parameters associated with species richness and diversity and distribution		Locality type	
		Non-invaded	***L. camara* invaded**
Richness	Number of species (N_0)	31.50 ± 6.24**	22.00 ± 4.07
	Peet index (P)	842.35 ± 291.59**	451.47 ± 165.01
	1. Margalef index (R_1)	3.50 ± 0.53**	1.11 ± 0.14
	2. Menhinick index (R_2)	4.68 ± 1.22*	0.78 ± 0.16
Diversity	Fisher's diversity index (α)	6.87 ± 1.30**	5.05 ± 0.84
	Shannon's index (H')	2.61 ± 0.32**	2.36 ± 0.32
	Simpson's index (λ)	0.12 ± 0.05	0.14 ± 0.06
	Hills number N_1	14.29 ± 4.42**	11.07 ± 3.56
	Hills number N_2	9.91 ± 3.71	8.11 ± 3.19
Distribution of diversity (Evenness or equitability)	Evenness E_1	0.76 ± 0.07	0.77 ± 0.07
	Evenness E_2	0.45 ± 0.09	0.50 ± 0.10

*Significantly different at level P < 0.05** and 0.1* from associated *L. camara* invaded localities, as estimated by t-test, ± is standard deviation.

use material trapped by these disturbances (Junk et al., 1982; Nakamura and Inahara, 2007). In this region exotics had a higher percentage share in total density of plants in invaded localities, but the trend was reversed in the case of abundance. Higher percentage values of exotics in total abundance of non-invaded localities indicated that in non-invaded localities, exotics were mostly restricted to small abundant patches, whereas they were distributed densely throughout in the area invaded by *L. camara*. Further, there was a significantly higher proportion of exotics among species found exclusively with *L. camara* against species present exclusively in non-invaded localities, indicating that *L. camara* facilitates the invasion of other exotics. It appears that *L. camara* invasion sweeps over native flora and promotes the establishment of other exotic species. Thus, there was a possibility that in near future exotics may cover larger areas of the region in comparison to endemics, as *L. camara* infestation continues increasing without any barrier. The increase in the ration of exotic to endemic species in Nayar region becomes crucial as this region is a part of Garhwal-Kumaon Himalayas (Uttarakhand), one of 25 micro-endemic centers in India (Subramani et al., 2005).

Basal areas and density of plants of a species, respectively, provide simple indicators of growth and survival rates of a species. In invaded areas there was lower basal area of plants, of which *L. camara* had most of the share; besides this there was decrease in the overall number of species, the number of individuals per species, and overall density. There were also lower chances of frequent occurrence of any species in invaded localities compared to associated non-invaded ones. In total there was significantly lower richness and diversity and overall health of plants in invaded localities compared to non-invaded ones. This may be attributed to thick monoculture of *L. camara* that alter the microenvironment (light, pH and temperature) beneath the *L. camara* thickets, and inhibit either germination or growth of other species (Sharma and Raghubanshi, 2007).

Although riparian zones can act as a buffer against fire and act as a refuge for fire-sensitive species, under some circumstances, like dry climate and the accumulation of dry fuel, riparian areas become corridors for fire movement. Fires in riparian zones create canopy gaps and drier conditions, which allow establishment of fire adapted species (Pettit and Naiman, 2007). Increased dominance of a fire loving species like *L. camara* in such an important buffer zone may have far reaching consequences on native riparian ecosystem. There may be a positive feedback between fires and invasion by *L. camara*, leading to a fire *L. camara* cycle that can have deleterious compositional and functional consequences for forest ecosystems (Hiremath and Sundaram, 2005, Dobhal et al., 2009). Being a complex process it is difficult to evaluate the effect of an invader on fire regimes (Strayer et al. 2006). However, reports of significant increase in *L. camara* seed germination in smoke (Raizada and Raghubanshi, 2010) and enhanced prolification after fire (Gentle and Duggin, 1997; Dobhal et al., 2009) supports the view given above.

Conclusions

L. camara poses a threat to local flora. The number, density and frequency and overall health of species were remarkably poor in invaded areas. Though it is premature to say, it seems that *L. camara* favours exotics over endemic species. However, more studies are required to further investigate this relationship. Further, due to its inflammable nature and dominance in regional flora, *L. camara* is a potential threat to riparian zones that can act as a buffer against fire and act as a refuge for fire-sensitive species. Consequently, beside individual species and life forms such as trees and herbs, the entire forest ecosystem itself is under threat due to *L. camara* invasion. It requires the immediate committed attention of ecologists, conservationists and policy makers.

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