Hindawi
International Journal of Ecology
Volume 2018, Article ID 1394814, 29 pages
https://doi.org/10.1155/2018/1394814

Research Article

Changes in the Ecological Parameters of Mixed Forests of Sal (*Shorea robusta* Gaertn.) Are a Function of Distance from the Human Settlements

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Received 17 March 2018; Revised 24 August 2018; Accepted 10 October 2018; Published 30 October 2018

Academic Editor: Ram Chander Sihag

Forests in Nepal are extremely important for supporting the livelihood of millions of people who collect forest products for their subsistence use and partly for income generation. Such inherent dependence is expected to cause disturbance in the forest ecosystem. We investigated changes in the structural assemblages caused by the interaction between anthropogenic disturbances and forest management activities in the mixed forests of Sal (*Shorea robusta* Gaertn.) of Terai, Central Nepal. We evaluated three buffer zone community forests (BZCFs), namely, Radha Krishna, Musharni Mai, and Janajagaran of Parsa Wildlife Reserve (PWR); the forest inside PWR was taken as a control. A transect of 2 km length was laid in each forest, and six plots, each of 1 ha size, were established at a successive interval of 300 m along the edge to the interior of the forests to count and record the diameter at breast height (DBH) of the studied plants. We observed that the species diversity increased linearly ($p < 0.05$) towards the forest interior in the BZCFs. Species other than *S. robusta* had significantly higher ($p < 0.05$) dominance and Importance Value Indices in the interior sites. We did not observe such trends in the control forest. Multivariate analysis showed that the sites of BZCFs had higher structural dissimilarity, but the control forest sites were closer to each other in composition. The forest sites near the settlements had undergone biotic homogenization (*S. robusta* mixed forest changed to *S. robusta* forest) due to the interaction between anthropogenic disturbances and forest management activities. On the basis of vegetation density, the edges of BZCFs appeared to be protected, but on the basis of diversity failed to do so. Future management strategies should be directed towards enhancing the diversity, heterogeneity, and forest quality, especially near the forest edges.

1. Introduction

Anthropogenic activities influence the ecological processes [1–3] and have extensive impacts on the forest ecosystems [4–7]. The fragmentation of natural forests creates a pattern in the landscapes and is regarded as one of the most important causes for the recent decline of forest species [8], and the human activities increase the risk of further degradation in the forests sharing borders with anthropogenic uses [9–12]. However, with an increasing concern towards forest degradation, management interventions are also underway with a focus on the restoration of degraded areas [13]. Human pressures from the nearby settlements and forest management activities interact to alter the forest structural and functional attributes [14]. Our concern was to determine the extent of such changes in the mixed forest of Sal (*Shorea robusta* Gaertn.; family: Dipterocarpaceae) of Terai, Central Nepal.

Terai forests of Nepal, dominated by *S. robusta*, are among the most disturbed ecosystems [15, 16]. Commonly occurring forests fires every year during dry months also kill young regenerations and burn the deciduous litter layer. In addition, these ecosystems are important for millions of people who depend on forest products for their subsistence

Table 1: List of predominant woody species (species with Importance Value Index > 10) found in the sampling sites and their local uses (all species are used as firewood).

Scientific name	Local name	Family	Local uses
Shorea robusta Gaertn.	Sal	Dipterocarpaceae	Fodder and animal bedding Religious plant Support for climbers (in gardens) Construction and furniture Handicrafts Cosmetics Seeds (oil) and resin Leaf plates and bowls Medicinal plant
Adina cordifolia (Willd. ex Roxb.) Benth. & Hook. f. ex Brandis	Karam	Rubiaceae	Fodder and animal bedding Support for climbers (in gardens) Construction and furniture Handicraft Medicinal plant
Lannea coromandelica (Houtt.) Merr.	Jinger	Anacardiaceae	Fodder and animal bedding Furniture Medicinal plant Living fences Gum
Lagerstroemia parviflora Roxb.	Botdhayaro	Lythraceae	Fodder and animal bedding Support for climbers (in gardens) Construction and furniture Handicrafts Tannins
Casearia graveolens Dalzell	Badkaule	Flacourtiaceae	Support for climbers (in gardens) Fruit extract used to poison fish in streams/rivers
Cassia fistula L.	Rajbrikshya	Fabaceae	Fruits/legume Veterinary medicine Construction and furniture Handicrafts Medicinal plant Religious plant Ornamental
Mallotus philippensis (Lam.) Müll.-Arg.	Sindure	Euphorbiaceae	Fodder and animal bedding Support for climbers (in gardens) Ornamental Construction and furniture Handicrafts Red dye Medicinal plant
Dillenia pentagyna Roxb.	Tatari	Dilleniaceae	Animal bedding Fruits Religious plant Vegetables Medicinal plant
Syzygium cumini (L.) Skeels	Jamuna	Myrtaceae	Fodder and animal bedding Fruits Religious plant Medicinal plant Support for climbers (in gardens) Construction and furniture

Table 1: Continued.

Scientific name	Local name	Family	Local uses
Semecarpus anacardium L.f.	Bhalayo	Anacardiaceae	Fodder and animal bedding Fruits and nuts Religious plant Support for climbers (in gardens) Medicinal plant
Miliusa velutina (Dunal) Hook. f. & Thoms.	Kalikath	Annonaceae	Fodder and animal bedding Fruits Support for climbers (in gardens) Construction materials Handicrafts
Terminalia alata Heyne ex Roth	Saj	Combretaceae	Fodder and animal bedding Construction and furniture Handicrafts Seeds Medicinal plant
Cleistocalyx operculatus (Roxb.) Meer. & Perry	Kyamuna	Myrtaceae	Fodder and animal bedding Fruits Construction Medicinal plant
Anogeissus latifolius (Roxb. ex DC.) Bedd.	Banjhi	Combretaceae	Fodder and animal bedding Support for climbers (in gardens) Construction Handicrafts
Terminalia bellirica (Gaertn.) Roxb.	Barro	Combretaceae	Fodder and animal bedding Fruits Construction and furniture Vegetable oil Medicinal plant
Phyllanthus emblica Linn.	Amala	Euphorbiaceae	Fruits and juice Religious plant Medicinal plant Support for climbers (in gardens) Construction and furniture Cosmetics Seed oil
Terminalia chebula Retz.	Harro	Combretaceae	Fodder and animal bedding Furniture Fruits Medicinal plant
Dalbergia latifolia Roxb.	Satisal	Fabaceae	Religious plant Ornamentals Handicrafts Construction and furniture Medicinal plant
Desmodium oojenense (Roxb.) Ohashi	Sandan	Fabaceae	Fodder Religious plant Construction and furniture Handicrafts Medicinal plant
Garuga pinnata Roxb.	Dabdabe	Burseraceae	Fodder and animal bedding
Buchanania latifolia Roxb.	Piyari	Anacardiaceae	Fodder and animal bedding Fruits Construction and furniture Handicrafts Medicinal plant

Table 1: Continued.

Scientific name	Local name	Family	Local uses
Dysoxylum gobara (Buch.-Ham.) Merr.	Lasune	Meliaceae	Fodder and animal bedding Construction and furniture Handicrafts Medicinal plant

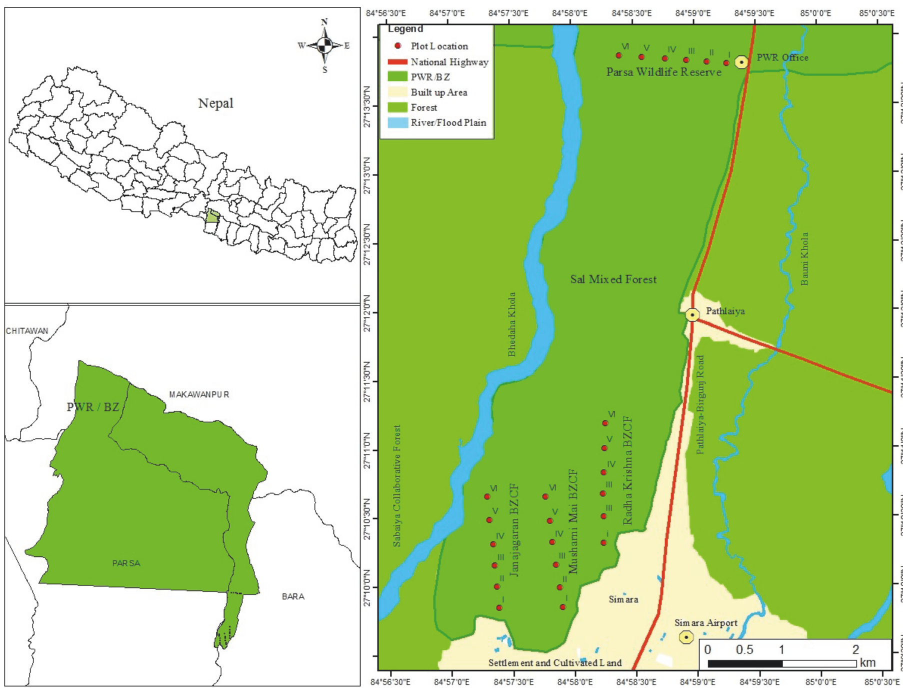

Figure 1: Location of studied BZCFs and PWR forest in Bara District, Central Terai, Nepal. In these BZCFs, the forest user groups are different and also vary in a number of households using forest resources. These BZCFs are the southernmost part of a large forest landscape also known as "Charkose Jhadi". People enter from the southern border of the BZCFs to collect/harvest forest resources.

(Table 1). Repeated extraction of forest resources to meet livelihood needs of adjoining human settlements can cause significant impacts on the forest regeneration, structure, and diversity, and these impacts often have been associated with the distance to the settlements [17–20]. In our studied buffer zone community forests (BZCFs), besides harvesting of the forest resources, the forests are also under regular management activities carried by Buffer Zone Management Committees, and the interaction between the disturbances and management interventions might have altered the ecological parameters differently. To our understanding, there are ample studies showing the impacts of forest disturbance on forest structure [16–19], but limited research exists on how management and disturbance interaction influences the composition, structure, richness, and taxonomic diversity of the forests. What ecological changes take place due to such interactions in the forests of Nepal are not known [21].

We attempted to study ecological changes in the Sal forest of Nepal as a result of interaction between inherent disturbances and ongoing management practices (for more than 20 years) in the BZCFs of Nepal. To understand responses of the woody plant species in the forests, our study aimed at elucidating (1) present condition of natural BZCFs in terms of forest community composition, distribution, density, richness, and species diversity as a function of distance from the human settlements, (2) changes in basal area (dominance) of woody species due to management and disturbance interventions from the edge to the forest interior, and (3) effect of anthropogenic disturbances and management interventions on the similarity and dissimilarities of the sites located along the distance from the human settlements. We hypothesized that forest structure differs when management interventions are applied in conjugation with the ongoing disturbances in the forests.

2. Materials and Methods

2.1. Study Area. Cross-sectional vegetation survey was conducted in three BZCFs of Parsa Wildlife Reserve (PWR) (PWR has been currently designated as a national park) at Gadimai Municipality, Central Terai Nepal, namely, Janajagaran BZCF (area: 371.10 ha), Musharni Mai BZCF (area: 231.31 ha), and Radha Krishna BZCF (area: 621.171 ha) (Figure 1). The forest in PWR was considered as a control.

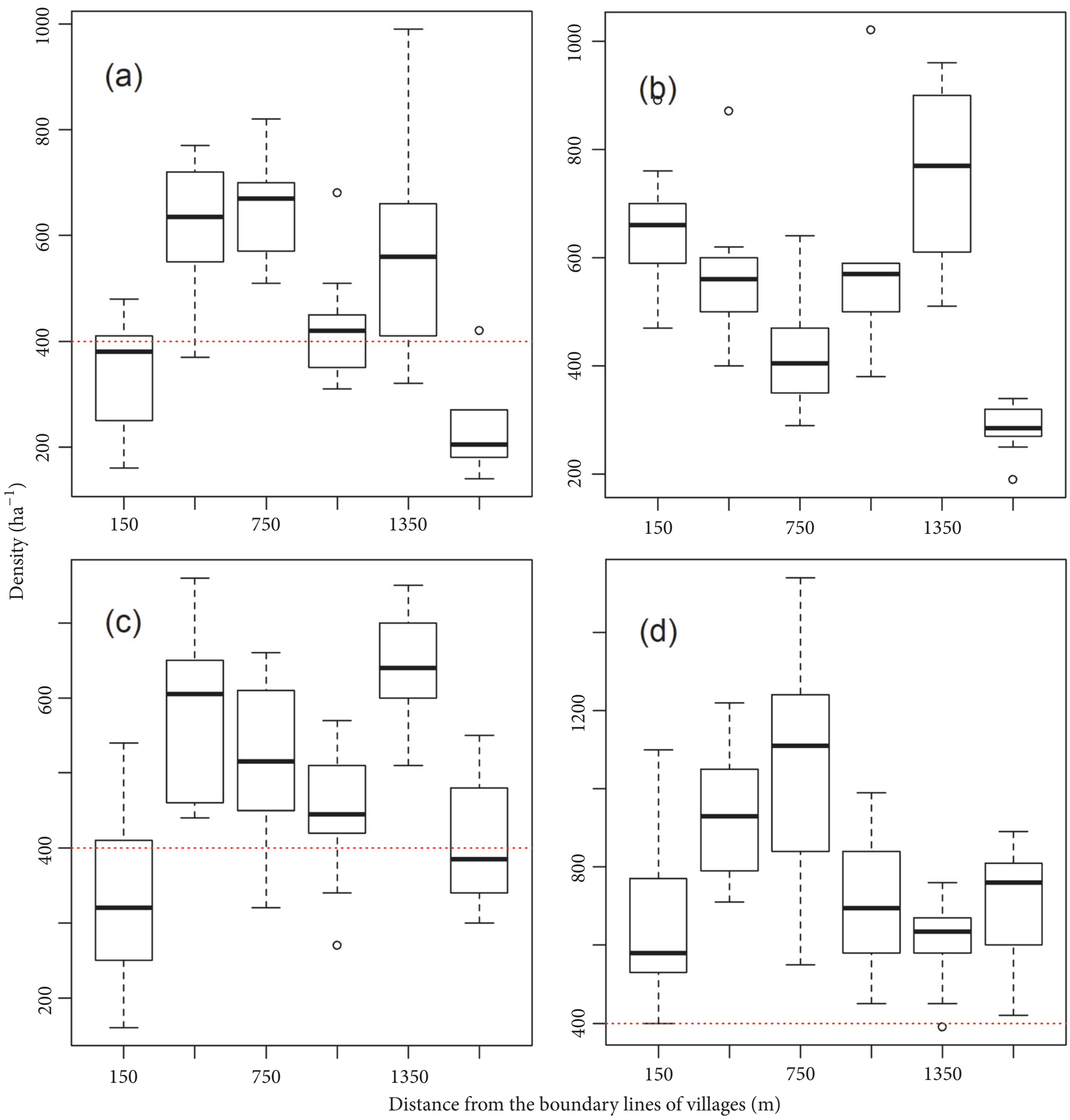

Figure 2: Box plot showing total density (stems ha^{-1}) of woody plants from the edge to the interior of the forests. (a) Janajagaran BZCF, (b) Musharni Mai BZCF, (c) Radha Krishna BZCF, and (d) Parsa Wildlife Reserve (control forest).

These forests are the part of the largest continuous forest landscape in Terai region, also known as "Charkose Jhadi" in Nepal. The BZCFs are situated in the southern part of PWR (Bhimeshwor BZCF is the other forest located in the southern part of PWR) on alluvial plains and composed of flood or river deposits of sand, silt, clay, coarser sediments, and conglomerates. The BZCFs are adjacent to each other with the connected boundaries between them. Since the forests are connected, the transects laid in the forests were kept at least at the distance of 1.5 km. The area harbors several protected faunal species such as Elephants (*Elephas maximus*), Royal Bengal Tiger (*Panthera tigris*), Gauri Gai (*Bos gaurus*), Wild Dogs (*Cannes aurous*), and many other common wild animals including spotted deer (*Axis axis*), barking deer (*Muntiacus muntjac*), hog deer (*Axis porcinus*), and wild boar (*Sus scrofa*). Common reptiles found in the area are golden lizard (*Calotes versicolor*), monitor lizard (*Varanus bengalensis*), krait (*Bungarus careleus*), branded krait (*Bungarus faciatus*), cobra (*Naja naja*), and common rat snake (*Ptyas mucosus*).

The climate in the area is tropical. A typical year can be divided into three main seasons: cold, hot, and rainy. April and May have the highest mean maximum temperature, while the coldest months are November, December, and January. Mean monthly minimum and maximum temperature are 18°C and 30°C, respectively. The average monthly rainfall in the area is 156 mm. Maximum rainfall occurs during the monsoon (June-September) season.

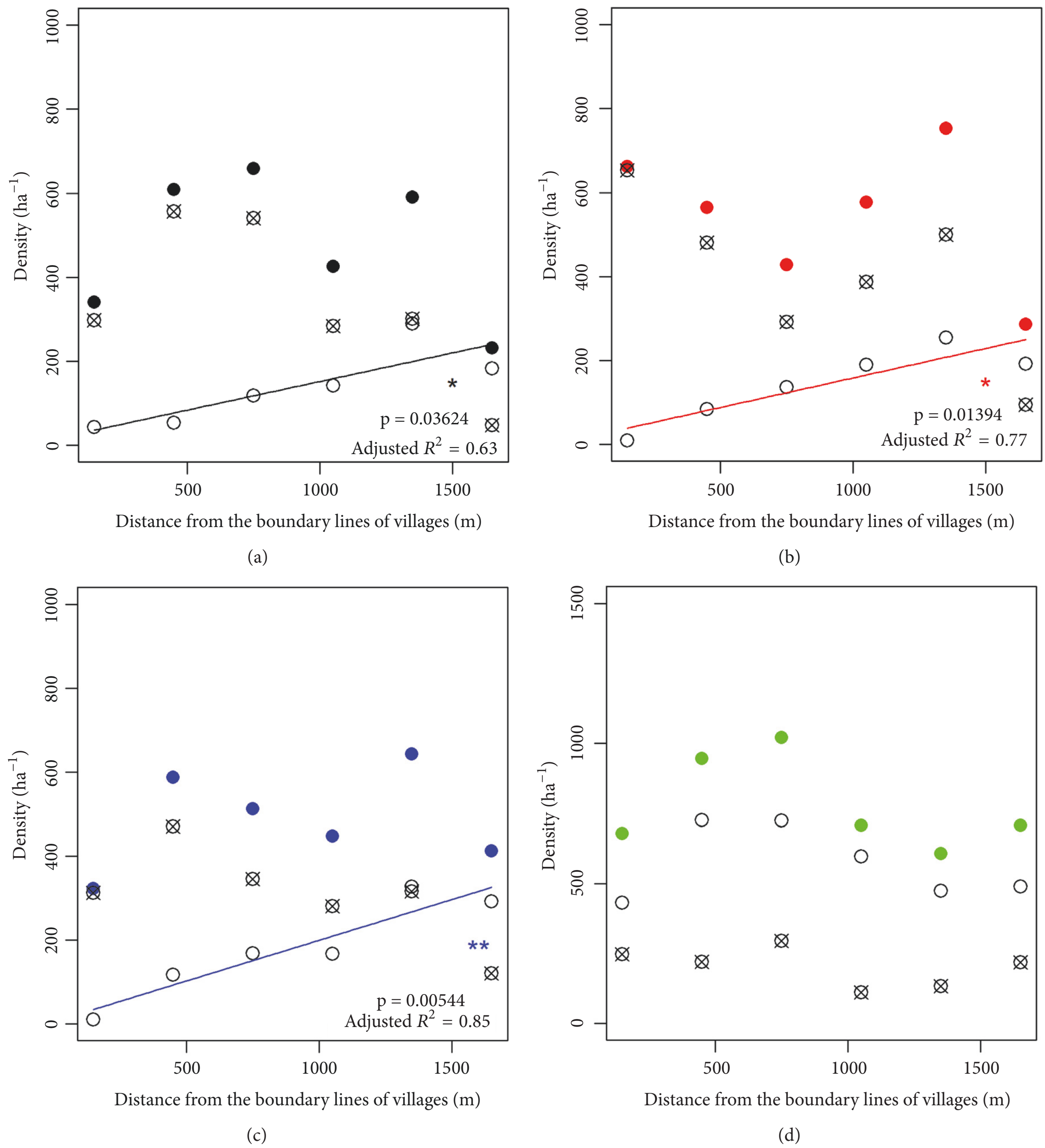

Figure 3: Density (stems ha^{-1}) of woody plant species as a function of distance from the village boundaries. In the figure, solid circles, hollow circles, and circles with crosses denote density of all woody species, density of species other than *Shorea robusta,* and density of *S. robusta,* respectively. For the density of stems other than *S. robusta,* the linear trend was significant for (a) Janajagaran BZCF ($p < 0.05$), (b) Musharni Mai BZCF ($p < 0.05$), and (c) Radha Krishna BZCF ($p < 0.01$), but the trend was nonsignificant for (d) Parsa Wildlife Reserve ($p > 0.05$).

2.2. Experimental Design and Sampling. A preliminary survey for the study was carried out during July 2015. Primary data collection and detail inventory of BZCFs and the protected forest inside PWR were carried out from July 2016 to October 2016. Using ArcGIS (10.2.2) and Google Earth Images (Google Earth 7.1.8.3036), an azimuth for each forest was oriented towards the forest interior, away from the corresponding settlement areas. A constant azimuth (355°, 350°, 1°, and 275° for Janajagaran BZCF, Musharni Mai BZCF, Radha Krishna BZCF, and PWR, respectively) was taken and a transect line was laid along the azimuth (Appendix A, Table 1). Similar sampling design was also adopted in other primary studies [7, 16, 17, 22].

Six plots each of 1 ha size were established on the left side of each transect at a successive interval (horizontal distance) of 300 m along the edge to the interior of each forest (150 m: Site I, 450 m: Site II, 750 m: Site III, 1050 m: Site IV, 1350 m: Site V, and 1650 m: Site VI). The farthest

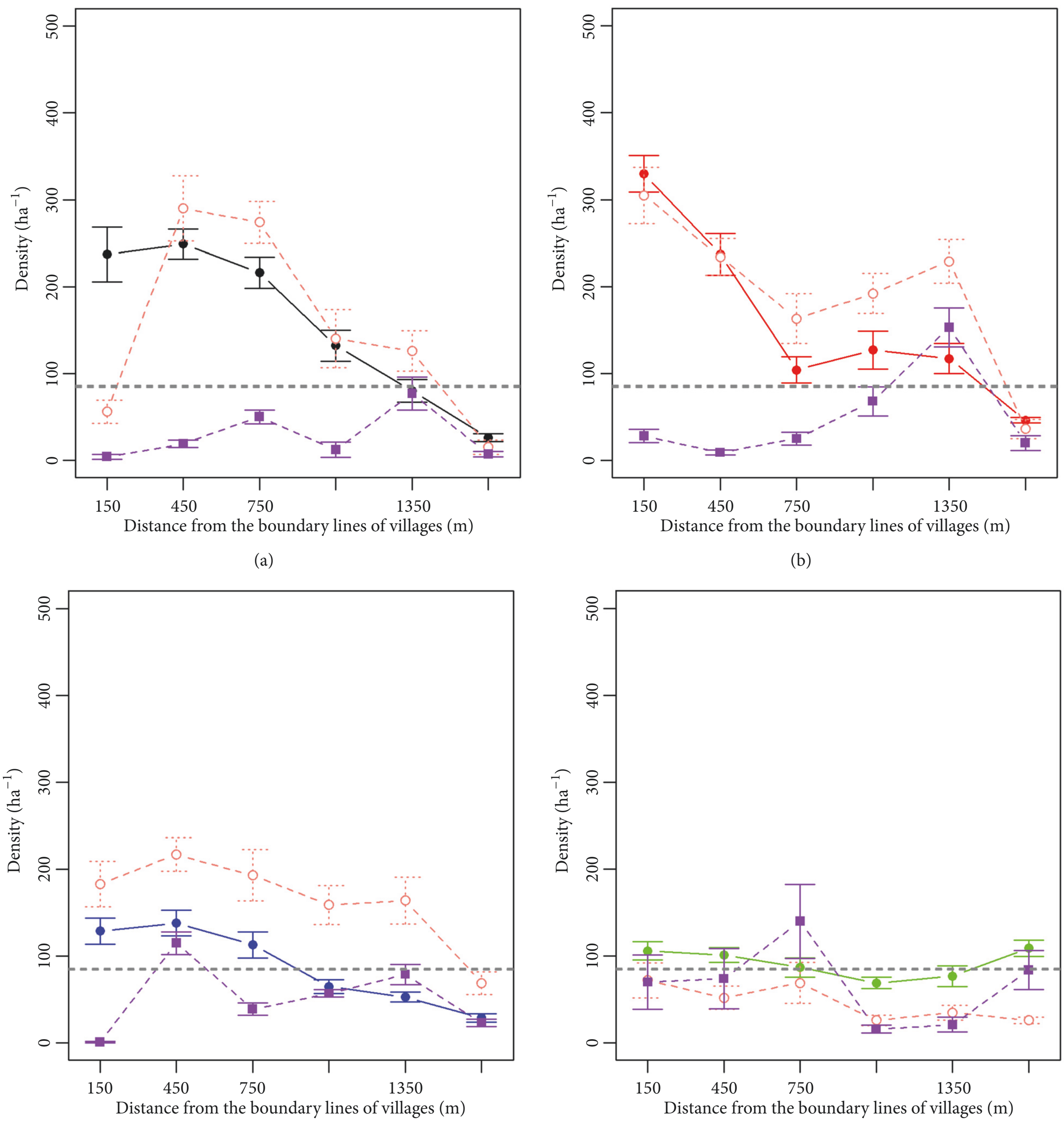

FIGURE 4: Density (stems ha^{-1}) of *Shorea robusta* (categorized as groups under saplings, poles, and trees) plotted against the distance from the village boundary lines. (a) Janajagaran BZCF, (b) Musharni Mai BZCF, (c) Radha Krishna BZCF, and (d) Parsa Wildlife Reserve. Solid lines in the figure indicate the density of the trees. Salmon colored dotted lines show the density of poles, and purple colored dotted lines show the density of saplings. The vertical lines are standard error bars. The horizontal lines are the reference density lines for the maximum number of mature trees (85 stems ha^{-1}) that 1 ha plot can withstand.

distance from the settlement (Site VI) consisted of relatively undisturbed stands (however, there were signs of illegal cutting of some individual stems). For the control forest, a transect was laid starting near the Central Office of PWR along the main entrance (fire line) towards the forest core. We used a handheld GPS (Garmin 60CSx) to determine the position of the plot-centers along the transect line (rope of 100 m was also stretched to ease transect layout). Each plot was then divided into 10 subplots each of 20 × 50 m for sampling [23]. The total number of sampling units (subplots) was sufficient to produce stabilizing species-area curves in the forests (Appendix B, Figure 13). In all

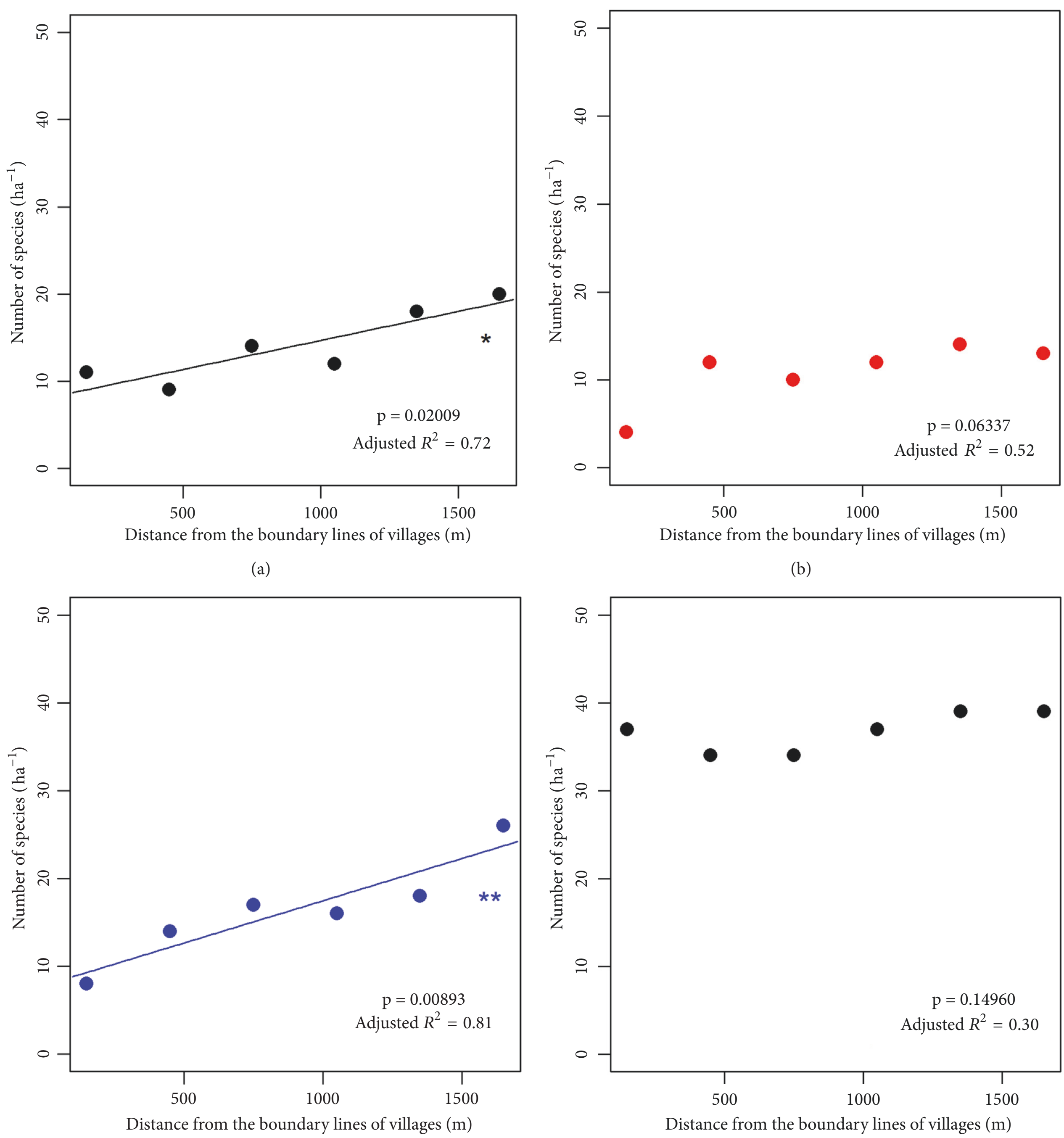

Figure 5: Observed species richness (species ha^{-1}) plotted against the distance from the village boundaries. (a) Janajagaran BZCF: significant ($p < 0.05$), (b) Musharni Mai BZCF: nonsignificant ($p > 0.05$), (c) Radha Krishna BZCF: significant ($p < 0.01$), and (d) Parsa Wildlife Reserve: nonsignificant ($p > 0.05$).

the studied forests, surface fire occurs at least once during the dry season of the year which usually destroys smaller seedlings, so we considered the woody species ≥ 1.5 cm in diameter at breast height (DBH) which have survived in moderate fire pressure. Structural attributes were collected from a total of 60 subplots in each studied BZCF. The woody species present were identified, counted, and tallied, and DBH of each individual ≥ 1.5 cm DBH was measured at 1.3 m above the ground with the help of a DBH tape (Kinglon Diameter Tape, Japan). Based on DBH, individuals were classified as saplings (1.5 to 10 cm DBH), poles (10 to 20 cm DBH), and trees (> 20 cm DBH). For a multistemmed tree at breast height, it was treated as a single individual whereby the diameters of all stems were measured separately and

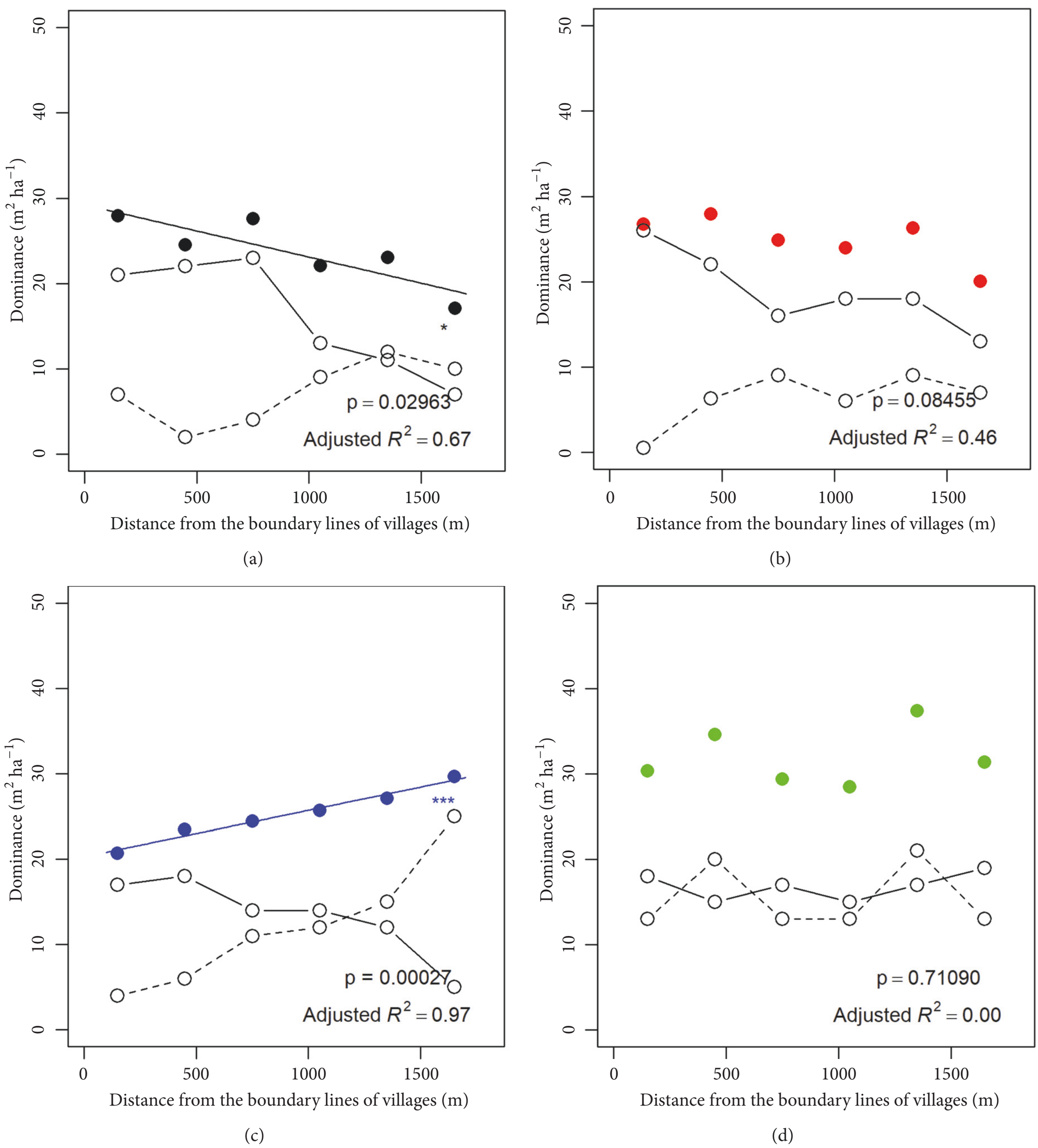

Figure 6: Dominance (basal area) of species as a function of the distance from the village boundaries. In the figure, solid circles with solid lines, hollow circles with solid lines, and hollow circle with dashed lines indicate total dominance, dominance of *Shorea robusta,* and dominance of other species except for *Shorea robusta,* respectively. (a) Janajagaran BZCF: significant ($p < 0.05$), (b) Musharni Mai BZCF: nonsignificant ($p > 0.05$), (c) Radha Krishna BZCF: significant ($p < 0.001$), and (d) Parsa Wildlife Reserve: nonsignificant ($p > 0.05$).

averaged. In case a tree had a buttress or an abnormality at 1.3 m height, the diameter was measured just above the abnormality.

Most plants were identified in situ; plants which were not identified to species in the field were identified by the National Herbarium and Plant Laboratories (KATH Herbarium Center) at Godavari, Lalitpur, Nepal (letter reference number 198 2073/2074). The species which could not be identified were considered as "unidentified".

2.3. Data Analysis. Basal area of live woody species (dominance) was calculated as $\Sigma \pi r^2$, where r is the radius (DBH/2) for all live woody species with DBH $\geq$ 1.5 cm. The density of a

Table 2: Geographical location of sampled sites∗ in the studied forests.

Forests		Site I	Site II	Site III	Site IV	Site V	Site VI
Janajagaran BZCF	Coordinates	27°09.822′N 084°57.253′E	27°10.018′N 084°57.215′E	27°10.172′N 084°57.216′E	27°10.326′N 084°57.205′E	27°10.500′N 084°57.357′E	27°10.675′N 084°57.396′E
	Elevation (m)	121	125	125	130	126	136
Musharni Mai BZCF	Coordinates	27°09.848′N 084°57.821′E	27°10.010′N 084°57.743′E	27°10.165′N 084°57.700′E	27°10.324′N 084°57.612′E	27°10.496′N 084°57.665′E	27°10.741′N 084°57.625′E
	Elevation (m)	109	113	108	118	120	135
Radha Krishna BZCF	Coordinates	27°10.334′N 084°58.101′E	27°10.525′N 084°58.103′E	27°10.678′N 084°58.121′E	27°10.821′N 084°58.132′E	27°11.022′N 084°58.126′E	27°11.203′N 084°58.105′E
	Elevation (m)	126	126	129	128	132	138
Parsa Wildlife Reserve	Coordinates	27°13.814′N 084°59.113′E	27°13.828′N 084°58.952′E	27°13.835′N 084°58.816′E	27°13.850′N 084°58.629′E	27°13.861′N 084°58.424′E	27°13.874′N 084°58.254′E
	Elevation (m)	200	199	203	200	210	202

∗Sites I, II, III, IV, V, and VI in the forests were 150 m, 450 m, 750 m, 1050 m, 1350 m, and 1650 m, respectively, far from boundary lines of villages. The gradient of increasing disturbance is from Site I to Site VI. Site I is nearer to settlements and prone to more resources (fuelwood, fodder, litter, etc.) collection as compared to Site VI. For the control forest (Parsa Wildlife Reserve), there was no such gradient of disturbances.

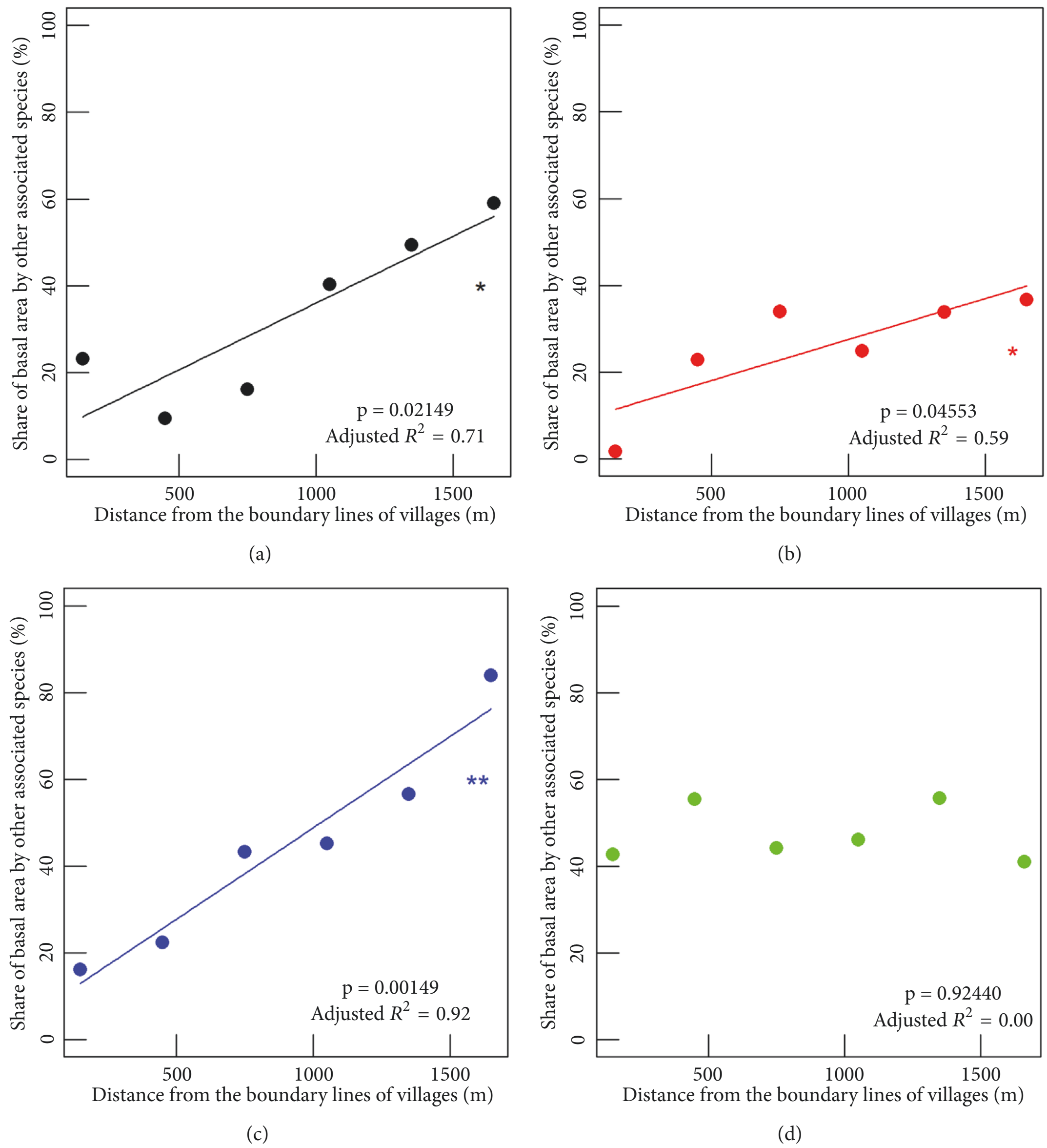

Figure 7: Dominance of species other than *Shorea robusta* as a function of the distance from the village boundaries. (a) Janajagaran BZCF: significant ($p < 0.05$), (b) Musharni Mai BZCF: significant ($p < 0.05$), (c) Radha Krishna BZCF: significant ($p < 0.01$), and (d) Parsa Wildlife Reserve: nonsignificant ($p > 0.05$).

Table 3: Observed richness, total density, and total basal area along the sites of Janajagaran BZCF.

Site	Observed richness (ha^{-1})	Density ± SD (individuals ha^{-1})	Basal area ± SD (m^2 ha^{-1})	Variance of frequency
I	11	340 ± 106.87	27.94 ± 10.99	761.82
II	9	609 ± 142.55	24.55 ± 6.66	1194.44
III	14	658 ± 97.27	27.61 ± 1.89	868.13
IV	12	426 ± 109.16	22.06 ± 2.69	1456.82
V	18	590 ± 227.50	23.02 ± 5.44	1287.91
VI	20	231 ± 78.94	17.10 ± 9.92	1231.58

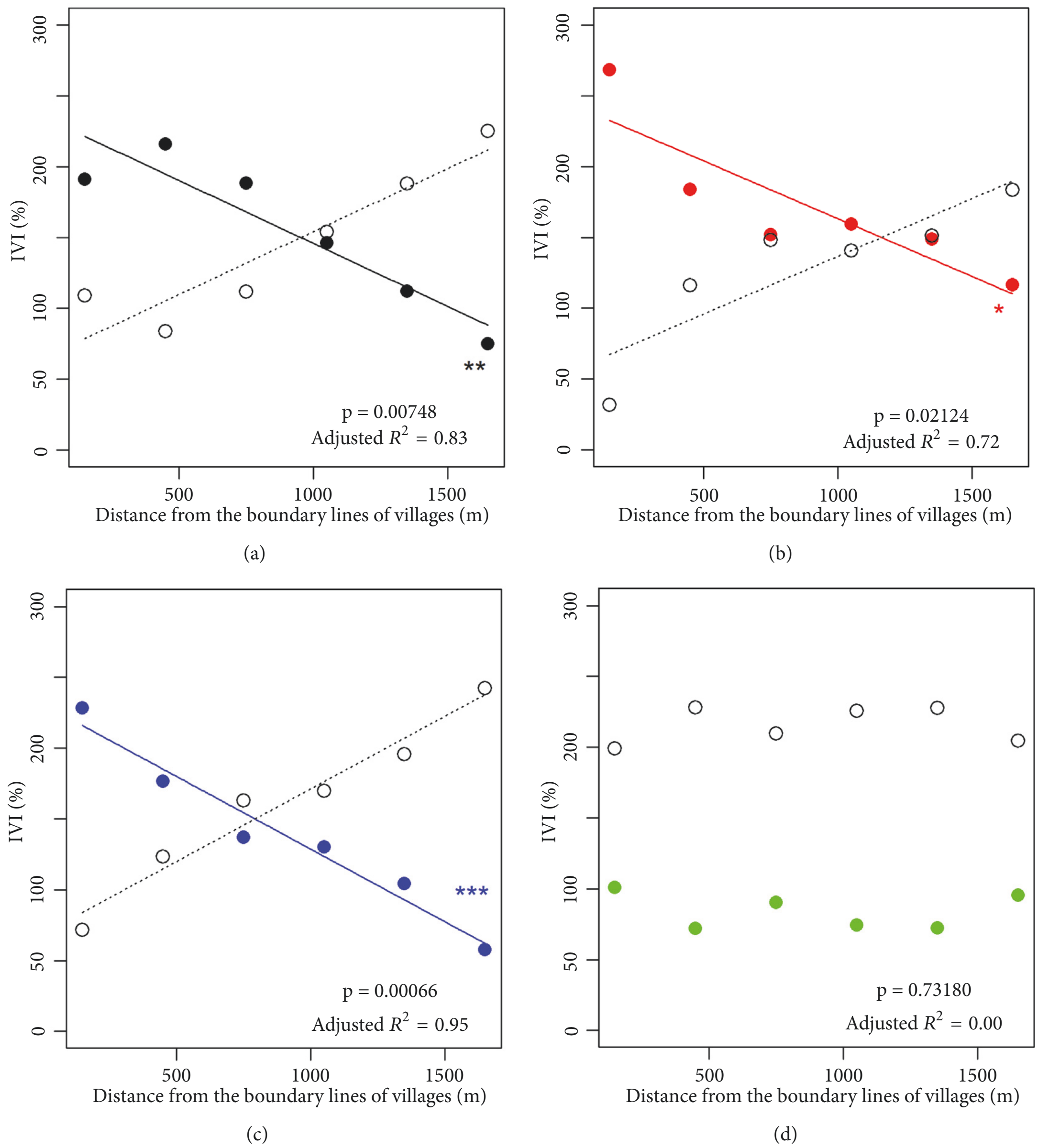

FIGURE 8: IVI (%) as a function of the distance from the village boundaries. (a) Janajagaran BZCF: significant ($p < 0.01$), (b) Musharni Mai BZCF: significant ($p < 0.05$), (c) Radha Krishna BZCF: significant ($p < 0.001$), and (d) Parsa Wildlife Reserve: nonsignificant ($p > 0.05$). The solid lines in the figure indicate IVI (%) of *S. robusta* and the dotted lines indicate total IVI (%) of other species except for *S. robusta*.

TABLE 4: Observed richness, total density, and total basal area along the sites of Musharni Mai BZCF.

Site	Observed richness (ha^{-1})	Density ± SD (individuals ha^{-1})	Basal area ± SD (m^2 ha^{-1})	Variance of frequency
I	4	662 ± 113.12	26.73 ± 5.53	1900
II	12	564 ± 131.17	27.92 ± 7.70	953.79
III	10	428 ± 109.52	24.87 ± 6.11	1262.22
IV	12	577 ± 169.84	23.94 ± 6.74	1384.09
V	14	753 ± 158.47	26.29 ± 4.42	1241.76
VI	13	286 ± 45.019	20.03 ± 6.52	1560.26

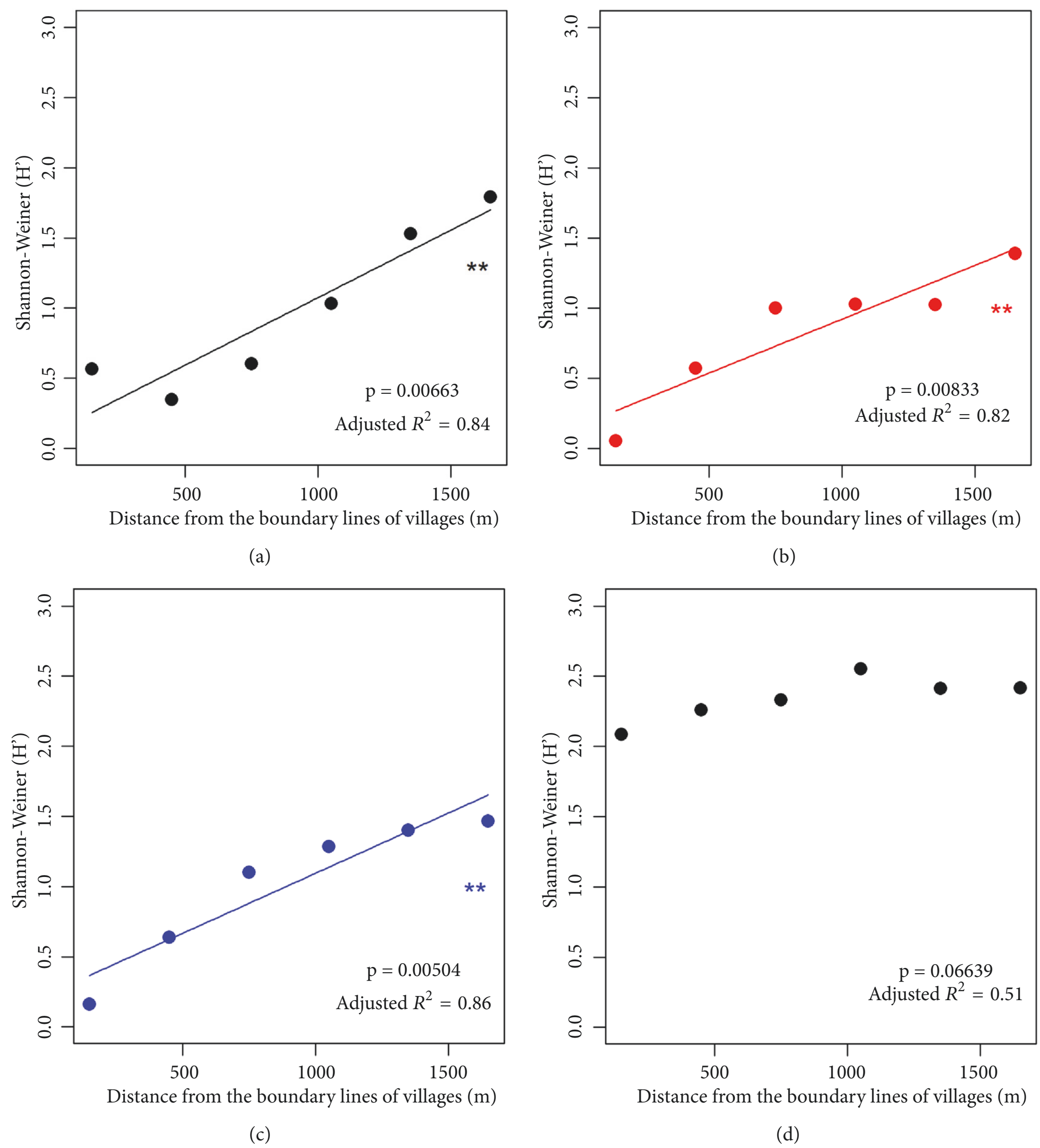

Figure 9: Shannon-Wiener H' diversity index as a function of the distance from the village boundaries. (a) Janajagaran Forest: significant ($p < 0.01$), (b) Musharni Mai Forest: significant ($p < 0.01$), (c) Radha Krishna Forest: significant ($p < 0.01$), and (d) Parsa Wildlife Reserve: nonsignificant ($p > 0.05$).

Table 5: Observed richness, total density, and total basal area along the sites of Radha Krishna BZCF.

Site	Observed richness (ha^{-1})	Density ± SD (individuals ha^{-1})	Basal area ± SD (m^2 ha^{-1})	Variance of frequency
I	8	323 ± 112.16	20.69 ± 6.74	942.86
II	14	587 ± 110.66	23.46 ± 4.53	965.39
III	17	513 ± 107.61	24.44 ± 4.25	1127.94
IV	16	448 ± 93.07	25.67 ± 6.00	1179.58
V	18	643 ± 71.81	27.09 ± 6.86	1379.41
VI	26	413 ± 89.20	29.68 ± 10.50	877.54

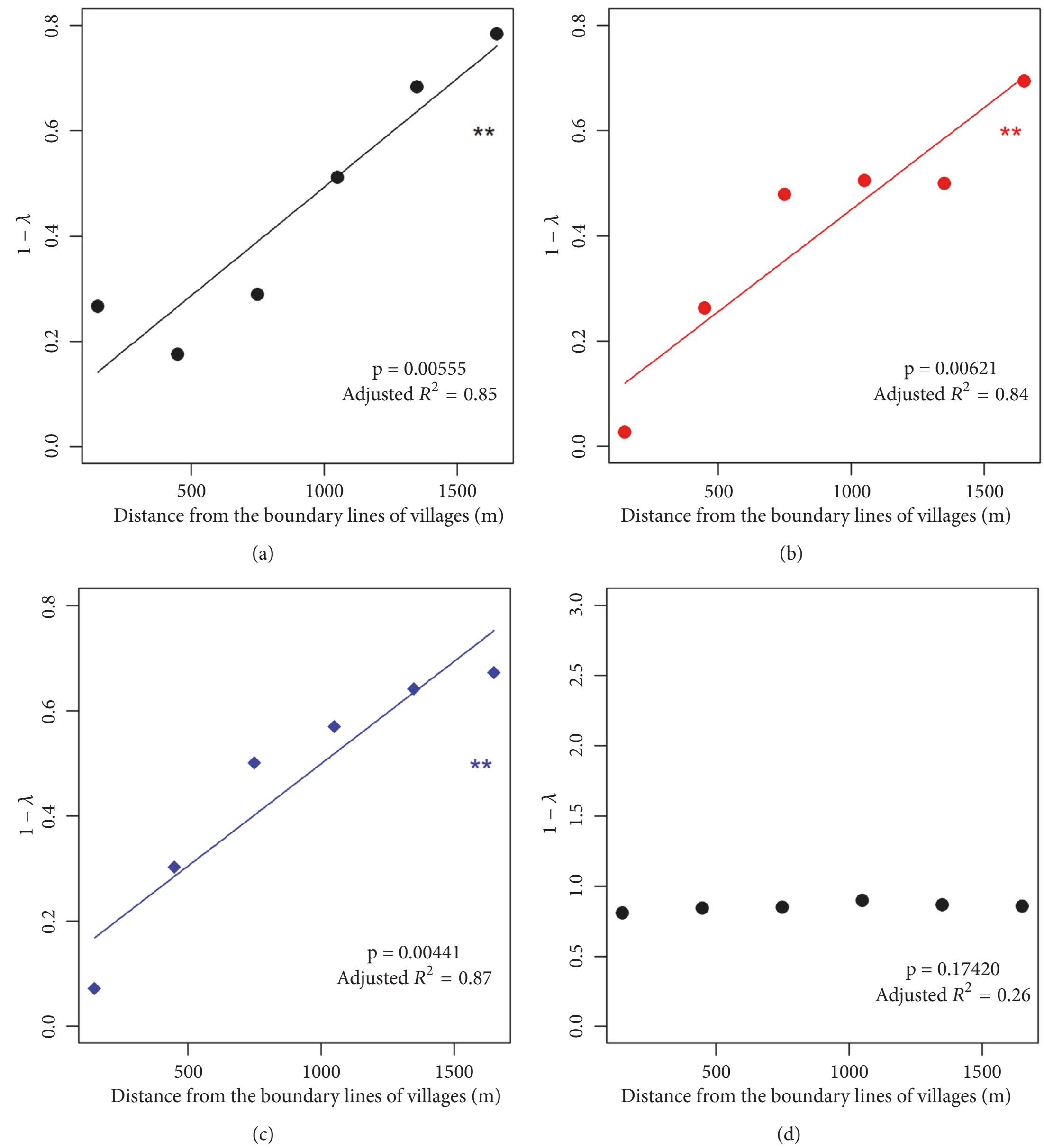

Figure 10: 1 – Simpson's λ (1 - $\sum$ pi^2) plotted against the distance from the village boundaries. (a) Janajagaran Forest: significant ($p < 0.01$), (b) Musharni Mai Forest: significant ($p < 0.01$), (c) Radha Krishna Forest: significant ($p < 0.01$), and (d) Parsa Wildlife Reserve: nonsignificant ($p > 0.05$).

Table 6: Observed richness, total density, and total basal area along the sites of Parsa Wildlife Reserve.

Site	Observed richness (ha^{-1})	Density ± SD (individuals ha^{-1})	Basal area ± SD (m^2 ha^{-1})	Variance of frequency
I	37	679 ± 250.31	30.34 ± 6.42	1001.87
II	34	946 ± 182.04	34.59 ± 9.71	1208.91
III	34	1021 ± 311.43	29.40 ± 6.18	1109.80
IV	37	707 ± 160.56	28.46 ± 8.19	1091.59
V	39	607 ± 112.45	37.38 ± 8.60	968.15
VI	39	708 ± 139.43	31.34 ± 6.61	960.46

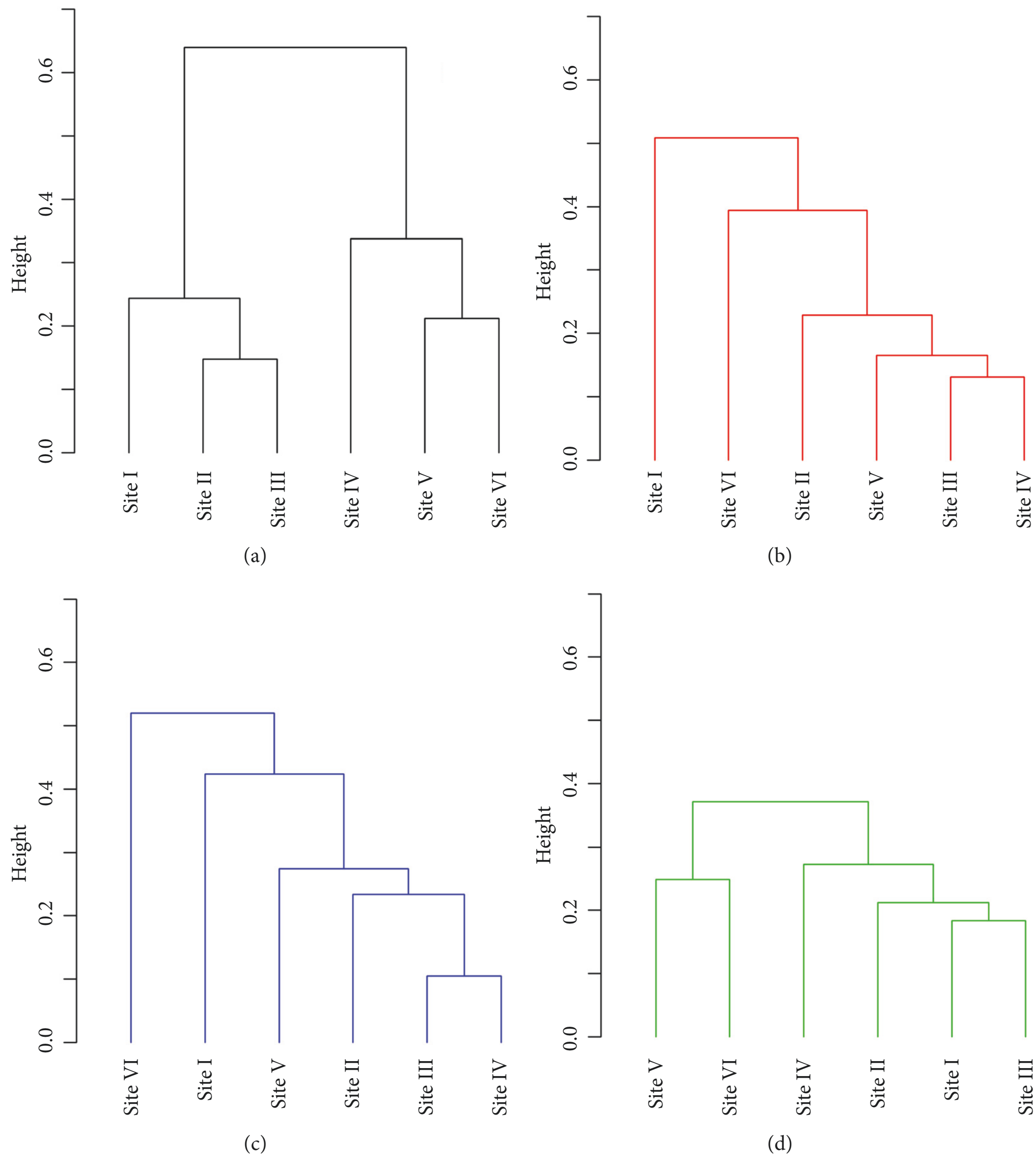

Figure 11: Multivariate agglomerative clustering (Ward D.2 group linkage) based on Bray-Curtis distance (species IVI dissimilarities) between the studied sites. (a) Janajagaran BZCF, (b) Musharni Mai BZCF, (c) Radha Krishna BZCF, and (d) Parsa Wildlife Reserve.

species was calculated as the number of individuals of species per unit area. Similarly, the estimated maximum density of mature *S. robusta* trees that 1 ha forest area can support was calculated with the mean value of the area covered by canopy projections of mature trees in natural growth conditions and considering that there will be no overlap of canopy between individuals of the species. The canopy projections (length) over cardinal and ordinal directions were measured based on the observation made vertically upwards and recorded as to whether or not the canopy of the trees obscures the sky [24]. The canopy cover area was calculated based on horizontal projections data and using readWKT and gArea functions in the rgeos package [25] and then was compared with 1 ha area.

The Importance Value Index (IVI) for each woody species was determined to evaluate the contribution of woody species in the forest composition, structure, and biomass. The IVI for a species was calculated by summing the relative frequency, relative density, and relative dominance [26–28]:

$$IVI_j = 100\left(\frac{n_j}{N} + \frac{d_j}{D} + \frac{x_j}{X}\right) \quad (1)$$

where IVI_j is the importance value of the jth species, n_j is the frequency of jth species, N is the sum of frequencies ($N = \sum n_j$), d_j is the number of individuals of the jth species present in the sample population, D is the total number of individuals in the sample population ($D = \sum d_j$), x_j is the sum of dominance for the jth species, and X is the total dominance across all species $X = \sum x_j$. Since relative frequency, relative density, and relative dominance are expressed in percentage, the maximum value of IVI is equal to 300.

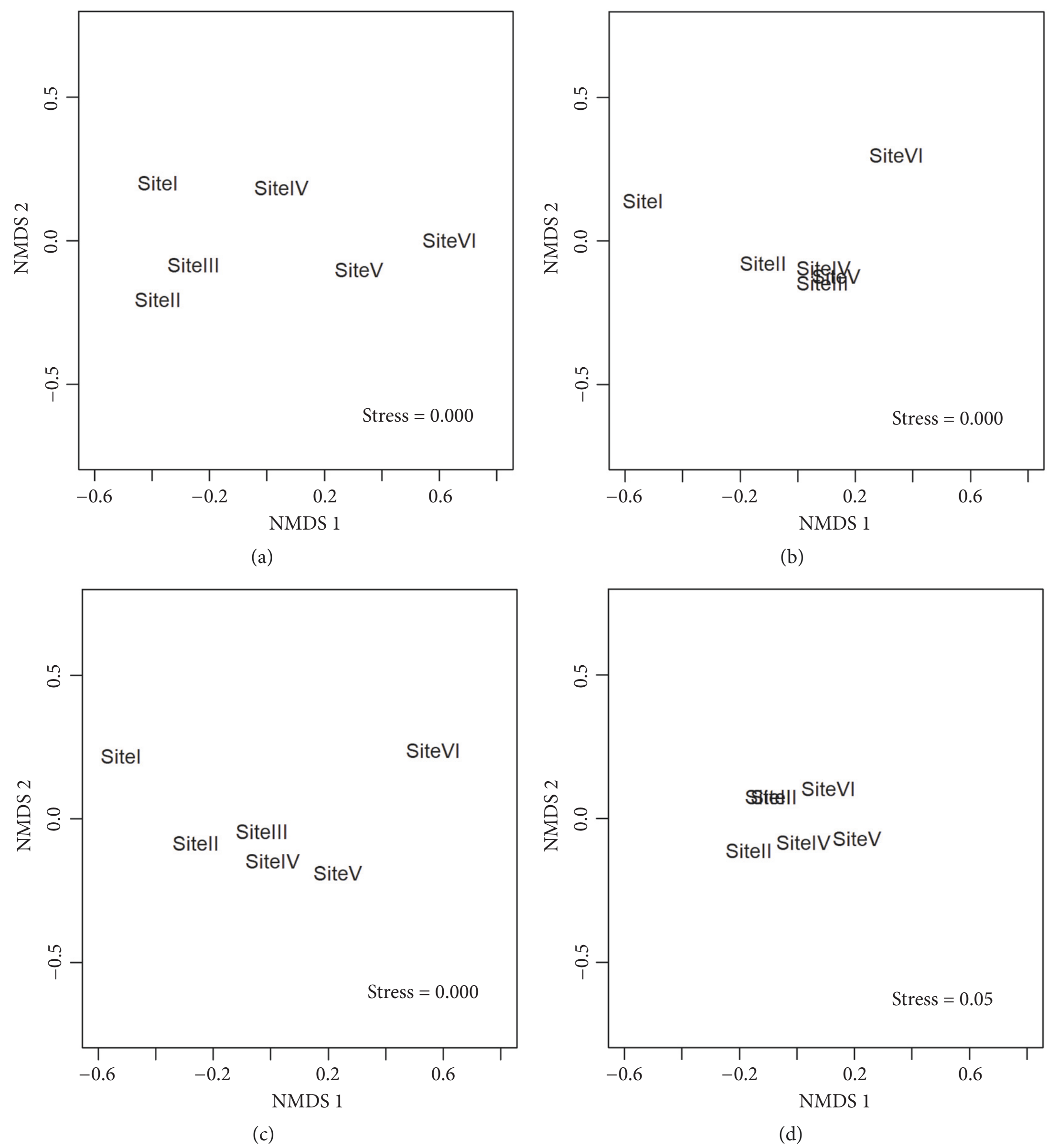

Figure 12: Nonmetric Multidimensional Scaling of the sites for (a) Janajagaran BZCF, (b) Musharni Mai BZCF, (c) Radha Krishna BZCF, and (d) Parsa Wildlife Reserve.

Species diversity (alpha diversity) was calculated by using Shannon-Wiener index [29] and it is defined as

$$H = -\Sigma pi \log(b)\, pi \qquad (2)$$

where pi is the proportional abundance of a species i and b is the base of the logarithm. The diversity function in the vegan package uses natural logarithms as the default while calculating Shannon-Wiener index, and 1– Simpson's alpha (which also describes overall alpha diversity) is calculated as 1 $-\Sigma pi^2$ [30]. All analyses for determining diversity (Shannon-Wiener, Simpson, and species accumulation curves) were performed using the diversity function in the vegan package [31].

To observe the functional association between forest community structure and distance from boundary lines of villages, a linear model was fit wherever applicable with the null hypothesis that there is no linear pattern between the structural attributes of forests and the distance from human settlements. Linear model assumptions were tested using the gvlma function in the gvlma package [32]. Residuals versus fitted and Q-Q plots were visualized.

Morisita's I_δ index of dispersion was used for determining the spatial pattern of individuals of the predominant woody species. I_δ, which is independent of sample size and diversity [33], was computed as follows [34]:

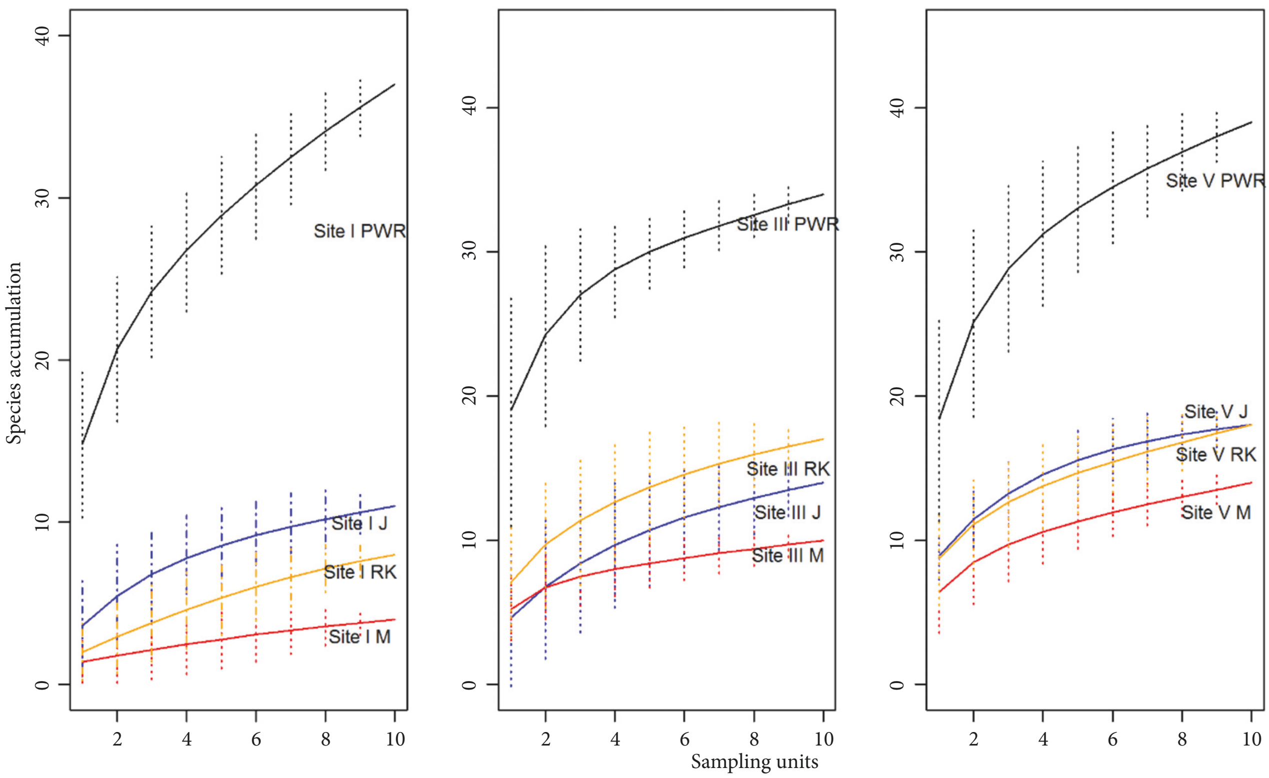

Figure 13: Species accumulation curves for different sites of studied forests plotted using Kindt's exact method. The curves are for Sites I, Sites III, and Sites V for Janajagaran (J), Musharni Mai (M), Radha Krishna (RK), and Parsa Wildlife Reserve (PWR) forests. The species accumulation curves reflected increase in number of species in the beginning with addition of sampling units. The vertical lines represent the standard deviations.

$$I_{\delta=}q\frac{\sum x_i (x_i - 1)}{N (N - 1)} \quad (3)$$

where q is the total number of subplots, N is the total number of individuals of the species in q subplots, and x is the number of individuals of a species in a subplot. Species were considered predominant if IVI > 10 observed in any one of the sites of the forests. We used dispindmorisita function in the vegan package to calculate intraspecific aggregation [31].

To examine the dissimilarity and similarity in species composition between the sites in the forests, Bray-Curtis Index (BCI) was used. BCI is a rank-order index and values were used to determine a standardized species score to combine the measurements of IVI in the woody plant species. The values of BCI range from 0 to 1. The value 1 reflects no similarity whereas 0 reflects complete similarity between plots. BCI of dissimilarity was calculated between the sites (from the edge to the interior of the forests) based on the IVI values determined for each species. Vegdist and hclust functions in the vegan package were used for determining dissimilarity and clustering (Ward.D2 group linkage), respectively [31]. Dissimilarity (DIS_{jk}) between sites j and k using BCI can be expressed as follows [35]:

$$DIS_{jk} = \frac{\sum_i^p abs\left(y_{ij} - y_{ik}\right)}{\sum_i^p \left(y_{ij} + y_{ik}\right)} \quad (4)$$

where y_{ij} and y_{ik} represent measures of species i in the sample sites j and k and abs indicates absolute value. To compare the dissimilarity in the forest community between sites, a matrix representation of the DIS_{jk} and the similarity ($S_{jk} = 1 - DIS_{jk}$) between the paired sites were tabulated and compared. A multivariate agglomerative clustering using Ward.D2 group linkage based on the Bray-Curtis distance of IVI values was performed.

We also determined the associated plant community composition and similarity between sites based on IVI of the species using Nonmetric Multidimensional Scaling (NMDS) ordination to collapse information from multiple species into just a few, so that they can be visualized and interpreted. In community ecology, NMDS is commonly regarded as the most robust unconstrained ordination method [36] and considered as an indirect gradient analysis approach for producing an ordination based on a distance or dissimilarity matrix. We chose Bray-Curtis distance measure and a maximum of 200 iterations for NMDS distance matrix. The analysis was formed with the metaMDS function in the vegan package [31]. To minimize the stress (usually the stress values more than 0.2 should be interpreted with caution and more than 0.3 are highly suspicious), NMDS was projected in K=3 dimensions (resulting in stress value for all our analysis less than 0.05; Shepard stress plots were visualized). All statistical analyses were performed in R [37].

Table 7: IVI of species in Janajagaran BZCF.

Species code	Name of the species	Site I	Site II	Site III	Site IV	Site V	Site VI
1	*Shorea robusta* Gaertn.	190.93	216.11	188.25	146.09	112.11	75.00
2	*Adina cordifolia* (Willd. ex Roxb.) Benth. & Hook. f. ex Brandis	32.81	4.62	8.21		9.47	
3	*Lannea coromandelica* (Houtt.) Merr.	14.96		3.84	21.80	4.44	9.96
4	*Lagerstroemia parviflora* Roxb.	10.61	35.60	32.71	41.19	36.87	36.11
5	*Schleichera oleosa* (Lour.) Oken	3.77		2.33	2.58	1.70	7.76
6	*Terminalia bellirica* (Gaertn.) Roxb.	5.18					3.07
7	*Careya arborea* Roxb.	4.36		3.20		7.56	7.18
8	*Casearia graveolens* Dalzell	13.19	7.39	10.40	13.16	25.42	28.89
9	*Cassia fistula* L.	7.62	3.78	12.87	2.44	2.76	1.69
10	*Mallotus philippensis* (Lam.) Müll.-Arg.	13.50	3.64	10.39	38.33	23.52	30.79
11	*Aegle marmelos* (L.) Correa	3.07		2.33			
12	*Dillenia pentagyna* Roxb.		5.24	6.31	22.48	24.16	28.92
13	*Syzygium cumini* (L.) Skeels		20.00	10.11		5.90	5.50
14	*Dysoxylum gobara* (Buch.-Ham.) Merr.		3.61				
15	*Semecarpus anacardium* L.f.			4.79		11.79	6.22
16	*Hymenodictyon excelsum* Wall.			4.26			
17	*Albizia* sps.				3.64		
18	*Miliusa velutina* (Dunal) Hook. f. & Thoms.				2.44	6.95	27.50
19	*Ehretia laevis* Roxb.				3.42	2.00	
20	*Cleistocalyx operculatus* (Roxb.) Meer. & Perry				2.45		
21	*Terminalia alata* Heyne ex Roth					17.03	15.13
22	*Terminalia chebula* Retz.					2.60	1.74
23	*Buchanania latifolia* Roxb.					1.30	
24	*Sterculia villosa* Roxb.					4.41	1.70
25	*Ficus religiosa* L.						2.41
26	*Anogeissus latifolius* (Roxb. ex DC.) Bedd.						6.03
27	*Dalbergia latifolia* Roxb.						2.15
28	*Wendlandia tinctoria* (Roxb.) DC.						2.26

3. Results

3.1. Community Structure and Distribution of Woody Plants. The studied BZCFs and PWR are *S. robusta* dominated mixed forests. The forests exhibit high total densities of woody plants (saplings, poles, and trees) but also high variance within forest sites (Figure 2). Total density (± SD) of woody species in Janajagaran BZCF ranged from 231±79 stems ha^{-1} to 658±97 stems ha^{-1} varying across different distances towards the forest interior from the boundary lines of the villages. Similarly, Musharni Mai BZCF and Radha Krishna BZCF also showed the wide range of variation in stem density (± SD) from 286±45 to 753±159 stems ha^{-1} and 323±112 stems ha^{-1} to 643±71.81 stems ha^{-1}, respectively. In PWR, the range of variation of densities (± SD) was from 607±113 to 1021±311 stems ha^{-1} (Appendix C, Tables 3–6). The median

Table 8: IVI of species in Musharni Mai BZCF.

Species code	Name of the species	Site I	Site II	Site III	Site IV	Site V	Site VI
1	*Shorea robusta* Gaertn.	268.26	183.83	151.92	159.47	148.73	116.36
2	*Adina cordifolia* (Willd. ex Roxb.) Benth. & Hook. f. ex Brandis	9.08	3.72	4.49		2.78	6.33
9	*Cassia fistula* L.	7.29	9.59	2.16	1.93	6.93	
8	*Casearia graveolens* Dalzell	15.36	22.60	29.91	30.03	34.10	20.51
12	*Dillenia pentagyna* Roxb.		22.19	25.87	15.06	15.47	17.52
13	*Syzygium cumini* (L.) Skeels		2.90	30.90	8.34		
20	*Cleistocalyx operculatus* (Roxb.) Meer. & Perry		9.80	3.10	2.04		
21	*Terminalia alata* Heyne ex Roth		7.16		9.47		2.75
4	*Lagerstroemia parviflora* Roxb.		21.11	24.64	34.56	25.39	54.35
17	*Albizia* sps.		4.98				
3	*Lannea coromandelica* (Houtt.) Merr.		7.34	12.16	11.88	18.46	
10	*Mallotus philippensis* (Lam.) Müll.-Arg.		4.79	14.85	19.66	23.20	48.78
16	*Hymenodictyon excelsum* Wall.				3.32	2.22	
14	*Dysoxylum gobara* (Buch.-Ham.) Merr.				4.24		2.70
7	*Careya arborea* Roxb.					2.27	
15	*Semecarpus anacardium* L.f.					2.06	2.10
5	*Schleichera oleosa* (Lour.) Oken					6.64	
29	*Ficus benghalensis* Linn.					2.88	
18	*Miliusa velutina* (Dunal) Hook. f. & Thoms.					8.88	2.46
26	*Anogeissus latifolius* (Roxb. ex DC.) Bedd.						18.75
56	*Pyrus pashia* Buch.- Ham. ex D.Don						4.47
31	UnidentifiedI						2.94

stem density was more than 400 individuals ha^{-1} (arbitrary value) in each site of PWR, but oscillations were observed across the sites in BZCFs. The variance of frequency indicates the abundance difference of woody species, within a site; high values indicate that the abundance of species in the plot differs from each other, whereas low values indicate that all the species have a similar pattern of abundance (Appendix C, Tables 3–6).

Significant pattern ($p > 0.05$) was not observed between the total density of species and the distance from the boundary lines of the villages in all the BZCFs (Figure 3). When stem densities were separated into the density of the dominant species *S. robusta* and the density of other woody species, a significant increasing linear trend was obtained between the density of other species (except *S. robusta*) and the distance from the boundary lines of the settlement areas (Figure 3) (Janajagaran BZCF: $p < 0.05$, Musharni Mai BZCF: $p < 0.05$, and Radha Krishna BZCF: < 0.01, but no significant difference was observed for PWR: $p > 0.05$). Similarly, the assemblage of *S. robusta,* when categorized as saplings, poles, and trees, reflected that the poles and trees had a high density near the human settlement areas in BZCFs (Figure 4). The BZCFs near the human settlements were receiving intense management and protection of the poles and tree-sized individuals of *S. robusta*. Densification has occurred in the area with very fewer plant species. The density of trees of *S. robusta* in the edges was very high above the estimated maximum density (85 stems ha^{-1}) of fully grown mature trees of *S. robusta* which 1 ha forest area can support. For PWR such difference in the density of *S. robusta* along the edge to the interior was not observed (Figure 4).

Table 9: IVI of species in Radha Krishna BZCF.

Species code	Name of the species	Site I	Site II	Site III	Site IV	Site V	Site VI
1	*Shorea robusta* Gaertn.	228.32	176.61	137.14	130.12	104.46	57.57
2	*Adina cordifolia* (Willd. ex Roxb.) Benth. & Hook. f. ex Brandis	7.39	10.17	14.76	8.87	4.61	10.04
3	*Lannea coromandelica* (Houtt.) Merr.	13.31	3.03	13.96	13.69	8.03	5.93
21	*Terminalia alata* Heyne ex Roth	19.56	7.36	16.06	9.72	10.51	19.41
12	*Dillenia pentagyna* Roxb.	6.81	15.13	22.69	21.04	17.26	23.97
6	*Terminalia bellirica* (Gaertn.) Roxb.	8.66	8.79	5.17	10.26	18.22	19.90
4	*Lagerstroemia parviflora* Roxb.	10.63	35.82	27.53	27.49	27.99	17.11
8	*Casearia graveolens* Dalzell	5.32	16.33	12.68	15.43	19.35	14.37
32	Baisake (Local name: Central Terai, Nepal)		2.38			1.31	
7	*Careya arborea* Roxb.		2.94	4.16	1.75	8.83	5.61
5	*Schleichera oleosa* (Lour.) Oken		2.55	4.13	5.92	6.10	3.18
10	*Mallotus philippensis* (Lam.) Müll.-Arg.		14.45	26.63	29.17	49.90	84.95
33	*Sapium insigne* (Royle) Benth. ex Hook. f.		2.22				
9	*Cassia fistula* L.		2.22	1.61		1.31	
18	*Miliusa velutina* (Dunal) Hook. f. & Thoms.			2.01	8.46	15.56	1.98
15	*Semecarpus anacardium* L. f.			5.27	11.14		1.47
26	*Anogeissus latifolius* (Roxb. ex DC.) Bedd.			2.30			
13	*Syzygium cumini* (L.) Skeels			2.29			1.64
34	*Lagerstroemia reginae* Roxb.			1.61			1.75
19	*Ehretia laevis* Roxb.				1.91		1.84
25	*Ficus religiosa* L.				3.51		1.89
35	*Madhuca longifolia* (Koeing) Macbride				1.52		
36	*Duabanga grandiflora* (Roxb. ex DC.) Walp.					2.62	
37	*Grewia eriocarpa* Juss.					1.31	
38	*Litsea monopetala* (Roxb.) Pers.					1.31	5.63
39	Unidentified II					1.31	
40	*Bombax ceiba* L.						6.34
17	*Albizia* sps.						3.57
14	*Dysoxylum gobara* (Buch.-Ham.) Merr.						1.64
41	*Toona ciliata* M. Roem.						3.67
42	*Trewia nudiflora* Linn.						1.56
43	*Premna barbata* Wall.						2.05
27	*Dalbergia latifolia* Roxb.						1.47
44	*Croton* sp.						1.46

Table 10: IVI of species in Parsa Wildlife Reserve.

Species code	Name of the species	Site I	Site II	Site III	Site IV	Site V	Site VI
8	*Casearia graveolens* Dalzell	16.20	18.69	12.30	15.48	4.96	4.95
4	*Lagerstroemia parviflora* Roxb.	28.03	35.81	23.25	18.65	21.96	15.84
45	*Bridelia retusa* (L.) Spreng.	0.85	3.15	6.74	4.04	1.81	3.51
18	*Miliusa velutina* (Dunal) Hook. f. & Thoms.	12.59	21.44	14.03	13.12	24.42	17.11
46	*Phyllanthus emblica* Linn.	6.00	1.19	4.30	13.76	5.99	6.46
15	*Semecarpus anacardium* L.f.	0.91				0.74	0.69
22	*Terminalia chebula* Retz.	8.02	6.92	6.03	0.99	0.82	
7	*Careya arborea* Roxb.	3.63	2.15	3.26	1.58	5.89	0.66
1	*Shorea robusta* Gaertn.	101.09	72.09	90.43	74.39	72.41	95.39
27	*Dalbergia latifolia* Roxb.	7.96	9.03	10.84	6.87	5.94	6.92
12	*Dillenia pentagyna* Roxb.	13.24	19.78	15.85	12.75	6.58	4.57
21	*Terminalia alata* Heyne ex Roth	13.69	15.55	11.17	10.55	12.71	13.78
2	*Adina cordifolia* (Willd. ex Roxb.) Benth. & Hook. f. ex Brandis	10.12	1.66	5.00	8.17	9.97	13.95
13	*Syzygium cumini* (L.) Skeels	5.67	12.24	7.78	0.99	0.81	2.51
47	*Desmodium oojenense* (Roxb.) Ohashi	15.74	12.51	5.83	24.32	13.45	13.93
26	*Anogeissus latifolius* (Roxb. ex DC.) Bedd.	8.07	7.92	4.87	13.34	4.44	10.80
48	*Garuga pinnata* Roxb.	6.97	8.47	15.50	7.70	11.72	13.53
3	*Lannea coromandelica* (Houtt.) Merr.	0.83	2.63	3.19	3.51	0.86	11.21
23	*Buchanania latifolia* Roxb.	10.68	9.14	12.54	11.12		0.67
19	*Ehretia laevis* Roxb.	0.83			5.32	3.01	3.82
54	*Lyonia ovalifolia* (Wall.) Drude	5.65	3.72	8.81	3.16	4.34	5.01
49	*Stereospermum personatum* (Hassk.) Chatterjee	2.83	3.92	3.30	7.07	2.84	0.67
10	*Mallotus philippensis* (Lam.) Müll.-Arg.	0.84				7.90	1.31
33	*Sapium insigne* (Royle) Benth. ex Hook. f.	1.69	3.44	4.60	3.40	6.36	2.05
50	*Bauhinia malabarica* Roxb.	0.83			0.69		3.21
51	*Bauhinia purpurea* L.	3.71	5.88	4.28	1.38	3.24	5.75
20	*Cleistocalyx operculatus* (Roxb.) Meer. & Perry	1.77	2.25				
17	*Albizia* sps.	0.96		3.04	4.67	3.77	2.52
52	Putalikath (Local name: Central Terai, Nepal)	1.82	5.84	0.66	0.76		1.36
14	*Dysoxylum gobara* (Buch.-Ham.) Merr.	1.95	1.62			22.96	4.36
5	*Schleichera oleosa* (Lour.) Oken	0.86			2.84	5.28	3.10
6	*Terminalia bellirica* (Gaertn.) Roxb.	0.98	2.20	2.99	3.66	6.12	1.32
55	*Tamarindus indica* L.		0.69				

Table 10: Continued.

Species code	Name of the species	Site I	Site II	Site III	Site IV	Site V	Site VI
56	*Pyrus pashia* Buch.- Ham. ex D.Don		0.71				
37	*Grewia eriocarpa* Juss.	1.70	4.94	5.94	6.93	6.99	6.44
16	*Hymenodictyon excelsum* Wall.	0.83	0.71	1.27	4.18	0.77	5.90
57	*Bauhinia variegata* L.		1.45	0.63			
58	*Ficus racemosa* L.		0.69			0.73	
9	*Cassia fistula* L.	0.82	0.68	0.75			
53	*Bauhinia vahlii* Wight & Arn	0.83	0.89		4.36		0.67
59	*Spatholobus parviflorus* (Roxb.) Kuntze			0.95			
60	*Nyctanthes arbor-tristis* Linn.			7.78			
61	*Viscum album* Linn.			0.66	1.71	3.15	6.26
62	*Gmelina arborea* Roxb.			0.79	4.60	2.40	1.77
63	*Antidesma acidum* Retz.			0.64		1.43	2.13
64	*Xeromphis spinosa* (Thunb) Keay				0.69		1.99
28	*Wendlandia tinctoria* (Roxb.) DC.				1.74	0.73	2.25
65	*Millettia extensa* (Benth.) Baker				0.81		
66	*Melia azedarach* Linn.				0.73		
67	*Holarrhena pubescens* (Buch.-Ham.) Wall. ex G. Don					1.15	1.66
40	*Bombax ceiba* L.					9.79	
68	*Alstonia scholaris* (L.) R. Br.					0.79	
69	*Cornus oblonga* (Wall.) Sojak					0.74	
34	*Lagerstroemia reginae* Roxb.	0.82					

We found a total of 69 woody species belonging to 30 families in all the sample plots of the studied forests. Plant species belonging to the Fabaceae family were the most abundant (12) followed by those belonging to the families Euphorbiaceae (7), Combretaceae (4), and Rubiaceae (4). The number of species varied within the sites from the forest edges to the interior. The numbers of woody species increased significantly as a function of the distance from the village boundaries for Janajagaran ($p < 0.05$) and Radha Krishna ($p < 0.05$) BZCFs. In the case of Musharni Mai BZCF, the number of species observed was the least for the site near the edge but a nonsignificant pattern was observed ($p>0.05$). For the control forest, such a trend was not observed ($p > 0.05$) (Figure 5). In BZCFs, species like *Dalbergia sissoo*, *Dalbergia latifolia*, *Wendlandia tinctoria*, *Bombax ceiba*, *Toona ciliata*, *Trewia nudiflora*, and *Premma barabata* were recorded only in the innermost sites.

The cross-sectional area (basal area) per unit sampling area is an indicator of woody species dominance. Basal area correlates with maturity and age of the woody plant species. Our study showed mixed patterns between total dominance and distance from the boundary lines of villages (Figure 6). A decreased linear trend was observed in Janajagaran BZCF ($p < 0.05$), a linear trend was absent in Musharni Mai BZCF, and an increased trend was observed in Radha Krishna BZCF ($p < 0.001$). Though no linear trend was present in the Musharni Mai BZCF, a decrease in the basal area moving from the edge to the interior of the forest was observed. As expected, PWR showed the oscillating pattern of increase and decrease of the total basal area along the sites. An interesting result was observed when the total basal area was segregated as contributed by *S. robusta* and the basal area of other species except for *S. robusta*. In BZCFs edges, the majority of the basal area was contributed by *S. robusta* but its value was observed decreasing when moving across the interior of the forests. In contrast, the basal area of other species showed an increasing trend ($p < 0.05$) in BZCFs (Figures 6 and 7) except for the control forest. Based on % basal area, the forest near

Table 11: IVI of predominant species and Morisita Index of Dispersion in Janajagaran BZCF.

Species code	Name of the species	Site I	Site II	Site III	Site IV	Site V	Site VI
1	*Shorea robusta* Gaertn.	190.93 (1.2)	216.11 (1.1)	188.25 (1.1)	146.09 (1.2)	112.11 (1.2)	75.00 (1.5)
2	*Adina cordifolia* (Willd. ex Roxb.) Benth. & Hook. f. ex Brandis	32.81 (10)	4.62 (10)	8.21 (4.7)		9.47 (2.3)	
3	*Lannea coromandelica* (Houtt.) Merr.	14.96 (3.1)		3.84 (10)	21.80 (3.8)	4.44 (4.7)	9.96 (3.1)
4	*Lagerstroemia parviflora* Roxb.	10.61 (3.8)	35.60 (1.6)	32.71 (1.4)	41.19 (1.3)	36.87 (1.2)	36.11 (1.4)
8	*Casearia graveolens* Dalzell	13.19 (2.5)	7.39 (5.4)	10.40 (2.9)	13.16 (2.7)	25.42 (1.2)	28.89 (1.9)
9	*Cassia fistula* L.	7.62 (5.0)	3.78 (10)	12.87 (2.5)	2.44 (10)	2.76 (5.4)	1.69 (10)
10	*Mallotus philippensis* (Lam.) Müll.-Arg.	13.50 (3.4)	3.64 (10)	10.39 (3.7)	38.33 (1.4)	23.52 (1.6)	30.79 (1.2)
12	*Dillenia pentagyna* Roxb.		5.24 (10)	6.31 (6.7)	22.48 (1.6)	24.16 (1.2)	28.92 (1.6)
13	*Syzygium cumini* (L.) Skeels		20.00 (2.3)	10.11 (3.1)		5.90 (4.3)	5.50 (4.7)
15	*Semecarpus anacardium* L.f.			4.79 (4.7)		11.79 (1.7)	6.22 (5.4)
18	*Miliusa velutina* (Dunal) Hook. f. & Thoms.				2.44 (10)	6.95 (3.6)	27.50 (1.7)
21	*Terminalia alata* Heyne ex Roth					17.03 (1.2)	15.13 (1.5)

Table 12: IVI of predominant species and Morisita Index of Dispersion in Musharni Mai BZCF.

Species code	Name of the species	Site I	Site II	Site III	Site IV	Site V	Site VI
1	*Shorea robusta* Gaertn.	268.26 (1.03)	183.83 (1.04)	151.92 (1.2)	159.47 (1.2)	148.73 (1.04)	116.36 (1.3)
8	*Casearia graveolens* Dalzell	15.36 (7.5)	22.60 (1.3)	29.91 (1.3)	30.03 (1.3)	34.10 (1.2)	20.51 (1.9)
12	*Dillenia pentagyna* Roxb.		22.19 (1.8)	25.87 (1.8)	15.06 (2.1)	15.47 (1.8)	17.52 (1.7)
13	*Syzygium cumini* (L.) Skeels		2.90 (10)	30.90 (1.6)	8.34 (3.1)		
20	*Cleistocalyx operculatus* (Roxb.) Meer. & Perry		9.80 (3.1)	3.10 (10.0)	2.04 (10.0)		
21	*Terminalia alata* Heyne ex Roth		7.16 (4.7)		9.47 (3.1)		2.75 (10.0)
4	*Lagerstroemia parviflora* Roxb.		21.11 (2.2)	24.64 (2.4)	34.56 (1.3)	25.39 (1.7)	54.35 (1.3)
3	*Lannea coromandelica* (Houtt.) Merr.		7.34 (4.7)	12.16 (5.4)	11.88 (3.1)	18.46 (1.3)	
10	*Mallotus philippensis* (Lam.) Müll.-Arg.		4.79 (5.4)	14.85 (2.2)	19.66 (1.8)	23.20 (2.3)	48.78 (1.1)
26	*Anogeissus latifolius* (Roxb. ex DC.) Bedd.						18.75 (1.7)

Table 13: IVI of predominant species and Morisita Index of Dispersion in Radha Krishna BZCF.

Species code	Name of the species	Site I	Site II	Site III	Site IV	Site V	Site VI
1	*Shorea robusta* Gaertn.	228.32 (1.1)	176.61 (1.02)	137.14 (1.1)	130.12 (1.1)	104.46 (1.1)	57.57 (1.1)
2	*Adina cordifolia* (Willd. ex Roxb.) Benth. & Hook. f. ex Brandis	7.39 (10.0)	10.17 (3.1)	14.76 (2.7)	8.87 (3.1)	4.61 (10.0)	10.04 (4.3)
3	*Lannea coromandelica* (Houtt.) Merr.	13.31 (4.7)	3.03 (10.0)	13.96 (2.1)	13.69 (2.0)	8.03 (2.3)	5.93 (3.6)
21	*Terminalia alata* Heyne ex Roth	19.56 (4.7)	7.36 (4.7)	16.06 (3.0)	9.72 (3.6)	10.51 (2.7)	19.41 (1.7)
12	*Dillenia pentagyna* Roxb.	6.81 (10.0)	15.13 (2.7)	22.69 (1.5)	21.04 (1.6)	17.26 (1.2)	23.97 (1.4)
6	*Terminalia bellirica* (Gaertn.) Roxb.	8.66 (10.0)	8.79 (3.1)	5.17 (4.7)	10.26 (2.3)	18.22 (1.9)	19.90 (2.8)
4	*Lagerstroemia parviflora* Roxb.	10.63 (4.7)	35.82 (1.8)	27.53 (1.4)	27.49 (1.3)	27.99 (1.2)	17.11 (1.5)
8	*Casearia graveolens* Dalzell	5.32 (10.0)	16.33 (2.2)	12.68 (1.8)	15.43 (1.8)	19.35 (1.4)	14.37 (1.7)
10	*Mallotus philippensis* (Lam.) Müll.-Arg.		14.45 (1.8)	26.63 (1.5)	29.17 (1.2)	49.90 (1.2)	84.95 (1.2)
18	*Miliusa velutina* (Dunal) Hook. f. & Thoms.			2.01 (10.0)	8.46 (2.1)	15.56 (2.8)	1.98 (10.0)
15	*Semecarpus anacardium* L.f.			5.27 (3.6)	11.14 (1.8)		1.47 (10.0)

the settlement areas was observed to have undergone biotic homogenization (*S. robusta* Terai Mixed Hardwood Forest to *S. robusta* Forest) due to disturbance and management interactions.

We calculated the Importance Value Index (IVI) for each species in every 1 ha plot. Though the forest was dominated by *S. robusta*, other species were identified as predominant species based on high IVI values (IVI > 10). Janajagaran BZCF, Musharni Mai BZCF, Radha Krishna BZCF, and Parsa Wildlife Reserve were observed to have 12, 9, 12, and 17 predominant species, respectively (Appendix D, Tables 7–10). In all the BZCFs, our results indicated that IVI of *S. robusta* was linearly decreasing (significant; $p < 0.05$ in all BZCFs) with moving farther from the villages, and consequently other species showed increasing IVI values with the distance. But the control forest did not show such an increasing or decreasing trend (Figure 8). The high IVI of *S. robusta* near the human settlement areas were due to the protection of *S. robusta* and thus increasing all the three parameters affecting IVI. Based on the variation of Morisita's dispersion index (I_δ), all these predominant species exhibited clumped distribution (Appendix E, Tables 11–14). No effect on the distribution pattern of species according to the distance from the settlements was observed (all species exhibited $I_\delta > 1$). The clumped distribution of the species reflects that the distance between neighboring individuals is minimized for each species.

3.2. Species Diversity along the Distance from the Human Settlements. To examine the variations in the species diversity of woody plants, Shannon-Wiener index (H') and Simpson's index (λ) were calculated for each plot and plotted against the distance from the village boundaries. The Shannon-Wiener index for the species diversity increased significantly ($p < 0.05$) for all the BZCFs (Figures 9(a), 9(b), and 9(c), respectively, for Janajagaran BZCF, Musharni Mai BZCF, and Radha Krishna BZCF) towards the forest edge to the interior. For PWR, this pattern was not observed (Figure 9(d)). At the nearer distance to the human settlements in BZCFs, all the sites showed very low diversity indicating a high dominance of *S. robusta* (the species receiving high management and restoration priority). For PWR, the index values were comparatively higher. Simpson's index of diversity, which ranges from 0 (highest diversity) to 1 (no diversity), also showed the similar pattern of increase when moving farther from the village boundary lines (Figure 10, 1 – Simpson's λ; $p < 0.01$ for BZCFs but insignificant for the control forest). This trend also indicates the conversion of natural mixed forests to the woodlands near the edges.

3.3. Community Similarity and Dissimilarity between the Sites. To demonstrate how the forest disturbances change the composition of the plant community as the distance gets closer to the human settlement areas, we determined similarity and dissimilarity between the sites. For Janajagaran BZCF, the maximum value of dissimilarity was 0.55 (similarity: 1 - 0.55 = 0.45) and the dissimilarity was between Site I versus Site VI and Site II versus Site VI. For Musharni Mai BZCF, the maximum value of dissimilarity was observed between Site I and Site VI (0.54) followed by Site I and Site V (0.42).

Table 14: IVI of predominant species and Morisita Index of Dispersion in Parsa Wildlife Reserve.

Species code	Name of the species	Site I	Site II	Site III	Site IV	Site V	Site VI
8	*Casearia graveolens* Dalzell	16.20 (1.2)	18.69 (1.6)	12.30 (1.3)	15.48 (1.1)	4.96 (1.8)	4.95 (1.9)
4	*Lagerstroemia parviflora* Roxb.	28.03 (1.1)	35.81 (1.2)	23.25 (1.1)	18.65 (1.3)	21.96 (1.1)	15.84 (1.2)
18	*Miliusa velutina* (Dunal) Hook. f. & Thoms.	12.59 (1.6)	21.44 (1.2)	14.03 (1.3)	13.12 (1.2)	24.42 (1.3)	17.11 (1.3)
46	*Phyllanthus emblica* Linn.	6.00 (3.0)	1.12 (10.0)	4.30 (2.8)	13.76 (1.3)	5.99 (1.6)	6.46 (2.1)
22	*Terminalia chebula* Retz.	8.02 (2.6)	6.92 (1.4)	6.03 (1.3)	0.99 (10.0)	0.82 (10)	
1	*Shorea robusta* Gaertn.	101.09 (1.4)	72.09 (1.4)	90.43 (1.3)	74.39 (1.1)	72.41 (1.3)	95.39 (1.1)
27	*Dalbergia latifolia* Roxb.	7.96 (1.8)	9.03 (1.2)	10.84 (1.2)	6.87 (1.8)	5.94 (2.5)	6.92 (1.4)
12	*Dillenia pentagyna* Roxb.	13.24 (1.8)	19.78 (1.3)	15.85 (1.8)	12.75 (1.5)	6.58 (2.1)	4.57 (2.3)
21	*Terminalia alata* Heyne ex Roth	13.69 (1.5)	15.55 (1.9)	11.17 (1.2)	10.55 (1.7)	12.71 (1.2)	13.78 (1.5)
2	*Adina cordifolia* (Willd. ex Roxb.) Benth. & Hook. f. ex Brandis	10.12 (1.8)	1.66 (4.7)	5.00 (1.7)	8.17 (2.1)	9.97 (1.9)	13.95 (2.1)
13	*Syzygium cumini* (L.) Skeels	5.67 (2.1)	12.24 (1.4)	7.78 (1.3)	0.99 (10.0)	0.81 (10.0)	2.51 (3.6)
47	*Desmodium oojenense* (Roxb.) Ohashi	15.74 (1.5)	12.51 (1.4)	5.83 (1.5)	24.32 (1.2)	13.45 (1.4)	13.93 (1.6)
26	*Anogeissus latifolius* (Roxb. ex DC.) Bedd.	8.07 (2.3)	7.92 (1.5)	4.87 (2.1)	13.34 (1.5)	4.44 (2.1)	10.80 (1.3)
48	*Garuga pinnata* Roxb.	6.97 (2.1)	8.47 (2.3)	15.50 (2.2)	7.70 (3.7)	11.72 (1.8)	13.53 (1.4)
3	*Lannea coromandelica* (Houtt.) Merr.	0.83 (10.0)	2.63 (5.5)	3.19 (4.0)	3.51 (3.4)	0.86 (10.0)	11.21 (1.4)
23	*Buchanania latifolia* Roxb.	10.68 (2.0)	9.14 (1.6)	12.54 (1.3)	11.12 (1.5)		0.67 (10)
14	*Dysoxylum gobara* (Buch.-Ham.) Merr.	1.95 (5.4)	1.62 (4.9)			22.96 (1.2)	4.36 (3.9)

Table 15: Index of similarity and dissimilarity among different sites for Janajagaran BZCF.

	Site I	**Site II**	**Site III**	**Site IV**	**Site V**	**Site VI**
Site I		**0.74**	**0.82**	**0.68**	**0.57**	**0.45**
Site II	0.26		**0.85**	**0.67**	**0.59**	**0.45**
Site III	0.18	0.15		**0.71**	**0.67**	**0.52**
Site IV	0.32	0.33	0.29		**0.74**	**0.65**
Site V	0.43	0.41	0.33	0.26		**0.79**
Site VI	0.55	0.55	0.48	0.35	0.21	

We observed similar trends for Radha Krishna BZCF with the highest dissimilarity between Site I and Site VI (0.59) followed by Site II and Site VI (0.49). Values showed the higher dissimilarity between the nearer plots and the farther plots in BZCFs. For PWR, the maximum dissimilarity was observed between Site II and Site VI, but the dissimilarity values across sites did not exceed 0.34. The results indicated that dissimilarity values and their clustering heights were higher between the sites of BZCFs than the control forest sites in PWR (Figure 11, Appendix F, Tables 15–18).

NMDS was conducted to ordinate the sites based on the Bray-Curtis distance of IVI values of the species. The NMDS results showed that the sites of BZCFs were ordinated in the farther distances as compared to PWR forest (Figure 12). In

Table 16: Index of similarity and dissimilarity among different sites for Musharni Mai BZCF.

	Site I	Site II	Site III	Site IV	Site V	Site VI
Site I		**0.70**	**0.58**	**0.59**	**0.58**	**0.46**
Site II	0.30		**0.80**	**0.81**	**0.77**	**0.62**
Site III	0.42	0.20		**0.87**	**0.84**	**0.66**
Site IV	0.41	0.19	0.13		**0.85**	**0.70**
Site V	0.42	0.23	0.16	0.15		**0.67**
Site VI	0.54	0.38	0.34	0.30	0.31	

Table 17: Index of similarity and dissimilarity among different sites for Radha Krishna BZCF.

	Site I	Site II	Site III	Site IV	Site V	Site VI
Site I		**0.75**	**0.67**	**0.64**	**0.53**	**0.41**
Site II	0.25		**0.80**	**0.78**	**0.70**	**0.51**
Site III	0.33	0.20		**0.90**	**0.76**	**0.63**
Site IV	0.36	0.22	0.10		**0.81**	**0.62**
Site V	0.47	0.30	0.24	0.19		**0.69**
Site VI	0.59	0.49	0.37	0.38	0.31	

BZCFs, Site I and Site II ordinated in the farthest distances from Site VI reflecting a high variation in the species composition due to varying gradients of anthropogenic pressures. However, in case of PWR, the sites were clumped (ordinated in the shorter distances) in the central region of the ordinated axes. The ordination distances, however, do not correspond to the original distances among the sites.

4. Discussion

In this paper, we assessed how the changes in the ecological parameters in the *S. robusta* mixed forest are a function of the distance from the human settlements, and the interaction between anthropogenic disturbances and the forest management. The changes in the structure and composition were determined by comparing their values from the edge to the interior sites of the BZCFs and also with the control forest conditions in PWR.

We did not observe a significant pattern between total stem density and the distance from the settlements, but when density was segregated into species, the sum density of species other than *S. robusta* witnessed a significant positive pattern (Figure 3). Human activities such as collection of fuelwood (leading to an absence of coarse woody debris in BZCFs that was present in the forest stands of PWR), fodder, litter, and other forest products, as well as grazing animals, had reduced the density of woody species in the forests. But the decrease had been compensated (regardless of species-wise contribution) by the forest management interventions in the BZCFs. Therefore, in overall, we observed neither an increase nor a decrease in the total stem density while moving towards the forest interior from the edges. Changes in the spatial and temporal heterogeneity as a result of anthropogenic activities have also been assessed in several other studies [8–11, 38].

Considering the total basal area, we observed mixed results in the three forests while moving from the edge to the interior. Basal area was observed with a significant decreasing trend for Janajagaran BZCF, an insignificant decreasing trend for Musharni Mai BZCF, and an increasing trend for Radha Krishna BZCF (Figure 6) along the edge to the interior of the forests. Previous research also demonstrated similar results of no effect on the basal area with a distance from the human settlements [17]. In contrast, another study has shown that biomass (a parameter indicating basal area) is reduced in the forest edge relative to the interior [39]. Consistent with this result, the basal area of the species other than *S. robusta* increased with the distance from the forest edges (Figure 6). Based on % basal area contributed, the forest edges were observed to have undergone biotic homogenization (*S. robusta* mixed stand to *S. robusta* stand) due to the disturbance and management interactions (Figure 6). The Ministry of Forests and Soil Conservation (MFSC) of Nepal has categorized the Sal (*S. robusta*) forest as a forest where *S. robusta* comprises more than 60% of the basal area and Sal Terai Mixed Hardwood Forest (STMH) as a forest where *S. robusta* comprises 33-60% of the total basal area [40]. In case of BZCFs, the edges had more than 60% *S. robusta* basal area, a percentage not observed in the interior stands of BZCFs and the control forest; in the latter forests the percent contribution of *S. robusta* was between 33 and 60% (Figure 7).

In our study, both Shannon-Wiener and 1 – Simpson's λ diversity values showed a positive trend with the distance from the boundary lines of villages in BZCFs (Figures 9 and 10). But in PWR such a trend was not observed. Some primary studies have determined a clear pattern of change in diversity, richness, density, and basal area of the tree species towards the forest interior from the edges [12, 20, 41], whereas other studies have obtained contrasting results with more species richness and abundancy of heliophilic species in the forest edge than the interior [42–44].

The increasing value of species diversity with the distance from the settlements in our study strongly supports that human interventions (interaction of both management and

Table 18: Index of similarity and dissimilarity among different sites for Parsa Wildlife Reserve.

	Site I	Site II	Site III	Site IV	Site V	Site VI
Site I		**0.81**	**0.82**	**0.77**	**0.69**	**0.76**
Site II	0.19		**0.78**	**0.73**	**0.68**	**0.66**
Site III	0.18	0.22		**0.75**	**0.69**	**0.73**
Site IV	0.23	0.27	0.25		**0.71**	**0.74**
Site V	0.31	0.32	0.31	0.29		**0.75**
Site VI	0.24	0.34	0.27	0.26	0.25	

disturbances) have fostered a decrease in the richness and evenness of plant community and have changed the *S. robusta* mixed stands to pure *S. robusta* stands near the forest edges due to overexploitation of other plant species. Consistent with observations of intense monoculture-driven forest management nearby human settlements, other researchers have also posited that intensification of silviculture threatens species diversity [45, 46] and leads to the development of a community dominated by a single species or even-aged stands [47]. Anthropogenic pressures which lead to changes in the biological diversity are also responsible for changing the composition and stand quality of the forest ecosystems, microclimate, and nutrient cycling [48]. Increase in the generalist woody species can be the site of food sources, nest sites, and roosting sites for a variety of other species [49]. Higher plant diversity enhances the stability of the physical, chemical, and biotic properties of soils [50]. The intermediate disturbance hypothesis explains that diversity is maximum at the intermediate level of disturbance [51]. In contrast, species diversity declined with increasing level of disturbance in our study (Figures 9 and 10). There are also views reflecting that stability increases with the complexity of the ecosystems [52, 53]. In addition, the similarity analysis between sites in BZCFs reflected that there is a very little similarity between the sites in the edges compared to the interior (Figure 11). The result was also supported by NMDS outcomes (Figure 12). In the case of the control forest sites, such variation in the similarity was not observed.

Our study, based on the structural attributes, showed loosely defined community assemblages in the edges of BZCFs primarily due to the anthropogenic activities. In the long run, the existing inherent disturbances and ongoing management in the Terai *S. robusta* mixed forests can potentially lead to a decrease in the stability of the ecosystems. Natural forest areas that have been disturbed or altered to a large spatial extent or degree may not reach the similar structural complex (richness and composition) as primary forest [54]. In this context, fostering heterogeneity of the woody plant species is essential for sustainability.

5. Conclusions

Our results clearly indicated the effects of distance from human settlements on the vegetative attributes in the BZCFs. Maximum disturbance on the structural characteristics was observed near the edges which gradually decreased along the interior of the forests. The stands near the edges were under active management; however, a decrease in the richness and species diversity of the woody species was observed when moving from the edge to the interior. The management interventions in the forest sites near the settlements have directed the stands of BZCFs towards biotic homogenization and densification. These conditions cannot support habitat requirements of multiple species, and if the homogenization continues towards the interior of the BZCFs, it ultimately will impact the species diversity of the landscape. These situations of ecological changes due to intervention between anthropogenic disturbances and management practices should be assessed in larger spatial and regional scales to frame the future forest management strategies.

Appendix

A. Predominant Species and Their Local Uses, and Geographical Location of the Sampled Sites

See Tables 1 and 2.

B. Species Accumulation Curves

The species accumulation curves for the BZCFs and Parsa Wildlife Reserve (control plot). The curves depend on the accumulation rates of new species over the increase in the sampling area. Comparatively more steep beginning rise of the curves showed that new species are increasing with addition of the sampling units. The accumulation rates of the new species in all forests were horizontal after the sampling area reached 1 ha (10 subplots each of 0.1 ha). This represents that 10, 0.1 ha plots are sufficient to represent the forest community at one site. See Figure 13.

C. Community Structure of the Studied Forests

See Tables 3, 4, 5, and 6.

D. Importance Value Index (IVI) for Woody Plant Species in Each Site in the Studied Forests. The Total Value of IVI Is 300 Which Is the Sum of Relative Frequency, Relative Density, and Relative Basal Area Values

See Tables 7, 8, 9, and 10.

E. IVI of Predominant Species and Morisita Index of Dispersion

Predominant woody species and their Importance Value Index (IVI) for each site. Total of 12 species were found predominant in Janajagaran BZCF, 10 species in Musharni Mai BZCF, 11 species in Radha Krishna BZCF, and 17 species in Parsa Wildlife Reserve. Predominant species are considered high IVIs (IVI > 10). The values in parenthesis show Morisita's index (I_δ) (a value of 1 indicates a random distribution, values >1 indicate clumped distribution, and values < 1 indicate a uniform or regular distribution). Chi-squared based probability shows that all the species showed clumped distribution (at critical level of 0.05) according to the distance from the boundary lines of villages (null hypothesis describes that the species have random distribution). See Tables 11, 12, 13, and 14.

F. Similarity and Dissimilarity among Different Sites of the Studied Forests

In the tables, the upper right section and the lower left section show similarity and dissimilarity values, respectively, between sites. See Tables 15, 16, 17, and 18.

Data Availability

The primary data used to support the findings of this study are included within the Appendix.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors are especially thankful to the forest user groups and administrations of Janajagaran BZCF, Musharni Mai BZCF, and Radha Krishna BZCF. The authors would also like to express their gratitude to the Department of National Parks and Wildlife Conservation and Office of Parsa Wildlife Reserve (recently designated as Parsa National Park), Nepal, for granting permission (letter reference numbers ECO335 – 2071/2072 and ECO074 – 2073/2074) to study the forests. They are thankful to National Herbarium and Plant Laboratories, Nepal, and Central Department of Botany, Tribhuvan University for the identification of plant specimens. The technical and field support from Wyoming Reclamation and Restoration Center (WRRC), Amrit Campus, and Central Department of Environmental Science, Tribhuvan University, Nepal, is also thankfully acknowledged.

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