

VEGETATION COMPOSITION AND PLANT BIODIVERSITY IN FOREST ECOSYSTEMS OF SIWALIKS IN NORTHERN HARYANA

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ABSTRACT

This paper analyzes vegetation composition, patterns of plant diversity and biodiversity conservation in Kalesar Reserved forest, Yamunanagar forest division (30°22'14.80" to 30°22'24.00"N, 77°33'47.00" to 77°33'57.00"E; 396m above mean sea level) in the foothills of Haryana Siwaliks, northern India. The dry plains *Shorea robusta* forest (undisturbed), *Shorea robusta* forest (disturbed), and *Haplophragma adenophyllum* plantation forest were selected for the study; density of trees was 543.75 to 737.5 trees ha⁻¹, and basal area 22.48 to 35.56 m² ha⁻¹. A total of 81 species was recorded in the three forests indicating moderately high diversity of the various functional groups of plants (trees, shrubs, herbaceous plants, and climbers). Most of the individuals (66 to 80%) of tree species were present in lower girth classes (i.e., C and D) ranging from 31 to 90cm cbh; 0.24 to 19.74% of trees in the intermediate girth classes (E, F, and G) ranging from 91 to 180cm cbh. The dominance diversity curves of trees, shrubs, and the herbaceous plants in the three forests showed a lognormal distribution. The Shannon index of diversity for trees in the three forests was 1.49 to 2.31. The Pielou's index of equitability for trees and shrubs varied from 0.66 to 0.91. The concentration of dominance was greatest in the plantation forest (0.345) as compared to the natural forests (0.16-0.23). The long term conservation of the biodiversity in this region of unstable Siwaliks can be ensured by creating public awareness about the value of biodiversity and allocating a greater share of benefits to the village poor from biodiversity conservation.

Keywords: *Plant Diversity, Tree Density, Tree Population Structure, Diversity Indices, Biodiversity Conservation*

INTRODUCTION

Forests are the precious resources which provide provisioning, regulatory, cultural and economic services to the mankind. Forests are a source of timber, fuel wood, food and the various kinds of raw materials. Forests play a key role in regulating climate, conserving biodiversity and providing livelihood to the people (MEA, 2005). Studies have explored the relationship between biodiversity and ecosystem functioning keeping in view the concerns of increasing loss of biodiversity in different types of terrestrial ecosystems (Schulze and Mooney, 1993; Kinzig *et al.*, 2002; Loreau *et al.*, 2002). Biodiversity and ecosystem multifunctional studies have shown that high species diversity is essential for multiple ecosystem functions as different species promote different functions (Hector and Bagchi, 2007; Zavaleta *et al.*, 2010; Isbell *et al.*, 2011). High biodiversity is needed to maintain ecosystem services and functions under changing environmental conditions (Isbell *et al.*, 2011). The maintenance of ecosystem services such as the diversity of pollinating insects, carbon storage, and the regulation and purification of water flows are essential for sustainable forest management. Biodiversity regulates all ecosystem services, but it can also be a service in itself, i.e., the existence value of a species under cultural services (Mace *et al.*, 2012). Biodiversity is also considered to have insurance value by providing resilience in the face of current or future changes in ecosystems and the services they provide.

Understanding species diversity and plant distribution patterns is important for assessing the complexity and sustainability of forest ecosystems. There are large anthropogenic demands on forest resources in different regions of India because more than 200 million people dependent on forests for livelihoods. Singh and Singh (1987) have extensively reviewed studies on vegetation composition of Kumaun Himalaya with emphasis on structural and functional aspects of forest ecosystems. The plant biodiversity of an undisturbed, mid-elevation evergreen forest of Western Ghats has been studied (Ganesh *et al.*,

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1996). The vegetation composition of natural and degraded forests in Chitrepani in Shiwalik region of central Nepal (Shrestha *et al.*, 2000) and the patterns of biodiversity in the *Shorea robusta* forests of the Terai region of Uttar Pradesh (Shukla, 2009) have been studied. Singh and Kushwaha (2008) have given an overview of forest biodiversity and its conservation in India and stressed the need for people's participation in biodiversity conservation and rehabilitation

The natural forest cover is only 3.64% of total geographical area in Haryana (FSI, 2011). However, plant diversity in forest ecosystem of Haryana has been studied by only a few workers (Jain, 1979; Rout and Gupta, 1989). This paper aims to analyze vegetation composition, patterns of plant diversity and biodiversity conservation strategies in natural and plantation forests at Kalesar Reserved forest in northern Haryana.

MATERIALS AND METHODS

Study Sites

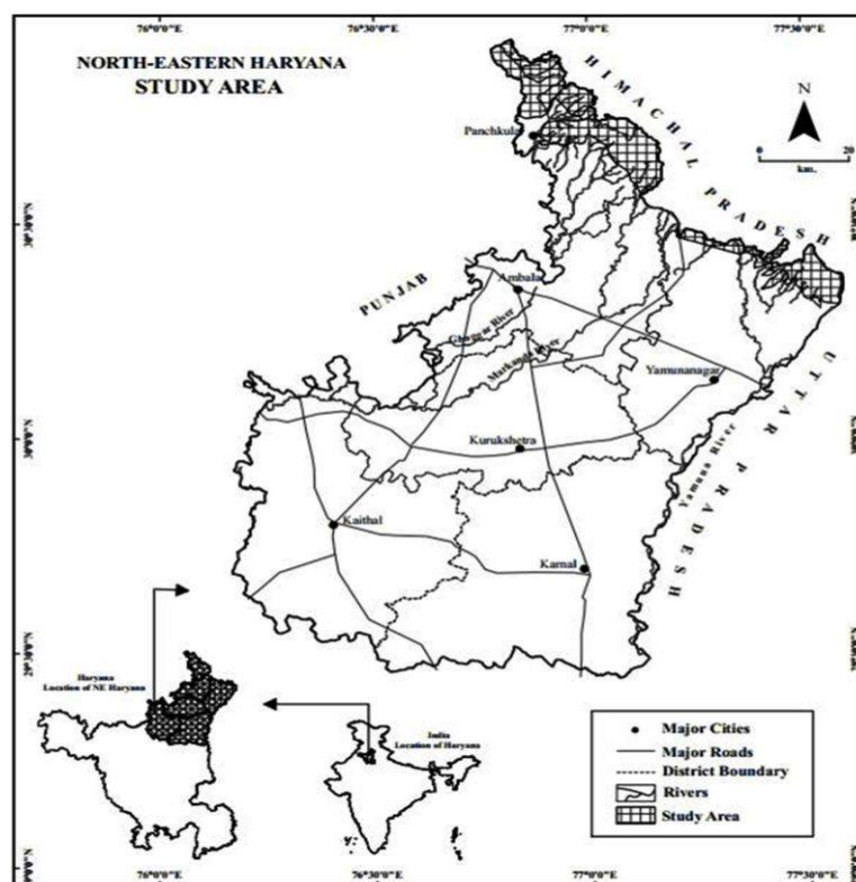


Figure 1: The location of Yamunanagar Forest Division on north-east Haryana

The total forest area in the Yamunanagar forest division in northern Haryana is 193 km² which forms 10.92% of the total geographical area of the district (FSI, 2009). The forests are mainly composed of dry Siwalik *Shorea robusta* forest, dry plains *Shorea robusta* forest, northern dry mixed deciduous forests, dry tropical riverine forests, and the plantation forests (Champion and Seth 1968, ICFRE 2013). The northern tropical dry plains *Shorea robusta* forest (undisturbed), *Shorea robusta* forest (disturbed and invaded by *Lantana camara*), and *Haplophragma adenophyllum* plantation forest, located in Kalesar Reserved forest, Yamunanagar forest division, in foothills of Haryana Siwaliks (30°22'14.80" to 30°22'24.00"N, 77°33'47.00" to 77°33'57.00"E; 396m above mean sea level), were selected for the study (Figure1). The Siwalik hill ranges occupy the northern fringe of Yamunanagar district; the hills are about

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500m high with respect to the adjacent alluvial plains. These are characterized by a broad tableland topography that has been carved into quite sharp slopes by numerous ephemeral streams come down to the outer slopes of the Siwaliks and spread much of gravels boulders, pebbles in the beds of these streams. The climate of the study area is subtropical and monsoonal with distinct winter, summer and rainy seasons (Figure 2a). A major portion of rainfall is received during the rainy month from June to September. The rainfall is highly variable in different months and from year to year. The area receives an annual rainfall ranging from 1025 mm to 1585.5 mm based on long-term data (Figure 2a). About 84% of the total rainfall is received during the monsoon months from June to September. The rainfall during winter is erratic and poorly distributed. The summer months from March to May are characterized by hot and dry conditions. During the study period from January 2012 to December 2012, the average monthly rainfall varied from 0.2 mm to 425 mm during different months (Figure 2b). About 95% of the total annual rainfall (932mm) was received in the rainy season during January 2012 to December 2012.

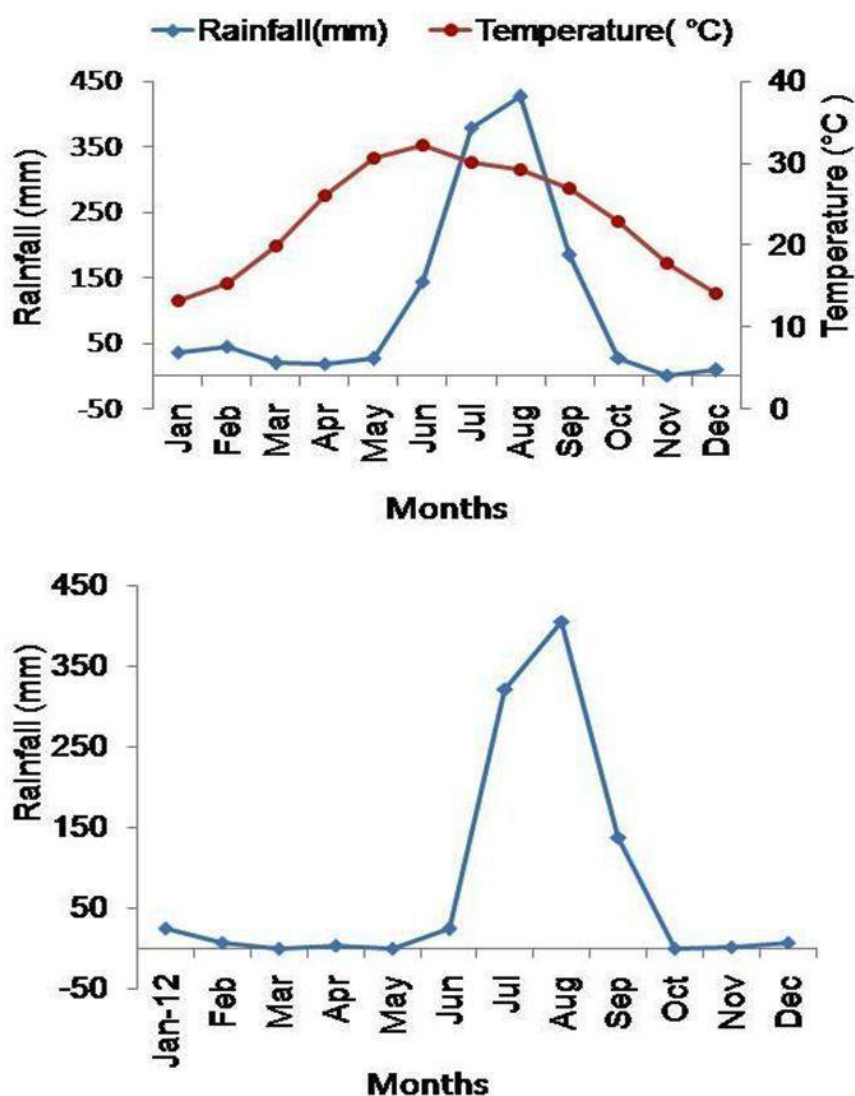


Figure 2a: Long-term monthly variation in temperature ($^{\circ}\text{C}$), rainfall (mm) during January 1991 to December 2000 at Kalesar – (Source: Haryana Forest Department Working Plan)

Figure 2a: Monthly variation in rainfall (mm) during January 2012 to December 2012 at Kalesar – (Source: Haryana Forest Department)

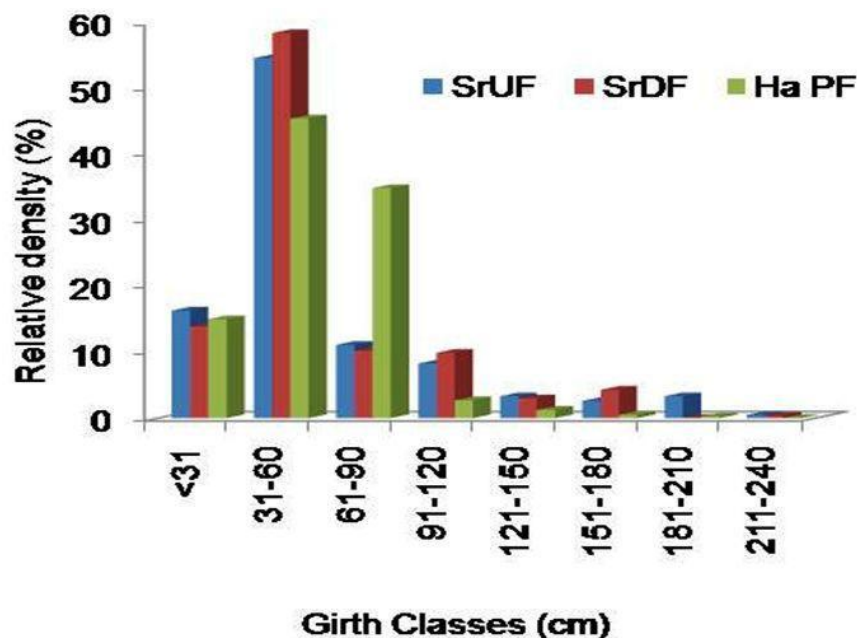


Figure 3: Population structure of trees in the *Shorea robusta* undisturbed forest (SrUF), *Shorea robusta* disturbed forest (SrDF) and *Haplophragma adenophyllum* Plantation forest (HaPF) at Kalesar

The soils of the study area are alluvial and sandy. Soil organic carbon (0-15cm soil depth) varied from 10.11 to 6.973 g C kg⁻¹ soil in different forest ecosystems (Table 1). There was significant difference in soil carbon and nitrogen due to soil depth (F= 111 to 172; d.f.=3,12; P<0.001). Soil pH varied from 6.49 to 7.33 up to 60cm soil depth. The bulk density of soil in the three forest systems ranged from 1.10 to 1.41 g m⁻³ across soil depths; the differences being significant due to soil depth (Table 1).

Table 1: Some soil characteristics of the *Shorea robusta* undisturbed forest, *Shorea robusta* disturbed forest and *Haplophragma* plantation forest at Kalesar reserved forest

Forest type/Soil Depth (cm)	Soil pH 1:2	Organic Carbon (g C kg ⁻¹ soil)	Nitrogen (g N kg ⁻¹ soil)	Bulk density (g cm ³)
<i>Shorea robusta</i> forest (Undisturbed)				
0-15	6.49±0.085 ^b	10.11±0.327 ^a	0.943± 0.052 ^a	1.10±0.033 ^b
15-30	6.89± 0.041 ^a	6.33± 1.088 ^b	0.437± 0.034 ^b	1.21±0.017 ^b
30-45	6.90± 0.085 ^a	3.47± 0.202 ^c	0.297± 0.013 ^c	1.29±0.012 ^a
45-60	6.97± 0.129 ^a	2.26± 0.191 ^c	0.154± 0.013 ^d	1.36±0.017 ^a
LSD (P<0.05)	0.27	1.041	0.166	0.106
F value d.f.=3,12; P<0.01	4.437	35.611	111.042	18.147
<i>Shorea robusta</i> forest (Disturbed)				
0-15	6.99± 0.061 ^b	6.973± 0.427 ^a	0.628± 0.030 ^a	1.25±0.013 ^b
15-30	7.09± 0.078 ^b	4.105± 1.18 ^b	0.256± 0.024 ^b	1.28±0.011 ^b
30-45	7.12± 0.086 ^b	1.225± 0.075 ^c	0.101± 0.007 ^c	1.37±0.009 ^a
45-60	7.40± 0.024 ^a	1.038± .013 ^c	0.0802± 0.002 ^c	1.41±0.025 ^a
LSD (P<0.05)	0.195	1.36	0.095	0.040
F value d.f.=3,12; P<0.01	6.698	19.881	172.134	23.511
<i>Haplophragma</i> Plantation Forest				
0-15	6.87± 0.084 ^c	8.39± 0.363 ^a	0.774± 0.054 ^a	1.153±0.013 ^b
15-30	7.05± 0.090 ^{bc}	5.17±0.834 ^b	0.361± 0.003 ^b	1.22±0.021 ^b
30-45	7.23± 0.079 ^{ab}	2.21± 0.201 ^c	0.182± 0.018 ^c	1.30±0.023 ^a
45-60	7.33± 0.032 ^a	1.48± 0.185 ^c	0.111± 0.002 ^c	1.36±0.034 ^a
LSD (P<0.05)	0.268	1.156	0.170	0.040
F value d.f.=3,12; P<0.01	8.215	44.053	111.130	13.765

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Analysis of Vegetation Composition

Sampling of vegetation in the dry plains *Shorea robusta* undisturbed forest, *Shorea robusta* disturbed forest and *Haplophragma* plantation forest was carried out during the study period January 2012 to December 2012. The quadrat method was used for analyzing plant diversity of trees (20x20m), shrubs, and climbers (5x5m sample-plot), herbs (1x1m sample-plot). For ground floor herbaceous vegetation and climbers, based on the plant phenology, sampling was undertaken during September to October, 2012 in order to cover maximum number of occurrence of species.

The density, basal area and Importance Value Index of the trees, shrubs, herbs and climbers were calculated following Phillips (1959) and Misra (1968). Importance Value Index (IVI) of trees and shrubs was calculated following Curtis and McIntosh (1951): Important Value Index (IVI) = Relative density (%) + Relative frequency (%) + Relative basal area (%). For herbaceous plants and climbers, the Important Value Index (IVI) was calculated as: = Relative density (%) + Relative frequency (%) + Relative abundance (%).

Population Structure of Tree Species

On the basis of girth measurement (cbh), the population structure of trees was prepared according to NRSA Manual (NRSA, 2008). The density and the relative density of the tree species belonging to different girth classes were calculated.

Analysis of Species Diversity Indices

Shannon-Weinner index (Shannon-Weinner, 1949) for species diversity was computed from the importance value index of various plant species.

The species diversity (\bar{H}) for trees, shrubs, herbaceous plants and climbers was determined using the following equation:

$$\bar{H} = -\sum_{i=1}^s (N_i/N) \ln (N_i/N)$$

Where, N_i = Importance value of one species

N = Total of importance value of all species

Concentration of dominance (C) was computed using Simpson's index (Simpson, 1949):

$$C = \sum_{i=1}^s (N_i/N)^2$$

Where, N_i = Importance value of one species

N = Total of importance value of all species

Equitability Index (e) was calculated following Pielou (1966), as:

$$e = \bar{H} / \ln S$$

Where, H = Shannon index

S = number of species.

Margalef's index of Species richness (d) was calculated using the following equation:

$$D = (S - 1) / \ln N$$

Where, S = total number of species

N = total density of all species.

The dominance – diversity curves (Magurran, 1988) for trees, shrubs and herbaceous plants for the three forest systems were plotted using log values of importance value index (IVI) and species sequence.

Analysis of Soil properties

The soil samples were collected from 0-15 cm, 15-30 cm, 30-45 cm, 45-60cm of soil depths using a soil corer from the sampling plots and a composite sample was obtained for three forest sites. The soil samples were air-dried and sieved through 2 mm sieve for analysis of soil organic carbon, soil nitrogen, soil pH. Sub-samples of air-dried soil samples were analyzed for organic carbon by dichromate oxidation method (Kalembasa and Jenkinson, 1973). Soil bulk density was determined by collecting a known volume of soil with help of metallic corer from 0-15 cm, 15-30 cm, 30-45 cm, 45-60cm of soil depth and

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soil was dried at 100°C till constant weight. The bulk density was determined by using soil weight/volume relationship. Nitrogen content in soil samples was analyzed by using KELPLUS Nitrogen Estimation System based on micro Kjeldahl method (Bremner and Mulvaney, 1965).

Statistical Analysis

One-way ANOVA (with Duncan's test for multiple comparisons) was used to analyze the effect of forest systems on soil properties (Gomez and Gomez, 1984). A significance level of $P < 0.05$ was used for all tests. All analyses were done using the program SPSS, ver. 16.0.

RESULTS AND DISCUSSION

Tree layer vegetation composition

The total tree density and basal area of trees in the undisturbed *Shorea robusta* forest are given in Table 2. The density of *Shorea robusta* was 185.42 trees ha⁻¹ and exhibited an Importance Value Index (IVI) of 110.42. The importance value indices of the tree species like *Mallotus philippensis*, *Ehretia laevis*, and *Litsea glutinosa* were 76.32, 39.85, and 34.66, respectively. The IVI of other tree species including *Aegle marmelos*, *Bombax malabaricum*, *Bredelia retusa*, *Diospyros tomentosa*, *Grewia elastica*, , *Schleichera oleosa*, *Sterculia villosa*, *Terminalia alata*, *Terminalia belarica* and *Ziziphus mauritiana* varied from 1.93 to 6.10.

Table 2: Density and basal area of trees and shrubs in the *Shorea robusta* undisturbed forest and disturbed forest and *Haplophragma* plantation forest at Kalesar reserved forest

Forest type	Density (trees ha ⁻¹)	Basal area trees (m ² ha ⁻¹)	Density shrubs (stems ha ⁻¹)	Basal area shrubs (m ² ha ⁻¹)
<i>Shorea robusta</i> Undisturbed forest	737.5	35.56	2911	0.26
<i>Shorea robusta</i> disturbed forest	543.75	22.48	5076	0.85
<i>Haplophragma</i> Plantation Forest	720.83	24.22	7917	0.58

A total of 19 tree species were recorded in the *Shorea robusta* disturbed forest, which has been invaded in the ground floor by *Lantana camara*. In the disturbed forest, *Shorea robusta* showed tree density of 122.92 trees ha⁻¹ and Importance Value Index (IVI) of 98.84. The importance value indices of *Mallotus philippensis* and *Ehretia laevis* were 37.27 and 34.90, respectively. The IVI of *Bauhinia vahlii*, *Cassia fistula*, *Cordia dichotoma*, *Diospyros tomentosa*, *Ficus religiosa*, *Garuga pinnata*, *Grewia elastica*, *Haplophragma adenophyllum*, *Holoptelea integrifolia*, *Holarrhena antidysenterica*, *Litsea glutinosa*, *Randia dumetorum*, *Schleichera oleosa*, *Terminalia alata*, *Terminalia belarica* and *Ziziphus mauritiana* varied from 1.49 to 29.84.

A total of 8 tree species were recorded in the *Haplophragma adenophyllum* plantation forest. In the plantation forest, *Haplophragma* showed tree density of 568.75 trees ha⁻¹, basal area of 24.22 m² ha⁻¹, and Importance Value Index (IVI) of 168. The IVI of *Acacia catechu*, *Ficus religiosa*, *Garuga pinnata*, *Holoptelea integrifolia*, *Holarrhena antidysenterica*, *Mallotus philippensis*, and *Terminalia alata* varied from 8.18 to 31.93.

Shrub Layer Vegetation Composition

In the *Shorea robusta* undisturbed forest, the shrub layer was dominated by *Clerodendrum viscosum* with an IVI of 122.98 followed by *Nepeta graciliflora* (IVI=74.82), *Lantana camara* (IVI=37.61) and *Coolebrookia oppositifolia* (IVI=28.16). The IVI of other shrub species varied from 11.45 to 24.98.

The density (2414 stems ha⁻¹) and IVI (138.91) of *Lantana camara* were greatest in the *Shorea robusta* disturbed forest. The IVI of other shrub species including *Adhatoda vasica* Nees, *Asparagus adscendens* Roxb., *Carissa spinarum* L., *Capparis zeylanica* L., *Clerodendrum viscosum* Vent., *Colebrookia oppositifolia* Smith, *Murraya koenigi* (L.) Spreng., and *Nepeta graciliflora* Benth. varied from 8.67 to 28.41.

The shrubs species of *Adhatoda vasica* Nees (IVI=75.61), *Carissa spinarum* (IVI=19.82), *Capparis zeylanica* (IVI=25.31), *Lantana camara* L. (IVI=21.83), *Murraya koenigi* (IVI=25.71), *Naringi crenulata* (IVI=17.89), *Nepeta graciliflora* (IVI=40.45) were recorded in the *Haplophragma* plantation forest.

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Vegetation Composition of Ground Floor Herbaceous Plants and Climbers

The vegetation composition of the herbaceous plants in the *Shorea robusta* forests and the *Haplophragma* plantation forest is given in Table 3. A total of 23 herbaceous species were recorded in the *Shorea robusta* undisturbed forest with dominance of *Chrysopogon fulvus* (IVI=28.93) and co-dominance of *Adiantum capillus-veneris* (IVI=21.83).

Table 3: Diversity of ground floor herbaceous plants and climbers in *Shorea robusta* undisturbed forest (UF), *Shorea robusta* disturbed forest (DF) and *Haplophragma* plantation forest at Kalesar

Plant species	Family	Importance Value Index (IVI)		
		<i>S. robusta</i> (UF)	<i>S. robusta</i> (DF)	<i>Haplophragma</i> (PF)
HERBS				
<i>Abution indicum</i> Sweet	Malvaceae	-	22.68	-
<i>Achyranthes aspera</i> L.	Acanthaceae	15.34	16.59	17.80
<i>Adiantum capillus-veneris</i> L.	Adiantaceae	21.83	-	22.58
<i>Ageratum conyzoides</i> L.	Asteraceae	18.62	18.76	-
<i>Alisicarpus</i>	Fabaceae		12.11	
<i>Anagallis arvensis</i> L.	Primulaceae	14.09	-	20.00
<i>Anisomeles indica</i> (L.) Kuntze	Lamiaceae	-	-	10.77
<i>Boerhaavia diffusa</i> L.	Nyctaginaceae	7.77	-	-
<i>Brachiaria reptans</i> (L.) C.A. Gardner & C.E. Hubb.	Poaceae	-	-	16.04
<i>Cassia tora</i> L.	Caesalpiniaceae	-	60.34	51.68
<i>Cenchrus setigerus</i> Vahl.	Poaceae	-	32.68	-
<i>Chloris dolichostachya</i> Lagas	Poaceae	13.89	15.80	-
<i>Chrysopogon fulvus</i> (Spreng.) Chiov.	Poaceae	28.93	-	-
<i>Desmodium gangeticum</i> (L.) DC	Fabaceae	-	20.16	-
<i>Commelina paludosa</i> Blume	Commelinaceae	17.11	-	20.48
<i>Desmodium pulchellum</i> (L.) Benth	Fabaceae	10.57	-	38.65
<i>Desmostachya bipinnata</i> (L.) Stapf	Poaceae	-	19.15	-
<i>Eulaliopsis binata</i> (Retz.) Hub.	Poaceae	20.81	-	-
<i>Euphorbia hirta</i> L.	Euphorbiaceae	9.89	-	20.34
<i>Ipomoea coptica</i>	Convolvulaceae	7.88	-	-
<i>Ipomoea pestigridis</i> L.	Convolvulaceae	-	15.62	-
<i>Inula indica</i>	Asteraceae	-	-	15.77
<i>Leucas mollissima</i> Wall.	Labiatae	11.59	-	18.23
<i>Oplismenus compositus</i> (L.) P. Beauv.	Poaceae	8.28	-	-
<i>Peristrophe bicalyculata</i> (Retz.) Nees.	Acanthaceae	-	15.23	-
<i>Phyllanthus nirurii</i> auct.	Euphorbiaceae	-	-	13.07
<i>Rauvolfia serpentina</i> (L.) Benth. ex Kurz.	Apocynaceae	7.25	-	-
<i>Sida cordifolia</i> L.	Malvaceae	6.73	-	11.09
<i>Sida ovata</i> Forsk.	Malvaceae	9.89	11.30	-
<i>Solanum indicum</i> L.	Solanaceae	14.27	11.17	10.43
<i>Solanum nigrum</i> L.	Solanaceae	12.74	-	
<i>Trichosanthes cucumerina</i> L.	Cucurbitaceae	12.31	-	-
<i>Tridax procumbens</i> L.	Asteraceae	9.08		-
<i>Urena lobata</i> L.	Malvaceae	9.88	18.78	13.07
<i>Vernonia cinerea</i> (L.) Less.	Asteraceae	11.25	-	-
<i>Xanthium strumarium</i> L	Asteraceae	-	9.63	-
CLIMBERS				
<i>Abrus precatorius</i> L.	Fabaceae	-	17.40	-
<i>Asparagus adscendens</i> Roxb.	Liliaceae	-	22.03	-
<i>Cissampelos glabra</i> Roxb.	Menispermaceae	35.79	35.08	32.22
<i>Coccinia grandis</i> (L.) Voigt	Cucurbitaceae	20.87	34.69	66.32
<i>Ichnocarpus frutescens</i> (L.) R.Br.	Apocynaceae	110.54	60.03	22.57
<i>Millettia auriculata</i> Wight & Am	Fabaceae	109.23	75.0	149.63
<i>Smilax zeylanica</i> L.	Smilacaceae	-	-	29.26
<i>Tinospora cordifolia</i> (Willd.) Mie. Ex Hk.f.& Thoms.	Menispermaceae	-	27.18	-
<i>Trichosanthes cucumerina</i> L.	Cucurbitaceae	23.57	28.58	-

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There were a total of 15 herbaceous plants with the dominance of *Cassia tora* (IVI=60.34) and co-dominance of *Cenchrus setigerus* (IVI=32.69) in the disturbed forest. In *Haplophragma* plantation forest, there was dominance of *Cassia tora* (IVI=51.68) and co-dominance of *Desmodium pulchellum* (IVI=38.65), Table 3.

The diversity of climbers was greater in the *Shorea robusta* disturbed forest as compared to *Shorea robusta* undisturbed forest and *Haplophragma* plantation forest (Table 3).

Population Structure of Trees

In the dry plains *Shorea robusta* forest, girth classes (cbh) of trees were ranging from 31cm to 270 cm. Most of the individuals (66 to 80%) of tree species were present in lower girth classes (i.e. C and D) ranging from 31 to 90cm cbh. There was 0.24 to 19.74% of trees in intermediate girth class (E, F, and G) ranging from 91 to 180cm cbh. Only 3.78% of trees were found to be present in higher girth class (H, I, and J) of 180-270cm (Figure 3). The *Shorea robusta* trees were found in higher girth classes, whereas the under storey tree species of *Mallotus philippensis* and *Ehretia laevis* showed its abundance in girth classes B and C. The population structure of trees, characterized by the presence of sufficient population of seedling, sapling and mature trees, indicate a successful regeneration of forest species (Saxena and Singh, 1984) and the presence of saplings under the canopies of adult trees also indicate the future composition of a community (Austin, 1977). In the studied forest ecosystems, the density of seedlings was affected by invasion of *Lantana camara* in disturbed forest; density of saplings (87 individuals /ha) seedlings (69 individuals/ha) of various tree species was lower as compared to that of undisturbed forest (143 saplings /ha; seedlings /ha). Due to suppression of *Lantana camara* in plantation forest, there was appreciable density of saplings (127 individuals/ha) seedlings (108 individuals/ha) of various tree species.

Diversity Indices

The values for Shannon's diversity index (H), Margalef's index (D), Simpson's index (Cd) and Pielou index (e) of diversity for the trees, shrubs, herbs and climbers for the *Shorea robusta* undisturbed forest, *Shorea robusta* disturbed forest and *Haplophragma* plantation forest are shown in Table 4.

The Shannon's diversity index for trees was: *Shorea robusta* undisturbed forest 1.80, *Shorea robusta* disturbed forest 2.31; 1.49 Plantation forest (Table 4). The reported range of Shannon's index has been found to vary 0.83-4.1 for the forests of the Indian sub-continent (Jha and Singh 1990, Pandey and Shukla, 1999), whereas for forests of western Ghats and montane temperate forests, it ranges from 1.99 to 3.99 (Jayakumar and Nair, 2013 and other references therein). The diversity index is generally higher in tropical forests, which is reported in the range of 5.06 to 5.40 for young and old stand, respectively (Knight, 1975). The diversity of tree species was higher in the *Shorea robusta* forest (1.80 to 2.31) as compared to the plantation forest (1.49).

Table 4: The indices of diversity in different forest ecosystems in Kalesar reserved forest

Forest Type	Species (n)	Shannon's index (H)	Margalef's index (D)	Simpson's index (Cd)	Pielou index (E)
Trees					
<i>Shorea</i> forest (Undisturbed)	15	1.80	2.12	0.23	0.66
<i>Shorea</i> forest (Disturbed)	19	2.31	2.86	0.16	0.78
<i>Haplophragma</i> Plantation Forest	8	1.493	1.064	0.348	0.718
Shrubs					
<i>Shorea</i> forest (Undisturbed)	6	1.53	0.627	0.26	0.852
<i>Shorea</i> forest (Disturbed)	10	1.83	1.05	0.25	0.80
<i>Haplophragma</i> Plantation Forest	9	2.00	0.89	0.16	0.91
Herbs					
<i>Shorea</i> forest (Undisturbed)	23	3.06	1.77	0.05	0.98
<i>Shorea</i> forest (Disturbed)	15	2.57	1.13	0.09	0.95
<i>Haplophragma</i> Plantation Forest	15	2.59	1.16	0.09	0.96
Climbers					
<i>Shorea</i> forest (Undisturbed)	5	1.37	0.56	0.29	0.85
<i>Shorea</i> forest (Disturbed)	8	1.97	0.82	0.16	0.95
<i>Haplophragma</i> Plantation Forest	5	1.34	0.51	0.32	0.83

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The concentration of dominance for trees (0.34) was greater in the plantation forest as compared to *Shorea robusta* disturbed and undisturbed forest ecosystems (0.16 to 0.23), Table 4. In this study, the concentration of dominance values are higher than the average value of tropical forest ($C_d = 0.06$; Knight, 1975). For the *Shorea robusta* undisturbed forest at Kalesar, equitability index (Pielou's index) for tree layer was 0.66; the values being 0.78 for the disturbed *Shorea robusta* and 0.72 for the plantation forest. Species richness (Margalef's index) for the trees was greatest for the *Shorea robusta* disturbed forest (2.86) followed by that of undisturbed forest (2.12) and plantation forests (1.06).

The Shannon's diversity index for the shrub layer was greatest in the plantation forest (2.0) as compared to that of the *Shorea robusta* undisturbed and disturbed forest (1.53 to 1.83), Table 4. The Margalef Index of species richness for shrubs was highest for the *Shorea robusta* (2.1.05). The concentration of dominance for shrubs (0.26) was greatest in *Shorea robusta* undisturbed forest, whereas in other forest ecosystems the values ranged from 0.16 to 0.25 (Table 4). Pielou's index for equitability for shrubs was found to range from 0.80 to 0.91 in the *Shorea robusta* forests and the plantation forest.

The Shannon's diversity index for the herbaceous layer in different forest ecosystems varied from 2.57 to 3.06; the values being greater for the *Shorea robusta* undisturbed forest. The Margalef Index for herbaceous layer was also greatest in the *Shorea robusta* undisturbed forest (1.77). The Pielou's Index of equitability for herbaceous layer varied from 0.95 to 0.98 in the three forests. The concentration of dominance for herbs was comparatively low; the values being 0.05 to 0.09 (Table 4).

The Shannon's diversity index and Margalef Index for climbers was greater in the *Shorea robusta* disturbed forest ($H = 1.97$; $D = 0.82$). It was observed that tree density affected the occurrence of climbers in the disturbed forest. The Shannon's diversity index for climbers in *Shorea robusta* undisturbed forest was 1.37 and the Margalef Index was 0.56. Pielou's Index of equitability for climbers varied from 0.83 to 0.95 in different types of forest ecosystems. The concentration of dominance for the three sites was: 0.16 to 0.32; the value being higher for the plantation forest (Table 4).

Dominance Diversity Curves

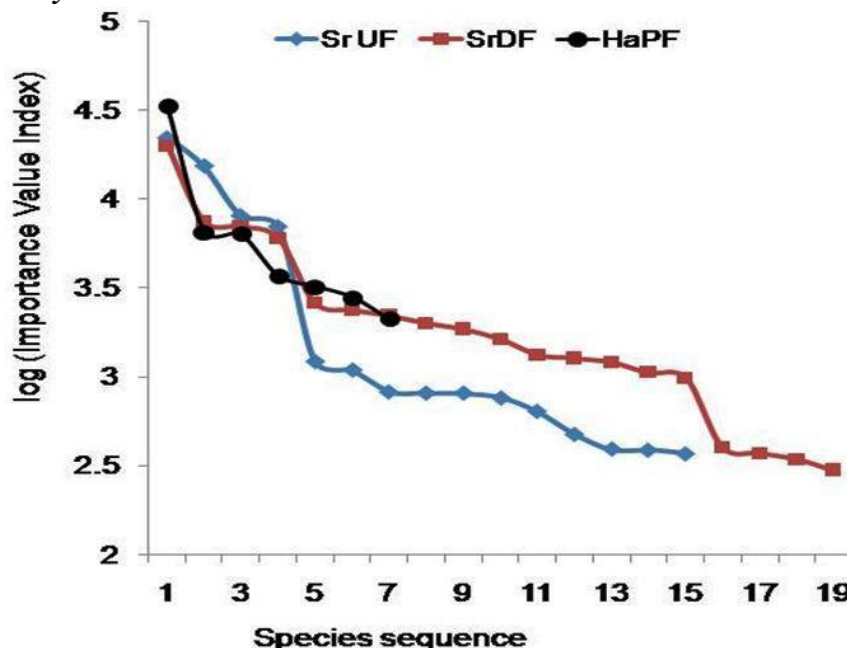


Figure 4: Dominance–diversity curves of tree species in *Shorea robusta* undisturbed forest (SrUF), *Shorea robusta* disturbed forest (SrDF) and *Haplophragma adenophyllum* plantation Forest (HaPF) at Kalesar

The interrelationships among species distribution in each community could be inferred quantitatively from dominance diversity curves, i.e., geometric, log, log-normal and random niche-boundary types

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(Preston, 1948; Whittaker, 1965). The dominance diversity curves for the trees, shrubs, and herbs in the three forest ecosystems are shown in Figures 4 to 6. The trees, shrubs, and herbs showed a lognormal distribution of plants as the niches were shared by several species in the studied forest ecosystems. The curves for the different functional groups of plants in different forest ecosystems were found to approach the log-normal model of Preston (1948). In the present study, a log normal distribution in the case of trees, shrubs and herbs is indicative of the highly mixed species composition (Whittaker, 1975).

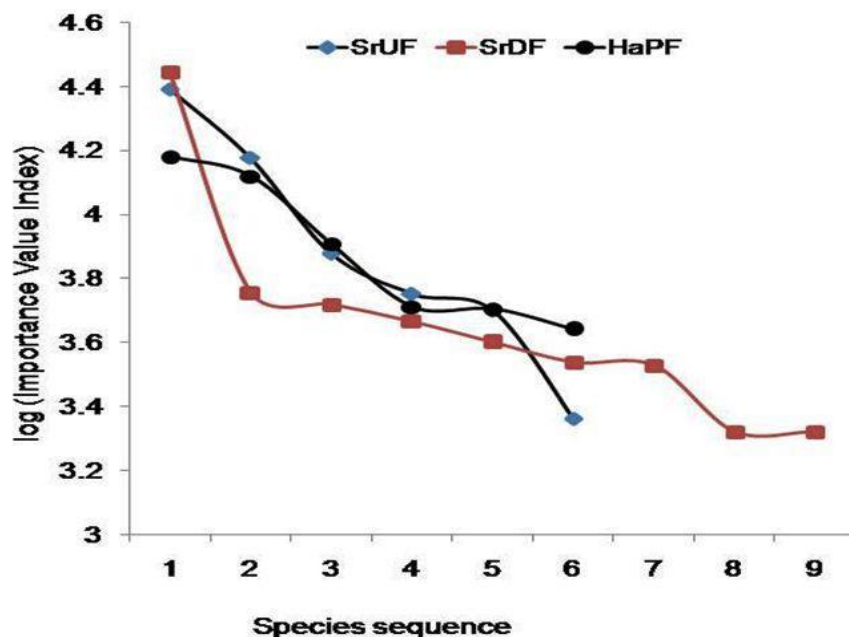


Figure 5: Dominance–diversity curves of shrub species in *Shorea robusta* undisturbed forest (SrUF), *Shorea robusta* disturbed forest (SrDF) and *Haplophragma adenophyllum* plantation Forest (HaPF) at Kalesar

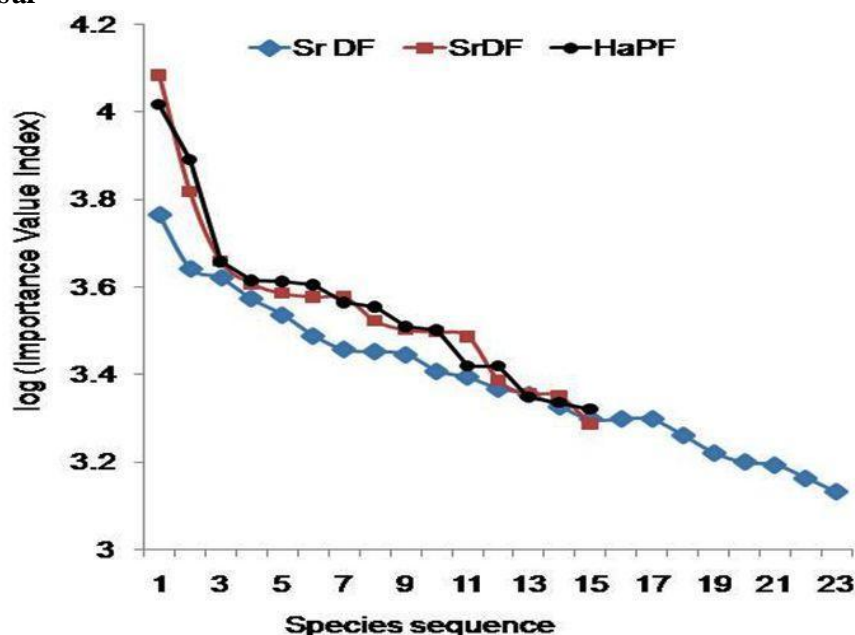


Figure 6: Dominance–diversity curves of ground floor herbaceous species in *Shorea robusta* undisturbed forest (SrUF), *Shorea robusta* disturbed forest (SrDF) and *Haplophragma adenophyllum* plantation Forest (HaPF) at Kalesar

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The interrelationships among species distribution in each community could be inferred quantitatively from dominance diversity curves, i.e., geometric, log, log-normal and random niche-boundary types (Preston, 1948; Whittaker, 1965). The dominance diversity curves for the trees, shrubs, and herbs in the three forest ecosystems are shown in Figures 4 to 6. The trees, shrubs, and herbs showed a lognormal distribution of plants as the niches were shared by several species in the studied forest ecosystems. The curves for the different functional groups of plants in different forest ecosystems were found to approach the log-normal model of Preston (1948). In the present study, a log normal distribution in the case of trees, shrubs and herbs is indicative of the highly mixed species composition (Whittaker, 1975).

Biodiversity Conservation

A total of 81 species were recorded during sampling of the forest vegetation indicating moderately high diversity of the various functional groups of plants (trees, shrubs, herbaceous plants, and climbers) in the forests. Many of the plant species are a source of timber, forest products (including flavors and fragrances, fibers, and saps and resins), fuelwood, fodder, fibers, dyes, tannins, oil, and medicinal plants. Species diversity in forests of Siwaliks often contribute to the economy of the local people by supplying material used for small-income generating activities, such as the sale of local foods, fodder, bhabhar grass and traditional medicines (Gupta and Kumar 2014). Several forest trees and shrubs bear fruits that are used by the local people. Species diversity in forests of Siwaliks often contribute to the economy of the local people by supplying material used for small-income generating activities, such as the sale of local foods, fodder, bhabhar grass and traditional medicines. Forests provide several intangible benefits including regulation of local and global climate by serving as the stores and sinks of carbon. Recent ecological research has shown the linkages between biodiversity and ecological functioning, and analyzed ecological processes regulating a number of ecosystem services.

The main services from forest ecosystems include: habitat provision, clean water, flood protection, carbon sequestration and storage, climate regulation, oxygen production, nutrient cycling, genetic resources for crops, and spiritual, cultural, recreational and tourism values. The ecosystem services approach can save many forest ecosystems with high biodiversity and willingness of society to protect their biodiversity. Therefore, it is required to link biodiversity and ecosystem functions (BEF) and biodiversity and ecosystem services (BES) perspectives as services are often regulated by multiple functions (Mace *et al.*, 2012).

Conclusions

Community characteristics like density, importance value index, and patterns of species diversity showed marked differences among the three forest ecosystems due to discernible variation in soil conditions and biotic influences. In the *Shorea robusta* forests, species diversity was high and dominance – diversity curves showed a log-normal distribution suggesting an almost equal apportionment of resources among various species. The dominance-diversity curves for the shrubs, and herbs also followed a log-normal distribution conforming to high species diversity of ground floor vegetation in the studied forest ecosystems. The long term conservation of the biodiversity can be ensured by creating public awareness about the value of biodiversity and allocating a greater share of benefits to the village poor from conservation. The annual value of ecosystem services can be used to make informed decisions and policies to help conserve forests, biodiversity and ecosystem services to improve human-well being in this region of unstable Siwaliks.

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