INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 5, Issue 4, October-December 2014: 511-526 www.ijcs.uaic.ro

QUANTITATIVE VEGETATION DYNAMICS AND INVASION SUCCESS OF LANTANA CAMARA FROM THE TROPICAL FORESTS OF DOON VALLEY

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Abstract

Structure, composition and function are the three important attributes of forest ecosystems. These attributes change in response to climate, topography, soil and disturbances. The above mentioned factors along with forest succession are also responsible for both local and landscape level variations in forest ecosystems. The present study aimed to analyse the quantitative vegetation dynamics and diversity of plants from the dry deciduous forests and fallow lands of Doon Valley. Forest sites were chosen from three extreme end of the valley and other sites were selected according to the level of variations to study species richness, regeneration and change in community composition in the context of overstorey structure and invasion success of a non native invasive species Lantana camara employing nested quadrat method. Change in community composition has taken place with Shorea robusta as the main dominant and Mallotus philippensis, Syzygium cumini and Ehretia laevis becoming co – dominant tree species in all community; this association is new for these forests. Effect of overstorey structure was noticeable, highest species richness and diversity was increasing with a decrease in tree density and basal area. Lantana camara over past few years has become a threat to the western Himalayan forests. On the basis of IVI (Importance Value Index) assessment it is clear that Lantana is profusely growing in all types of habitats, on the other hand the invasion of other plant species is restricted to their suitable habitats. The invasion success of Lantana was found depending on forest gap size as gap size was significantly correlated to the inflorescence, infructescence and pollinator visitors.

Keywords: *Phytodiversity; Importance Value Index (IVI); Invasive Alien Species (IAS), Vegetation Ecology; Biological invasion; Biodiversity measurement*

Introduction

Vegetation is the most obvious physical representation in the majority of terrestrial ecosystem. The structure and composition of the vegetation not only reflects the nature of basic trophic structure but also forms habitat for numerous organisms. Therefore, information on these parameters of the vegetation with concurrent recording of environmental factors become quite valuable in a variety of ecological problems such as an input to Environmental Impact statements, in monitoring the management practices or as a basis for predicting possible changes [1, 2]. Changes in vegetation overtime may also need to be described using concept of succession and climax [3]. Owing to a wide altitudinal and topographic variation, GHNP

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supports a large number of vegetation types. Several abiotic and biotic (largely anthropogenic) factors influence the vegetation of this Park. Quantitative information on these aspects therefore, becomes crucial for the conservation and management of biodiversity in the area. The knowledge of the floristic composition of a plant community is a prerequisite to understand the overall structure and function of any ecosystem. Vegetation is the most precious gift, nature has provided to us, as it is meeting all kinds of essential requirements of the humans in the form of food, fodder, fuel, medicine, timber, resins, and oil, etc. Garhwal Himalaya has been a centre of floristic as well as ecological studies from past hundreds of years. The first authentic attempt to collect the plants from Garhwal Himalaya was made by an English officer Thomas Hardwicke in 1796. He collected large number of plants from Alaknanda Valley [4]. The study on the North Western Himalaya got acceleration after the establishment of Botanical Garden at Saharanpur by Hastings and Forest Research Institute. Duthie [5] revised and supplemented the catalogue of the plants of Garhwal based on the collections made by Strachey and Winterbottom during the years 1846-1849.

The Indian Himalayan Region (IHR) is considered as the repository of biological and cultural diversity and supports about 18,440 species of plant, includes 1748 species of medicinal plants and 675 species of wild edibles [6]. The representative biodiversity rich areas of the IHR have been protected through a Protected Area Network (PAN). At present there are 5 biosphere reserves, 28 national parks, and 98 wildlife sanctuaries in IHR covering 51,899.238 km^2 [7]. These protected areas are distributed in tropical, temperate, and alpine ecosystems. The following study was conducted in one of the protected areas, Kedarnath Wildlife Sanctuary, which falls in Western Himalayan Uttarakhand State of India to enumerate the wealth of higher plants.

Doon Valley covers the outer Himalayan ranges in the north and north-east and Shiwalik ridge in the south and south-west, with rivers Ganga and Yamuna forming the other two sides. Due to wide variations in topography and other factors, Doon valley possesses a very rich and varied flora and has been explored by various workers [5, 8-14].

The study sites chosen for the present study are experiencing the wide range of anthropogenic disturbances like collection of fuel and fodder, cattle grazing, increase in the population near the villages of the study sites. In recent years, especially after the inception of Uttarakhand in year 2000 and Dehra Dun's (Doon Valley) becoming the capital of this state, this valley is expanding exponentially. The Doon Valley dry deciduous sal forest is rare and one of its kind which is now experiencing remarkable change. There has been noticeable change in the land use system of this valley due to the setting up of over 200 small scale industries, increasing population, widening of roads, construction of national highways and flyovers, illegal land encroachment, increasing tourist flux and development of urban townships. These factors are continuously affecting the dynamics and phytodiversity of this valley, also promoting the invasion of some noxious woody shrubs like *Lantana* which gradually decreasing the native biodiversity. In some of the forest peripheries chosen in this study are found heavily infested by this invasive shrub which further suppressing the growth of many native species. An alien plant also referred to as exotic, introduced, foreign, non-indigenous or non-native, is one that has been introduced by humans intentionally or otherwise through human agency or accidentally from one region to another. An alien plant that has escaped from its original ecosystem and is reproducing on its own in the regional flora is considered a naturalized species. Those naturalized aliens that become as successful as to spread in the flora and displace native biota or threatens valued environmental, agricultural or personal resources by the damage it causes are considered invasive. According to the convention for biological diversity, invasive alien species are the second largest cause of biodiversity loss in the world and impose high costs to agriculture, forestry and aquatic ecosystems. In fact, introduced species are a greater threat to native biodiversity than pollution, harvest and disease combined.

Lantana camara L. (*Lantana* henceforth) has been known by at least five different polynomial descriptive names, including *Lantana*, *Viburnum* and *Periclymenum* [15]. Linnaeus first described and gave it its binomial name, *Lantana camara*, in 1753 [15]. *Lantana* (Verbenaceae) is among top ten invasive weeds on the earth [16]. It grows as a very robust and aggressive scrambling woody shrub, in its native range in Tropical America; *Lantana* generally remains confined to small thickets up to 1.0m diameter [17]. However, in its naturalized range, like current study areas in Doon Valley where competition is more with the native trees it forms dense monospecific thickets, with individual reaching of 2 – 6m height (Personal observation) and spreading in 2 – 4m diameter. However, it may grow as high as 15 meters, if sufficiently supported by other vegetation [18]. The stems are four angled and have small, soft but sharp recurred prickles.

Lantana has a relatively short taproot with many lateral roots branching out to form a dense root mat. The foliage and young stems are characteristically aromatic. Its success as a woody weed is attributed to: (i) its toxicity to potential herbivores; (ii) the presence of allelochemicals; (iii) its ability to produce large amounts of flowers and seed; (iv) its long range seed dispersal capabilities; and (v) its reproductive versatility [19].

This weed grows well on nutrient deficient barren soils [20] and increased light availability [21]. *Lantana* is highly allelopathic and allelochemicals are present in all the parts of the shrub. The chemicals when released in surroundings interfere with germination and growth of many species [22]. These features of *Lantana* make it potentially stronger to prevent natural regeneration of some tree species and other native shrub species. It ultimately blocks succession and replaces native species [23, 24] and poses threat to the natural biodiversity.

Restoration of sal forest is much necessary to retain the native plant species and therefore a complete inventory and phytodiversity is needed from this valley. In some previous study from this region mentioned the amplitude of disturbances like frequent forest fires, collection of fodder and fuelwood, grazing of cattle and other climatic changes in the valley have forced the locals to go for cooler places like Asarori and Rajpur forests putting extra pressures on these areas and its nearby forests. The peripheries of Selaqui – Jhajra forest and nearby places are now intruded by different industries which further increasing the heavy instability of workers. All these perturbations must have put some impact on the dominance and diversity of the forests of Doon Valley. Therefore, the objectives of the present study were to 1. Quantify the species diversity from Doon Valley to provide current status of species richness and diversity. 2. Invasion success of *Lantana* from the most disturbed fallow lands and different forest communities, in Doon Valley, Uttarakhand.

Materials and methods

The Experimental Site

The present study was carried out in the Doon Valley, situated in western Himalayan part of India (Fig. 1). The Doon Valley is surrounded by hills on all the sides and has a varied range of subtropical deciduous forests mainly dominated by *Shorea robusta*, *Syzygium spp., Terminalia spp., Ehretia spp., Litsea spp.* and others. It is lying between latitudes 29°55' and 30°30'N and longitudes 77°35' and 78°24'E. It is a saucer-shaped valley about 20 km wide and 80 km long, with a geographical area of about 2,100 km^2. The valley is longitudinal, intermontane, synclinally depressed boulder [25, 26] filled with coarse clastic fan, Doon gravel of the late Pleistocene and Holocene [27]. The valley is uniformly oriented in northwest-southeast direction, with lesser Himalayas in the northwest and the Siwalik ranges in the southwest. The two major hydrologic basins of the valley are the Ganga (or Ganges) in the southeast, with the Song and Suswa as its main tributaries, and the Yamuna in the northwest, with the river Asan as its main tributary.

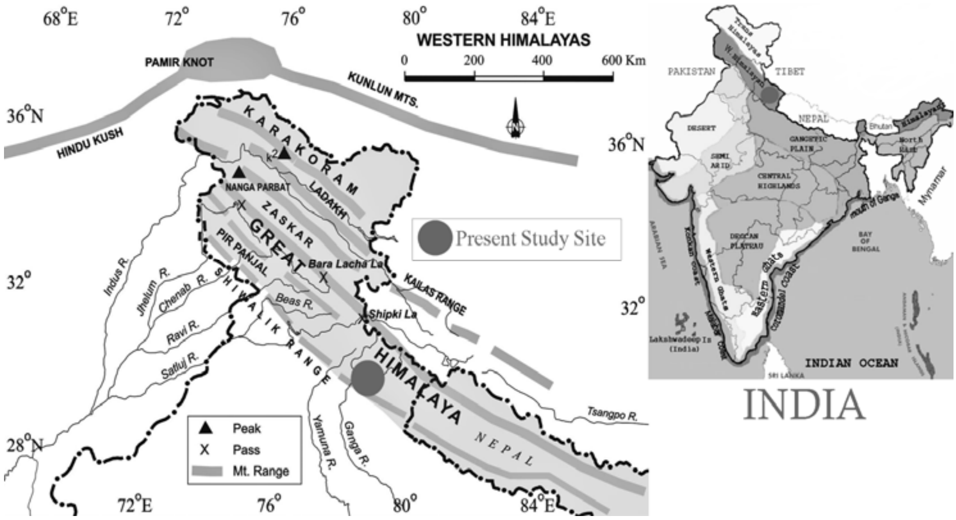

Fig. 1. Map of Western Himalayan part showing the present study sites.

Though many parts of the study sites were completely covered by forests with Sal as their dominant species, other sites include fallow land, tourist places, suburban areas which are heavily invaded by *Lantana camara, Parthenium hysterophorus, Ageratum conyzoides, Chromolaena odorata* and other invasive species. To make the present study more dynamic and resourceful eight sampling sites were selected covering all parts of the valley named Golatappar (open canopy area), Railway tracks (abandoned land), Asarori forest (dense forest area dominated by Sal and *Syzygium* spp.), Sahastradhara (tourist place), Rajpur forest periphery (Sal dominated forest), Selaqui/Jhajra (abandoned residential plots and riverside forests dominated by Sal), Jolly Grant airport (protected urban area) and Mothronwala (swampy area) (Table 1).

The present study area was thoroughly surveyed for its topography, microclimate and biotic stress conditions. The vegetation was analyzed by means of random sampling to give most representative composition of the subtropical vegetation. The vegetation survey was carried out by nested quadrat method. Ten quadrats 5×5 m^2 size were laid on each site for studying shrubs while twenty quadrats of 1×1 m^2 size were laid for the herbaceous vegetation. Vegetation composition was evaluated by analysing the frequency, density, abundance and Importance Value Index (IVI) according to Mishra [28] and Curtis and McIntosh [29] as given below:

Frequency = (Total No. of quadrate in which the species occurred / Total No. of quadrats studied) x 100 (1)

Density = Total No. of individual species / Total No. of quadrats studied (2)

Abundance = Total No. of individual species / Total No. of quadrate in which the species occurred (3)

Density was expressed as individual's m^{-2} and the frequency was calculated as percentage.

Table 1. Comparative analysis of dominant species with their IVI value from all the study sites

Name of study Sites	Name of species	Family	Growth Pattern	Mean % Cover	IVI
Golatappar	*Lantana camara* L.	Verbenaceae	Shrub	28.4	16.73
	Parthenium hysterophorus L.	Asteraceae	Herb	41	44.06
	Chromolaena odorata K. & R.	Asteraceae	Herb	11	15.11
	Diplazium esculentum Retz.	Athyriaceae	Fern	10.9	15.13
Railway Tracks	*Ageratum conyzoides* L.	Asteraceae	Herb	26	38.67
	Parthenium hysterophorus L.	Asteraceae	Herb	38.4	55.12
	Achyranthes aspera L.	Amaranthaceae	Herb	8.9	16.95
	Adhatoda zeylanica L.	Acanthaceae	Shrub	21.5	16.58
Asarori Forest Periphery	*Ageratum conyzoides* L.	Asteraceae	Herb	10.8	24.62
	Chromolaena odorata K. & R.	Asteraceae	Herb	10.4	23.89
	Lantana camara L.	Verbenaceae	Shrub	21.2	19.56
	Parthenium hysterophorus L.	Asteraceae	Herb	10.8	24.62
Sahastradhara	*Ageratum conyzoides* L.	Asteraceae	Herb	11	22.6
	Adhatoda zeylanica L.	Acanthaceae	Shrub	20.8	18.9
	Lantana camara L.	Verbenaceae	Shrub	27.9	24.7
	Parthenium hysterophorus L.	Asteraceae	Herb	15.5	30.1
Rajpur Forest Periphery	*Chromolaena odorata* K. & R.	Asteraceae	Herb	9	27.59
	Lantana camara L.	Verbenaceae	Shrub	20.7	22.82
	Parthenium hysterophorus L.	Asteraceae	Herb	10.3	30.93
	Sida cordifolia L.	Malvaceae	Herb	7.2	22.97
Selaqui and Jhajra Forest Periphery	*Ageratum conyzoides* L.	Asteraceae	Herb	12	25.43
	Lantana camara L.	Verbenaceae	Shrub	26.9	20.76
	Parthenium hysterophorus L.	Asteraceae	Herb	16.6	33.57
	Achyranthes aspera L.	Amaranthaceae	Herb	7.9	18.17
Jolly Grant Air Port	*Ageratum conyzoides* L.	Asteraceae	Herb	11.2	28.38
	Arundinella spicata Dalzell.	Poaceae	Grass	15.7	37.96
	Lantana camara L.	Verbenaceae	Shrub	26.8	30.01
	Parthenium hysterophorus L.	Asteraceae	Herb	9	23.69
Mothronwala	*Ageratum conyzoides* L.	Asteraceae	Herb	20.2	32.69
	Chromolaena odorata K. & R.	Asteraceae	Herb	14.5	24.67
	Parthenium hysterophorus L.	Asteraceae	Herb	25.2	39.73
	Lantana camara L.	Verbenaceae	Shrub	25.1	20.85

Importance Value Index (IVI)

Based on the quantitative characters like frequency, density and dominance (Basal area or cover) the overall dominance of a species on the entire community is measured by analyzing the synthetic character called Importance Value Index (IVI). Phillips [30] reported that IVI expresses the abundance and ecological success of any species. The value of IVI was computed by summation of the value of the relative frequency, relative density and relative dominance [29].

Relative Frequency (%) = (Frequency of a species / Frequency of all species) x 100 (4)

Relative Density (%) = (No. of individual of a species / No of individuals of all species) x 100 (5)

Relative Dominance (%) = (Basal area of a species / Basal area of all species) x 100 (6)

Importance Value Index (IVI) = Relative Frequency + Relative Density + Relative Dominance (7)

Basal cover is considered as the portion of ground surface occupied by a species [30]. Basal area measurement was calculated by using following formula:

Total Basal Cover (TBC) = mean basal area of a species × density of that species (8)

Mean Basal Area (MBA) = $C^2/4 \times 3{,}14$ (9)

Where C = average circumference of one individual of that species and MBA is expressed as cm^{-2} $herb^{-1}$ [28].

Biodiversity Measurement

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

$$D = \frac{\sum n_i(n_i - 1)}{N(N-1)} \quad (10)$$

Where n_i = the total number of organisms of each individual species
N = the total number of organisms of all species

Simpson's Index of Diversity (SID).

The formula is: SID = 1 – D

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

Shannon Diversity Index (H´)

$$H' = -\sum_{i=1}^{S} (P_i * \ln P_i) \quad (11)$$

Where: H = the Shannon diversity index; P_i = fraction of the entire population made up of species I; S = numbers of species encountered; ∑ = sum from species 1 to species S

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

Habitat Diversity

It represents differences in species composition between very different areas or environments and the rapidity of change of those habitats. It is calculated by the formula given by Whittaker [32].

$$\beta = Sc/S \quad (12)$$

Where, Sc = Total no. of species in all the communities, S = No. of species in a community

Field Survey

Intensive floristic surveys were conducted covering most of the habitat types between 1500-3200 m. Field identification of flowering plants was done with the help of regional floras, research papers and reports [33 - 38]. A set of duplicate specimens were collected for less known and doubtful species and preserved at DAV (PG) College Herbaria. All the species were later verified by comparing the specimens housed at the Herbaria of Forest Research Institute, Dehra Dun and Botanical Survey of India (North circle), Dehra Dun.

Result

During the present study only those shrubs and herbs species were recorded from all the study sites which were growing frequently with the invasive shrub *Lantana*. Site wise species and their phytosociological analysis and the major species growing with *Lantana* is shown in Figure 2.

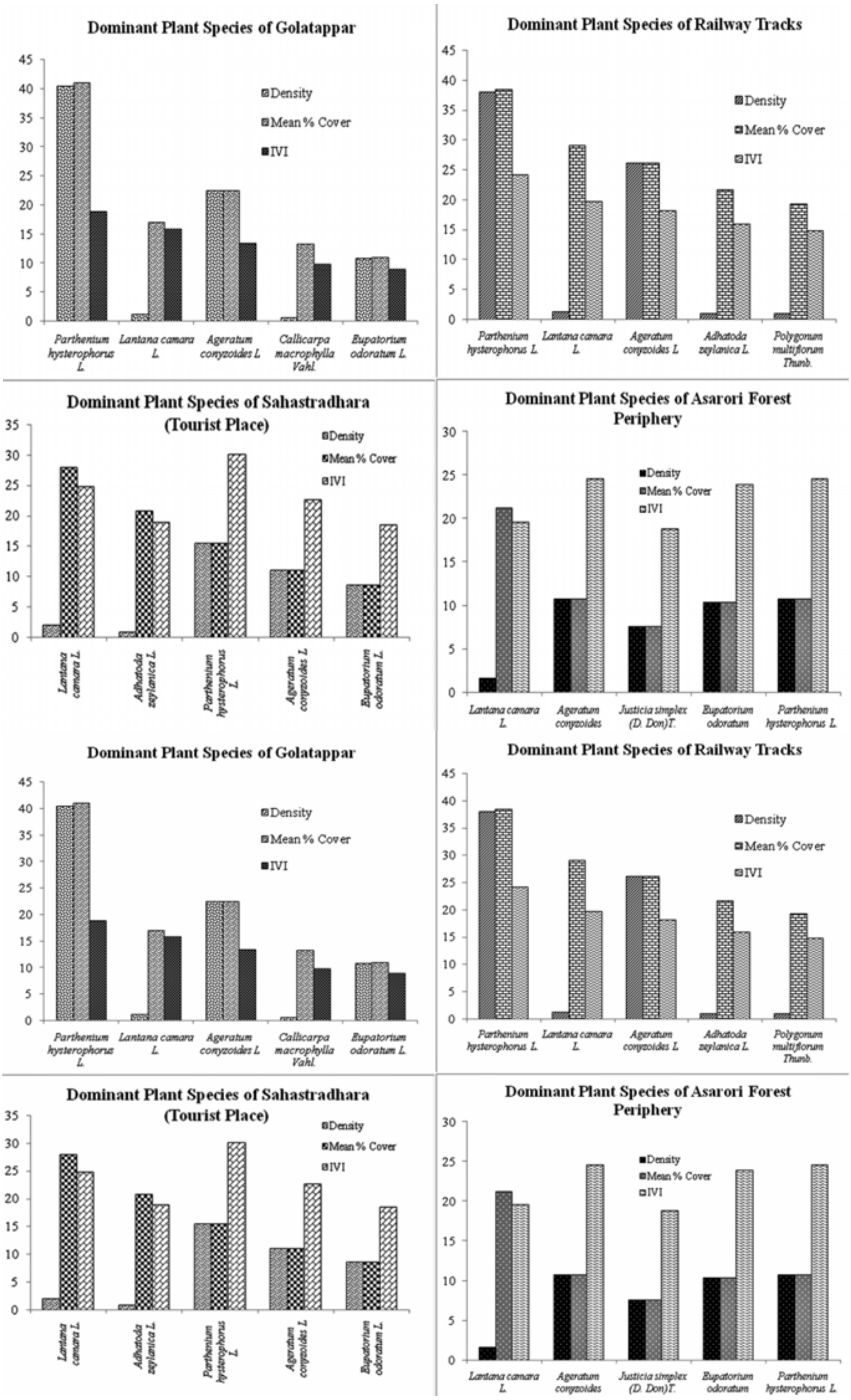

Fig. 2. Dominant plant species of Doon Valley

The sites wise result is as follows:

Site 1 (Golatappar)

In Golatappar the highest IVI was recorded for *Parthenium hysterophorus* L. (44.06) with a mean % cover of (41) followed by *Ageratum conyzoides* L. with IVI (26.39) and mean % cover (22.5) and *Lantana camara* L. with IVI (16.73) and mean % cover (28.4).

Site 2 (Railway Tracks)

Railway tracks were abandoned with moderate human activity. The maximum IVI was recorded for *Parthenium hysterophorus* (55.12) with a mean % cover of (38.4) followed by *Ageratum conyzoides* with IVI (38.67) and mean % cover (26) and *Lantana camara* with IVI (21) and mean % cover (29).

Site 3 (Asarori Forest Periphery)

The understory of Asarori forest periphery is heavily covered with many invasive shrubs and herbs. The maximum IVI value (24.62) was calculated for two species *Parthenium hysterophorus* and *Ageratum conyzoides* with (10.8 %) of mean coverage followed by *Eupatorium odoratum* syn. *Chromolaena odoratum* (L.) King & Rob with an IVI of (23.89) and a mean % cover of (10.4) closely followed by *Lantana camara* with an IVI and mean % cover of (19.56) and (21.2) respectively. On the other hand *Justicia simplex* was found strongly showing its presence with an IVI of 18.78 and a mean % cover of 7.6. The Simpson's diversity index for this site was 0.948. The Simpson's index shows a diverse sampling pattern from this site.

Site 4 (Sahastradhara)

Sahastradhara is a famous tourist place and therefore high biotic interference level is much obvious. Because of the high anthropogenic activity the invasion of shrubs like *Lantana camara*, *Parthenium hysterophorus, Chromolaena odoratum, Adhatoda zeylanica* etc. are very frequent and abundant. The maximum IVI (30.1) from this site was recorded for *Parthenium hysterophorus* with a mean % cover (15.5), followed by *Lantana camara,* with an IVI (24.7) and mean % cover (27.9), whereas, the recorded IVI for *Adhatoda zeylanica* was 18.9 and mean % coverage was 20.8. *Chromolaena odoratum* also verified its presence with an IVI value 18.5 and mean % cover 8.5. Simpson's diversity Index for this site was 0.947.

Site 5 (Rajpur Forest Periphery)

The data summarise the occurrence of 25 plant species in this site. *Parthenium hysterophorus* showed the highest density value (10.3 individuals/m^2), *Parthenium* with this high density value was found to be the dominant species having maximum IVI value (30.93) and mean % cover (10.3), followed by *Chromolaena odorata* with an IVI value (27.59) and mean % cover (9). The other two species which had high IVI values were *Lantana camara* and *Sida cordifolia* with the IVI value (22.82) and (22.97) respectively. The lowest density was recorded for *Xylosoma longifolium* (0.02 indivuduals/m^2), with lowest value of IVI (2.29) and coverage (0.6).

Site 6 (Selaqui and Jhajra Forest Periphery)

The Importance value of species in Selaqui/Jhajra forest periphery showed that *Parthenium hysterophorus* was the most dominant species with IVI value (33.57) and coverage (16.6), followed by *Ageratum conyzoides* and *Lantana camara* with IVI value (25.43) and (20.76) respectively. However, *Achyranthus aspera* and *Sida spinosa* were successful in registering their presence with a firm turnout of IVI (18.17) and (14.82) respectively. The lowest was calculated for *Phyllanthus emblica* L. with an IVI value 2.58 and mean coverage of 0.6%. Minimum density (0.1 individuals/m^2 and 0.03 individuals/m^2) were reported for the species *Jasminum nudiflorum* Lindl. and *Phyllanthus emblica* L. respectively.

Site 7 (Jolly Grant Airport)

A total of 26 plant species have been recorded in this site. The highest value of density (15.7 individuals/m^2), was recorded for *Arundinella spicata* Dalzell., followed by *Ageratum conyzoides* (11.2 individuals/m^2) and *Parthenium hysterophorus* (9 individuals/m^2). *Arundinella spicata* with 100% frequency was the dominant species showing maximum IVI (37.96) and mean coverage 15.7% followed by *Lantana camara* with IVI (30.01), *Ageratum conyzoides* with IVI (28.38), *Parthenium hysterophorus* with an IVI value (23.69) and *Achyranthus aspera* with IVI (23.27). The minimum IVI value (0.03) was calculated for *Ziziphus mauritiana* Lam. with coverage of 0.7%.

Site 8 (Mothronwala)

The site was represented by 25 plant species. *Parthenium hysterophorus* showed maximum density (25.2 individuals/m^2), with highest IVI value (39.73). Followed by other co dominant species *Ageratum conyzoides* (32.69), *Chromolaena odorata* (24.67), *Lantana camara* (20.85) and *Floscopa scandens* (20.17).

Lantana's success in tropical forest gaps

To obtain reliable data on pollinator visitation to *Lantana* inflorescence, we selected the largest gaps included in our sample (gap size range: 5m^2 –100 m^2). We then measured pollinator visitation rates to inflorescences between 09:00 and 16:00 hr, during April, 2012. Measurements were conducted in such that all the gaps were measured within all sampling days, and we rotated sampling order among gaps such that daily variation in visitation rates should not affect our assessment of inter-gap differences. We counted the number of visits to each of five randomly selected inflorescences on the largest patch within each gap during 10 min observation periods, and obtained a total of 10 such periods for each gap. When calculated the correlation between the gap size and the average visited pollinator a strong correlation (r = 0.80, R^2 = 0.63, t = 5.41) was recorded (Figure 3). From the regression analysis between the gap area (m^2) and pollinator visitation rate to inflorescence of *Lantana,* we found the significant F value 0.00004676 which was less than the α value (0.05), this concluded that there was a significant linear correlation.

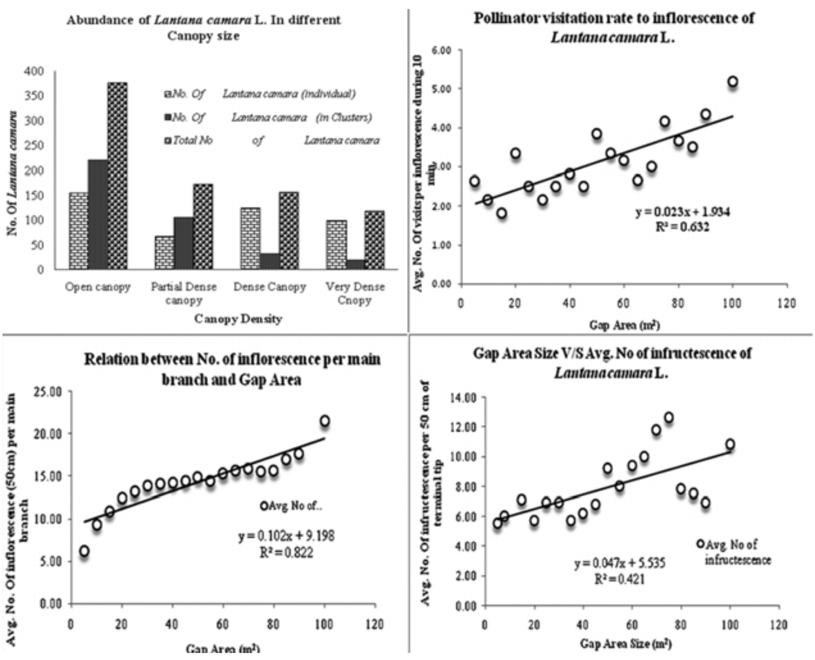

Fig. 3. Different measured parameters of *Lantana* with relation to forest gap size

During the survey we found an average of (6.20 – 21.50) inflorescences per 50 cm terminal tip of main branches depending upon the gap size from $5m^2$ to $100m^2$. The number of inflorescence per 50 cm terminal tip from each gap size was found significantly and positively related to gap size and canopy openness (Fig. 3). This was later proven after comparing the computed F value with tabular value at (1, n-2) degrees of freedom. We found that the calculated value of F (78.65) was greater than the tabular F value (4.45) at (1, 17) degrees of freedom at 5% level of significance and therefore concluded that the F value is significant. If the Computed F value is significant then we can assume that the regression coefficient β is significantly different from 0 and therefore, the null hypothesis can be rejected with the conclusion that there is a significant positive relationship between the no. of inflorescence and the Gap size.

Gap size and canopy openness had no direct influence (R^2 = 0.42) on the number of infructescences per main branch tip or the number of fruit per infructescence (Fig. 3). We found a different result after comparing the computed F value with tabular F value at (1, n - 2) degrees of freedom. This clearly showed that the calculated F value (12.36) was greater than the tabular F value (4.45) at (1, 17) degrees of freedom at 5% level of significance and hence we assumed that F value was significant. Also the significant F value (.0026) was found lesser than the value of α (0.05). In general if the Computed F value was found significant then the regression coefficient, β is significantly different from 0 and therefore, the null hypothesis can be rejected concluding there was a significant positive relationship between the no. of infructescence and the gap size.

Discussions

Structure composition and function are the three important attributes of forest ecosystem. The attributes change in response to climate, topography, soil and disturbances. The above mentioned factors along with forest succession are also responsible for both local (within stand) and landscape level variations in forest attributes, thereby producing spatial heterogeneity [39].

Heywood [40] indicated a correlation between the global size of higher taxa (family level) and the number of exotic species within these taxa. He found that the largest angiosperm families also supply a large proportion of exotics or invaders. Members of Poaceae, Asteraceae, Fabaceae and Brassicaceae represent most alien species in the world [41]. Asteraceae and Fabaceae are the largest families of flowering plants in the world. In their analyses, Asteraceae and Fabaceae were also contributors to the largest proportion of exotic species in the study area. Most of the species were introduced mainly from the tropical areas of Asia and America, which is in accordance with the findings of other studies conducted in different parts of the tropics; species introduced from tropical origin adapt well in tropical destinations [42].

We identified native species richness to be the most important predictor for both the number and the percentage of alien species. A decrease in the percentage of alien species with the number of native species is expected in any case assuming spatially regularly distributed exotic species richness and given the mathematical connection between both variables. For the relationship between exotic and native species richness, however, controversial results have been reported inducing a vivid debate referred to as the “invasion paradox” [43].

Fridley *et* al. [43] found a mainly positive relationship between native and non-native species richness for studies conducted over broad spatial scales, while fine scales and in particular experimental settings support a negative relationship. The discussion is mainly based on the large number of studies in temperate systems.

In general, disturbed areas are suspected to support exotic species invasions [44]. Disturbance events increase resource availability and reset succession; this increases the chance of colonization and establishment for many invasive species [45]. Disturbance events can be natural (floods, cyclones, landslides) or anthropogenic (eutrophication, land use, clearing). However, up to date, disturbance-mediated invasion is suggested to be most effective when invaders are ruderals that are adept at primary succession [46], whereas in the study area most of the invading species are trees which are more adapted to early stages of a secondary succession.

Lonsdale [47] identified a positive relationship between human impact (the number of visitors and development) and exotic species richness in nature reserves. In the study area, the supply of phosphorus and bulk density is connected to higher numbers of exotic species. This indicates that land use intensity facilitates the introduction of alien [42, 48] address the interrelationship between biodiversity and invasibility in the tropics. For the study area, exotic and native richness are significantly negative correlated. This indicates that land use intensity facilitates the introduction of alien species. Hill *et* al. [49] identified the same pattern in Australian woodland. Soil fertilization was found to support exotic richness in various studies [44, 50].

The nature of a plant community at a place is determined by the species that grow and develop in such environment [51]. Difference in the species composition from site to site is mostly due to micro environment change [52]. The patterns of distribution depends both on physico – chemical nature of the environment as well as on the biological peculiarities on the organisms themselves. Among the sites, under study, an overview of distribution patterns for herbs and shrubs show that contiguous pattern was the most common followed by random pattern.

The high Importance Value Index (IVI) of a species indicated its dominance and ecological success, its good power of regeneration and greater ecological amplitude. The present analysis is mainly focussing on all the herbs and shrubs growing frequently with other invasive species in different land use. The highest (IVI) value was recorded for *Parthenium hysterophorus, Lantana camara, Ageratum conyzoides, Opuntia dillenii, Eupatorium odoratum, Sida acuta* from all the sites. These species were the most dominant and successful species of all the land uses, which generally shows the continued biotic influence of the area. These species were frequently present throughout the area as the climatic and edaphic conditions are much suitable for the establishment of these species.

The presence of disturbance in the form of canopy openings increases resource availability and also modifies the microclimate, which is consistent with the disturbance patch invasion model [21]. The model state that the removal of competitive biomass and disruption of inter specific competitive interactions creates patches of increased resources. In the present study area canopy openings, which resulted from local disturbance, create patches of greater light availability. Increase in light availability follows gradient of disturbance intensities. Light has long been recognized as an important plant resource [53] that may interact with other plant resources to affect plant performance [54]. The increase in light availability increases the overall performance of *Lantana* particularly the growth rate [55]. Moreover, Chandrashekar and Swamy [56] also reported that light availability in relatively less canopy enhance the growth of individual *Lantana*.

The dense cover created by vertical stratification of *Lantana* may reduce the intensity or duration of light under its canopy and thus decrease the herbaceous cover. This could be due to the creation of a photosynthetically inactive light regime at ground level [57]. Below certain thresholds, however, light limitation alone can prevent herbaceous species survival regardless of other resource levels [58]. It is likely that herbs are influenced by the amount of light that reaches the forest floor, and this may be probably one of the mechanisms responsible for the decline of herbaceous vegetation. Sharma and Raghubanshi [59] advocated that the growth architecture pattern of *Lantana* is such that it prevents the light penetration to the forest floor, leading to the decline of tree seedlings and possibly the herb flora. With the present study it is clear that the vegetation of Doon Valley is unique with sal as a dominant tree species; however the underground was fully occupied with invasive species like *Lantana, Parthenium, Chromolaena, Ageratum, Eupatorium adenophorum* and many more. The fragmented sal forests of Doon Valley due to round the year tourist activity, gradual urbanization and industrialization providing a corridor to the invasive species, which after getting resources from the nature increasing the amplitude of their invasiveness. The present study will help identifying the associate plant species of *Lantana* from different habitats; also will document the relationship of forest gaps with different attributes of *Lantana.*

Conclusions

The Doon Valley sal forest is one of its own kind but due to big forest gaps and invasion of many exotic species the biodiversity and richness of species is reducing every day. Due to industrialization, round the year tourist activity and soil modifications the invasive species like *Lantana camara* is flourishing with profound growth rates. The present paper is an attempt to record and quantify the associate plant species grown fearlessly with *Lantana* from the valley and their growth intensity is measured with the help of IVI (Importance Value Index) a simple yet powerful ecological tool to measure biodiversity assessment. The results of the present study also reveal that forest gaps are favoring the growth of *Lantana* by increasing the pollinator visitors, no. of inflorescence, and infructescence, which are the most important attributes in *Lantana*'s invasion success in tropical forests. Sahastradhara, amongst all the study sites is the most disturbed site due to round the year tourist activity and therefore recorded the maximum *Lantana* density and IVI, this can be argued that disturbed sites are the favorable places for plant invasion, however the growth of *Lantana* was not found restricted to the disturbed sites only but a profuse growth of this invasive species was recorded from all the study sites irrespective of their habitat, topography and soil type. This shows that *Lantana* in today’s world can grow at any place by making the place and conditions conducive for its further invasion. The results will help the policy makers and researchers to further extend the research opportunities with better results and management strategies.

Acknowledgements

We are thankful to the department of Botany and National forest library, ICFRE, Dehradun for providing both laboratory and literary facilities. We extend our thanks to the Department of Botany, DAV (PG) College, Dehradun India for providing the laboratory and statistical facility. We also thank FSI (Forest Survey of India) Dehradun, India for helping in identifying the plant species and providing the necessary forest inventory data and the State Forest Reports.

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Received: May, 09, 2014
Accepted: November, 25, 2014