Journal of Institute of Science and Technology, 27(2), 109-124 (2022)
ISSN: 2467-9062 (print), e-ISSN: 2467-9240
https://doi.org/10.3126/jist.v27i2.49614

Research Article

TREES SPECIES DIVERSITY AND REGENERATING POTENTIAL ALONG DISTURBANCE GRADIENT IN CHANDRAGIRI HILL, KATHMANDU, CENTRAL NEPAL

Ram Sharan Dani[1,2], Chitra Bahadur Baniya[2]*
[1]*Trichandra Multiple Campus, Ghantaghar, Kathmandu, Nepal*
[2]*Central Department of Botany, Tribhuvan University, Kirtipur, Kathmandu, Nepal*
**Correspondence: chitra.baniya@cdb.tu.edu.np*
(Received: *November 11, 2022;* ***Final Revision:*** *December 31, 2022;* ***Accepted:*** *December 31, 2022)*

ABSTRACT
Tress species regeneration is greatly influenced by climatic, topographic, and anthropogenic activities. Present study was designed to examine the tree species diversity and their regeneration patterns along the anthropogenic disturbance gradient in the temperate forest of Chandragiri Hill, Central Nepal. Data were obtained from 90 sample plots ranging between 1560 to 2290 m asl after randomly sampling along three disturbance classes classified based on canopy coverage and degrees of disturbance activities in 2021. Circumference at breast height (1.37 m height above the ground) of each tree individual was measured and classified into tree, sapling, and seedling. A total of 47 tree species belonging to 42 genera and 26 families were obtained by this study. The highest species richness for seedlings and saplings was obtained in severely disturbed areas and tree species richness in the moderately disturbed area. The tree stands density varied between 350 to 1017 individuals ha^{-1} with the total basal area between 12.7 to 72.78 m^2 ha^{-1} with the least value in a highly disturbed area and highest in the least disturbed area. The seedling and sapling densities were found increased from lower to more disturbed forests indicating that the forest fragmentation negatively affected the regeneration. The highest values of the Shannon Weiner index, Pielou Index, and the lowest value of the Simpson index were observed at moderate disturbance areas. About 36 to 60% of species were found regenerating in the less disturbed and moderately disturbed forests and no regeneration in severely disturbed areas. Elevation, canopy cover, landslide, and slopes were found to be the most influential variables in forest regeneration as significantly represented by CCA1. The present study has found a moderate level of disturbance to become beneficial for better regeneration of tree species. So, the reduction of excessive disturbance from local people would be a better option for the adequate regeneration of tree species.

Keywords: Central Nepal, disturbance gradient, species diversity, temperate forest, regeneration

INTRODUCTION
Vegetation community structure in term of composition and diversity is greatly shaped by biotic and abiotic disturbances (Chapagain *et al.*, 2021; Sagar *et al.*, 2003; White & Jentsch, 2001). Landslides, wind, storms, hails, and fires are common abiotic disturbances whereas anthropogenic activities like lopping, cutting, grazing, tapping, removal of biomass, leaf litter collection, firing, construction of access tracks, hiking trails, habitat fragmentation, agricultural encroachment, insects or parasitic infestation, etc. are common examples of biotic disturbances. The diversity and species richness are perpetually affected by frequently changing frequency of multiple disturbance factors (Sagar *et al.*, 2003; Sapkota *et al.*, 2009; Zhu *et al.*, 2019).

Disturbance may have both negative and positive impacts on the forest ecosystem by fluctuating the environmental condition (Gautam *et al.*, 2016). Intensities of both natural and anthropogenic disturbances are the major cause of change in species diversity (Connell & Lowman, 1989; Huston, 2014; Ruprecht *et al.*, 2009) and play a crucial role on plant structure and animal communities (Bennett & Adams, 2004; Elderd & Doak, 2006). Higher the intensity or frequency of disturbances, plant diversity decrease (Gautam *et al.*, 2016; Sapkota *et al.*, 2009). The exact understating of the relationship between biotic and abiotic interaction of forest ecosystems and human influences on biodiversity are crucial for forest management and conservation activities.
Moderate disturbance shows positive correlation with species diversity of forest (Whittaker & Niering, 1965; Wangda & Ohsawa, 2006; Sapkota *et al.*, 2010; Sassen & Sheil, 2013) due to community co-existence (Molino & Sabatier, 2001; Sheil & Burslem, 2003) while high disturbance eliminate several species especially loss of late invader species and less disturbance leading to the removal of adapted species just after disturbance (Sheil & Burslem, 2003).

Anthropogenic disturbance not only determine the species composition, it also plays active role in regeneration of plant species (Khumbongmayum *et al.*, 2006). They also regulate tree diversity and forest

dynamics at the local and regional scales (Ramírez-Marcial *et al*., 2001; Kennard *et al*., 2002). The knowledge of the tree composition, their population and regeneration is vital for the development of strategies of conservation (Mishra *et al*., 2013). In forest ecosystem tree species provides habitats and resources for other flora and fauna, therefore information on species diversity and richness are fundamentals to other living organisms as well (Malik *et al*., 2014) and they modulate the structural intricacy and ecological heterogeneity (Malik & Bhatt, 2016).
Tree species regeneration is a one of the best pieces of evidence denoting the species composition in the ecosystem (Khumbongmayum *et al*., 2006). The potential of regeneration of each species indicates the capability to complete life cycle on its habitat. The study of regeneration not only illustrates the present status but also give the future trend of forest dynamics (Malik & Bhatt, 2016; Singh *et al*., 2016). Regeneration potentiality also describes the natural geographic distribution ranges (Grubb, 1977). The strength of survival and growth of juvenile stage (seedlings and saplings) govern the successful potential of regeneration (Good & Good, 1972). Several studies (Malik *et al*., 2014; Malik & Bhatt, 2016; Saikia *et al*., 2017) claimed that the regeneration of each living species is most important towards achieving long-term sustainability of forests.

Mountain forest ecosystems are vulnerable and facing several biological and physical disturbances for inhibition of regeneration process leading to poor regeneration (Kräuchi *et al*., 2000). The major groups of disturbances include biomass removal, deforestation, agricultural encroachment, access track development, over grazing, lopping for fodder and fuelwood, firing, etc. (Shrestha *et al*., 2013). Especially temperate forests, very near to the capital city, are facing several anthropogenic challenges that range from habitat destruction and fragmentation to severe damage on the biological resources. It will be greatly costly if we are unable to take immediate actions to minimize the anthropogenic disturbance activities. For that we need more comprehensive statistics on regeneration trends for development and implementation plans of sustainable forest conservation and management (Eilu & Obua, 2005). So, this research was aimed to uncover the species diversity and regeneration outline of tree species in temperate forest of Chandragiri Hill, Central Nepal.

MATERIALS AND METHODS

Study area

The research has been carried out in the Chandragiri Hill Forest (27°27.04'N to 27°49.15'N), lies towards south-west border of Kathmandu Valley, the capital city of Nepal with elevation ranges from 1365 and 2550 m asl (Fig. 1) in the year April to November 2021. The forest characterizes by a typical temperate vegetation with three distinct zonation. This mid-hill forest is dominated by *Schima wallichii* - *Alnus nepalensis* forest towards the lower elevations (below 1900 m asl), *Quercus-Berberis* forest in the upper elevation (above 1900 m asl) and *Quercus* forest in between.

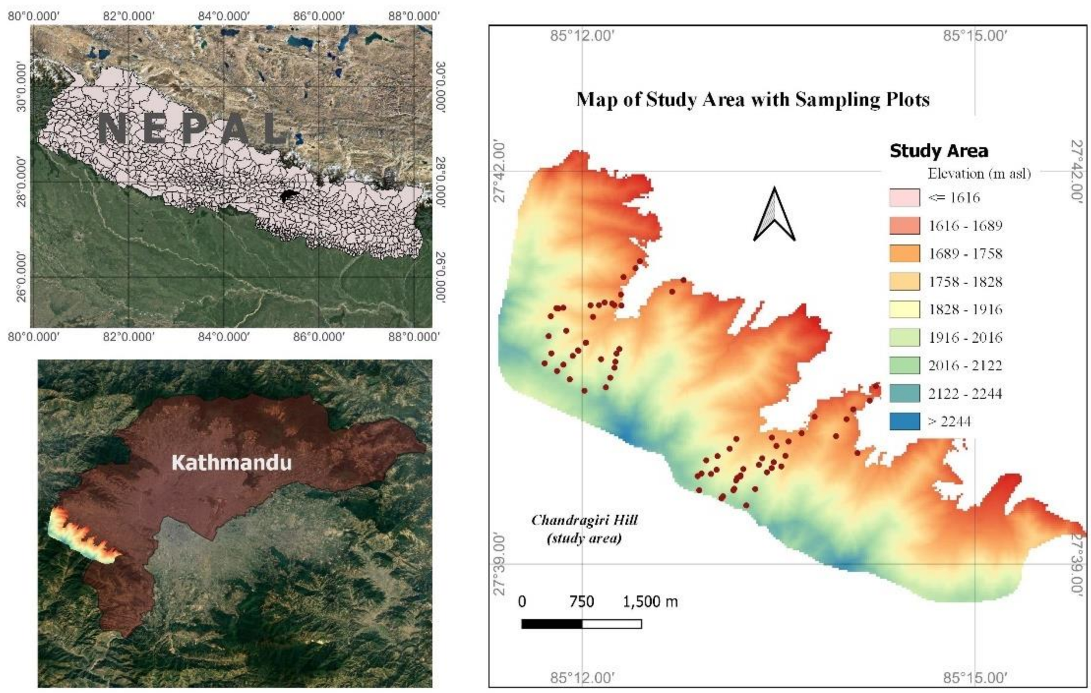

Figure 1. Map of study area showing sampling plots with elevational ranges

Chandragiri Hill has an annual mean temperature of 17.67°C with 3.2°C in winter to 18°C in summer. The annual rainfall ranges between 117 to 378 mm; 80% precipitation cascades between June to September (CBS, 2019). The Hill has both natural as well as planted forests with more than a dozen community managed forests.

Disturbance Assessment

The canopy cover and frequency of anthropogenic activities were identified for the categorization of disturbance levels within forest. The canopy cover was measured directly on each plot by using spherical densiometer (Lemmon, 1956, 1957; Werner, 2009). The percentage of crown coverage was taken four cardinal points: north, east, south and west. Plotwise crown cover percentage was calculated by multiplying the number of grid points by 1.04 (correction factor of the device). Since the spherical densiometer has 24 square grids, each grid bears 4 corners represented by dots; total forms 96 dots in each plot (It gives 100/96 coverage = 1.04).

Intensity of cattle grazing was measured by counting pilings of cow dung inside the proposed study area. Anthropogenic activities were calculated by their absence (-) or presence (+) of activities and the incidence of activities was later transformed into percentage. Based on canopy cover and frequency of anthropogenic activities, three disturbance modules were identified, viz. (i) Less disturbed (LD) [close canopy >75% and nil or seasonal human activities], (ii) Moderately disturbed (MD) [open canopy 40-75% and moderate intensity of human activities, (iii) Severely disturbed (SD) [open canopy <40% with high human activities like lopping, grazing, fire, litter and biomass removal].

Study Design

The composition of forests was analyzed by nested quadrat methods (Curtis & McIntosh, 1950; Kent & Coker, 1992). The research plots were located at various sites with a minimum distance of 30 m between plots. Extreme topography (very steep) and unreachability constrained our ability to take a stratified random sampling approach. Hence, the plots were selected after walking along two gravel roads present inside the forest. The size of each plot was 20 m × 20 m and divided into four equal subplots of 10 m × 10 m for tree species, 5 m × 5 m for saplings and 1 m × 1 m for seedling as suggested by Curtis and McIntosh (1950) and Phillips (1959). Altogether, 90 plots were sampled for trees (9 sites x 10 quadrats), 360 for sapling (9 sites x 10 quadrats x 4 sub-quadrats) and 360 for seedling (9 sites x 10 quadrats x 4 sub-quadrats). In every subplot, all terrestrial plants and vascular plant species were recognized and recorded. The values obtained from four subplots aggregated to get data of the plot. Plant species were identified in the field using field guides (Polunin & Stainton 1984; Press *et al.,* 2000; Rajbhandari *et al.,* 2017; Raskoti 2009; Shrestha *et al.,* 2018; Watson *et al.,* 2011). Identification of unknown specimens and validation of identified specimens was achieved by comparison of material deposited at Tribhuvan University Central Herbarium (TUCH) and National Herbarium and Plant Laboratories (KATH). For nomenclature we followed IPNI (2022) and updated electronic version of Press *et al.* (2000).

Species composition and Biodiversity indices

The growth forms of each individual tree species that occurred inside each quadrat were categorized into one of the three groups: trees, saplings, and seedlings based on circumference at breast height (CBH) measuring at 1.37 m height for trees and saplings, and 10 cm above the ground for seedlings (Knight 1963). Individuals having circumference ≥ 31.5 cm CBH were considered as trees, individuals with <10.5 cm circumference were considered as seedling, and those with moderate dimension (10.5–31.5 cm) as saplings (Knight, 1963).

The composition and structure of the forest were determined by following Mueller-Dombois and Ellenberg (1974). Community composition, species diversity and equitability (distribution of abundances among species) as a measure of alpha diversity were calculated for each site by using Shannon-Wiener index (Shannon & Weaver, 1963), Simpson diversity index (Simpson, 1949), and Pielou species evenness index (Pielou, 1966).

Shannon-Wiener diversity index (Shannon & Weaver, 1963) emphasizes the randomness of each species present at the respective site and denotes both species richness and equitability. Increasing values of the index refers to greater species richness and evenness of species. It was measured by the following formula:

$$\text{Shannon-Wiener index (H')} = -\sum_{i=1}^{s} p_i \, ln \, p_i$$

Simpson's index (Simpson 1949), represents the concentration of dominance and is considered more as a dominance index as it accounts proportion of a species in each sample. The values of Simpson index ranges between 0 to 1 with clear meaning of greater dominancy (homogenous community) toward value of 1 and heterogenous or diverse community near the values of 0. It was measured by following formula:

$$\text{Simpson's index (D)} = \left(\frac{\sum n\,(n-1)}{N\,(N-1)}\right)$$

In both indexes, *pi* is the proportion (n/N), *n* = total number of individuals of a species, *N* = total number of individuals of all species, *ln* is natural log and ∑ is the sum of calculation, *S* is the number of species.

Pielou evenness index (Pielou, 1966) refers to the degree of relative dominance of each species. Its values range between 0 to 1 with complete evenness toward the value 1 and not evenness near values of 0. It was measured by following formula:

Pielou evenness index (J') $= \frac{H'}{ln\ S}$,

where H' is the number derived from the Shannon-Weiner diversity index and S is the total number of species.

Regeneration status

The regeneration of tree species was determined based on population density of seedling, sapling and adult in each 100 m². The regeneration classes such as Fair, Good, New, Not and Poor regeneration of each species was derived after following Khan *et al.* (1986), Khumbongmayum *et al.* (2006) and Shankar (2001). Regeneration status was considered as: (i) Good Regeneration (GR) = number of seedlings > saplings > adults; (ii) Fair Regeneration (FR) = number of seedlings > or ≤ saplings ≤ adults or seedling ≤ sapling > adults or seedling ≥ sapling without adult stage; (iii) Poor Regeneration (PR) = species survives only at sapling stage, but not seedlings (number of saplings may be less or equal to adults); (iv) None Regeneration (NR) = species is present only in adult form (no seedling and sapling stages) and (v) New Regeneration (NW) = species has no adults, only represented by juvenile stages (only seedlings or saplings present).

Data analysis

Statistics were used to discover the relationships of species richness among types of disturbances and topographical factors with the species richness. The mean values of the response variables were tested by using one-way ANOVA with post hoc Tukey HSD test and normality by Shapiro test; the level of significance was fixed as $\alpha = 0.05$. To evaluate the correlation between species richness with disturbances, we calculated the Pearson's correlation coefficient.

A Detrended Correspondence Analysis (DCA) (Hill & Gauch, 1980) was applied to examine the overall variance of the dataset and length of gradient in term of axis length present in the sample by species data matrix. The length of the gradient by the DCA1 was 3.45 standard deviation *(SD)* unit and the eigenvalues for same axis was 0.54. Hence unimodal application of ordination method, Canonical Correspondence Analysis (CCA) was justified (Leps & Smilauer, 2003).

A canonical correspondence analysis (ter Braak 1986) was used to visualize levels of disturbances on tree species composition. The CCA biplot was used to explain relationships among different tree species composition and disturbance categories. All statistical analysis for species composition and model selection were executed by using '*vegan*' package (Oksanen *et al.,* 2007) through R programs (R Core Team, 2022).

RESULTS

Types of disturbances

Various natural and anthropogenic disturbance activities were reported from the forests of the studied area like construction of hiking trails, gravel roads, recreational spots, access tracks development, rubbish dumping, formation of fence lines, soil erosion and landslides, forest fire, animal (livestock and wildlife) grazing, trunk cutting, lopping of branches, leaf litter collection, bush cutting, agricultural encroachment, and resin tapping from pine. The lopping of branches for fodder was one of the main practices noticed in the study area; nevertheless, other frequent practices of logging, burning, and trampling also occurred. Lopping was usually practiced in all seasons but more frequently during the dry period when alternate source of animal foods was scared. Lopping was severe at low altitudes due to easy accessibility from local residence. Leaf-litter collection for compost manuring and winter firings of trunk and branches were also reported in the study area for charcoal production. The present study confirmed that 17% of land area was undisturbed, 31% land area was less disturbed, 28% were moderately disturbed and 31% were highly disturbed (Fig. 2).

Species diversity

Present study found a total of 2018 stems belonging to 45 species, 40 genera and 25 families of adult trees (Table 1). Among them, 38 species, 34 genera of sapling and 42 species, 35 genera of seedling species were found in the study area belonging to 23 families in both. Rosaceae (7 species) was the most dominant family in adult plants tracked by Fagaceae (5 species), Lauraceae, Theaceae (3 species each) and Berberidaceae, Ericaceae, Myricaceae, Myrsinaceae Oleaceae, Pinaceae (2 species each). Similarly, Fagaceae (5 species) was dominant in sapling habit followed by Lauraceae, Rosaceae (3 species each), Theaceae, Berberidaceae, and Eriaceae. Myrsinaceae, Oleaceae and Pinaceae (2 species each). Fagaceae (6 species) was the most common family found in the study area followed by Rosaceae (5), Mysinaceae (4), Lauraceae (3), Ericaceae, Oleaceae and Pinaceae (2 species each) in seedling habit (Fig. 3). The tree species richness shows linear unimodal hump shaped pattern with the degree of disturbances, i.e., highest species diversity at moderate disturbance and less diversity at less and severely disturbed regions (Fig. 4).

The less disturbed areas were found holding the highest species richness (44 adult stage, 29 sapling species and 31 seedling species) followed by moderately disturbed region (45 trees species, 30 sapling species and 34 seedling species) and severely disturbed regions (29 trees species, 36 sapling species and 37 seedling species). Highest tree species richness (45 species) was reported in moderately disturbed region and lowest (29 species) at severely disturbed region. The highest sapling (36 species) and seedling species richness (37 species) were found in less severely disturbed region and lowest species richness was observed in less disturbed region (29 sapling and 31 seedling species) (Table 1).

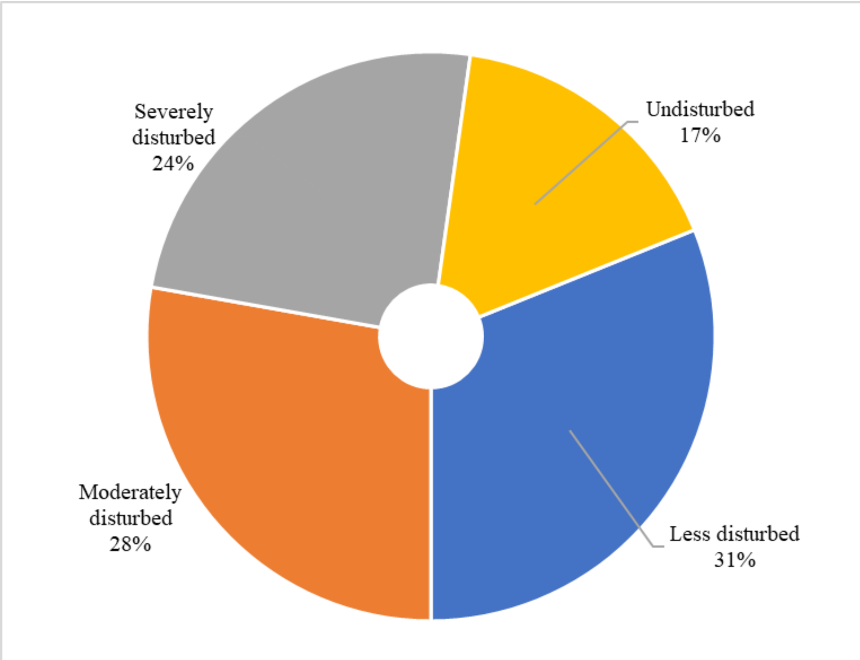

Figure 2. Levels of disturbance in the study area; nearly one fifth forest area was undisturbed and remaining area were facing different levels of disturbances

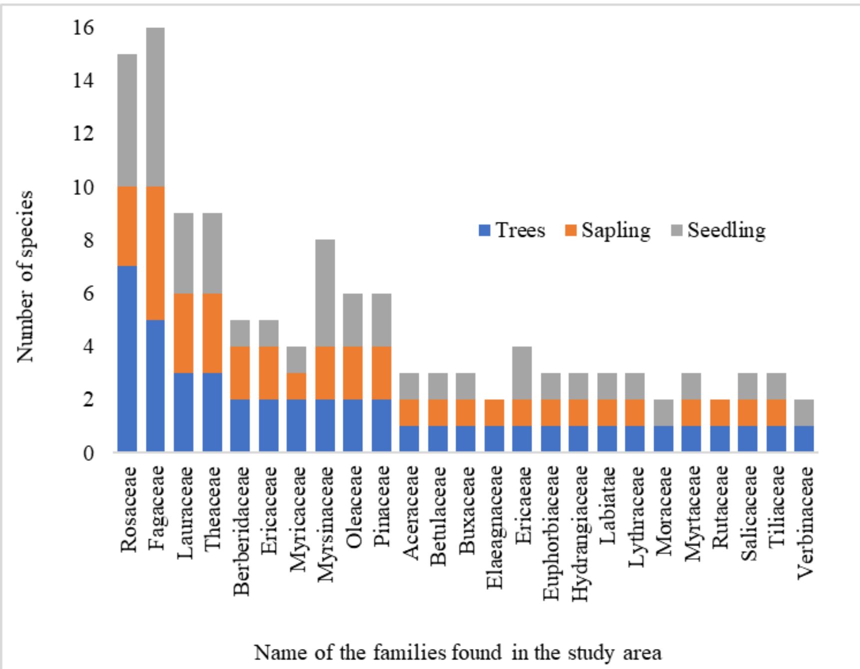

Figure 3. The number of plants species in each family in the study area

Table 1. Species diversity and richness in different disturbance regimes

Determinants	Disturbed regions								
	Less disturbed			**Moderately disturbed**			**Severely disturbed**		
	Species	Genera	Family	Species	Genera	Family	Species	Genera	Family
Adult tree species	44	39	24	45	40	25	37	38	23
Sapling species	29	24	21	32	26	24	36	31	21
Seedling species	31	24	23	36	27	22	41	38	30

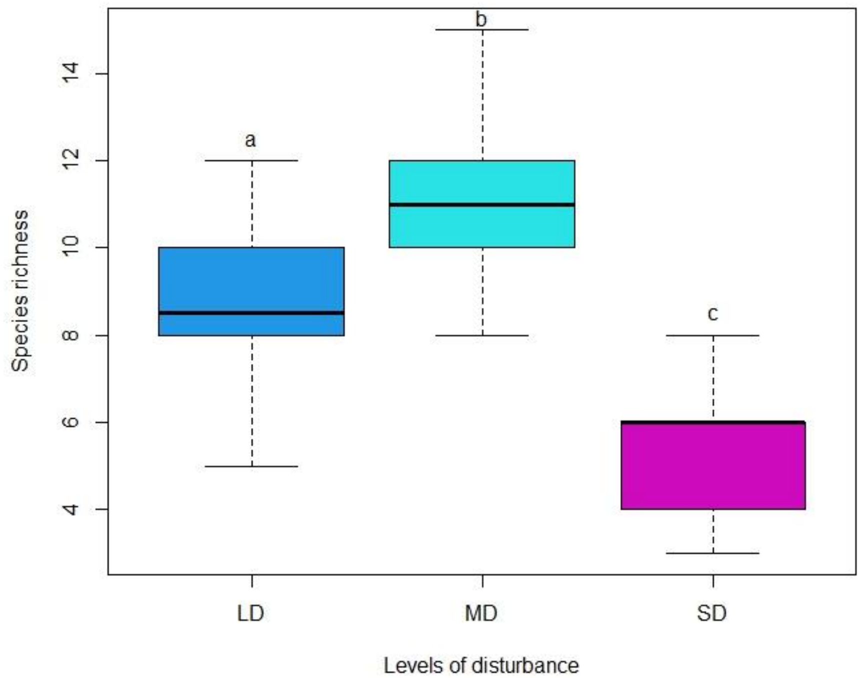

Figure 4. Boxplot showing species richness in three different levels of disturbances: statistically significant highest diversity in moderately disturbed region (MD) than in the least disturbed (LD) and severely disturbed regions (SD) supporting the moderate disturbance hypothesis.

Highest tree species density (1017 individual per ha) was reported from less disturbed region as compared to moderately disturbed (537 individual per ha) and severely disturbed regions (350 individual per ha) (Table 2). Highest stand density was reported for *Alnus nepalensis* (317) and *Schima wallichi* (209) at lower region and *Quercus semecarpefoila* (117), *Berberis aristata* (112) at upper elevation.

The values of total tree basal area coverage ranged between 12.7 (severely disturbed region) to 72.78 m^2 ha-1 (less disturbed region) with moderate value in moderately disturbed area (38.33) (Table 2). The species like *Alnus nepalensis* and *Schima wallichii* showed very high basal area at lower elevation and *Quercus semecarpefolia* in upper elevation.

The lowest Shannon-Wiener Index (H') value of trees was reported in severely disturbed region as 1.47±0.036 (mean±SE) and the highest values for moderately disturbed region (4.6±0.041) and less disturbed region (3.52±0.04). The Shannon-Wiener Index value varied from 3.01 (severely disturbed) to 2.89 (less disturbed) for sapling species. Similar values of index were reported for seedling species as well 2.04 (less disturbed) to 2.45 (severely disturbed) (Table 2).

The Simpson's index (D) for trees species were found varied from 0.032 (less disturbed region) to 0.19 (severely disturbed). The values of Simpson index of sapling species varied from 0.06 (less disturbed) to 0.12 (heavily disturbed) while minimum 0.01 (moderately disturbed) to 0.14 (severely disturbed) was reported for seedling species (Table 2).

Pileu evenness index (J') for tree species were reported varied lowest 0.051 (severely disturbed region) to highest 0.102 (moderately disturbed region) as sapling species. Whereas its value was minimum in moderate disturbed region in seedling species (0.092) and maximum in less disturbed regions (0.71).

Table 2. Mean and standard error of diversity indices, evenness index and basal area in less, moderately and severely disturbed area for tree species (with ±SE)

Determinants	Disturbed regions		
	Less disturbed	Moderately disturbed	Severely disturbed
Stand density (per ha)	1017 ± 17.02	537 ± 22.09	350 ± 9.85
Total Basal Area (m2 per ha)	72.78 ± 2.10	38.33 ± 1.67	12.70 ± 0.76
Shannon Wiener index (H')	3.52 ± 0.03	4.69 ± 0.04	1.474 ± 0.02
Simpson index (D)	0.032 ± 0.01	0.033 ± 0.01	0.069 ± 0.01
Pileu evenness index (J')	0.08 ± 0.01	0.104 ± 0.01	0.051 ± 0.01

Regeneration potential of tree species

Densities of juvenile (saplings and seedlings) individuals were found to increase from more to least disturbance gradient. This study has found fairly good regeneration of tree species. The majority of the severely disturbed sites were unsuitable for regeneration while less and moderately disturbed stands showed good or poor regeneration. Half of the tree species (51.06%) exhibited good regeneration, followed by poor regeneration (25.53%), fair regeneration (10.6%), no regeneration (8.51%) and new regeneration (2.26%) (Table 3). The leading species showed better regeneration potential in less, moderate, and severely disturbed sites with unequal densities. Some tree species like *Caryopteris foetida*, *Mahonia nepaulensis*, *Princepia utilis* and *Wendlandia puberula* were noticed as not regenerating species in the study area. Similarly, *Aesculus indica* and *Taxus wallichiana* were found encroaching the new habitat near agriculture regions on lower elevation (Table 4).

Table 3. Regeneration status of tree species in the study area

Determinants	Number of regenerating tree species in disturbed regions			Total species (%)
	Less disturbed	Moderately disturbed	Severely disturbed	
Fair regeneration	3	2	-	5 (10.64)
Good regeneration	22	2	-	24 (51.06)
Poor regeneration	11	1	-	12 (25.53)
New regeneration	1	1	-	2 (4.26)
None regeneration	-	-	4	4 (8.51)

Table 4. Tree species and their regeneration status in the study area (GR = good regeneration, FR = fair regeneration, PR = poor regeneration, NN = none regeneration, NR = new regeneration)

SN	Tree species	Acronyms	Family	Regeneration status
1	*Acer oblongum* Wall. ex DC.	Ace_obl	Aceraceae	*PR*
2	*Aesculus indica* (Wall. ex Cambess.) Hook.	Aes_ind	Sapindaceae	*NR*
3	*Alnus nepalensis* D.Don	Aln_nep	Betulaceae	*GR*
4	*Berberis aristata* Roxb.	Ber_ari	Berberidaceae	*GR*
5	*Camellia kissi* Wall.	Cam_kis	Theaceae	*GR*
6	*Caryopteris foetida* (D.Don) Thellung	Car_foe	Verbinaceae	*NN*
7	*Castanopsis indica* (Roxb.) A.DC.	Cas_ind	Fagaceae	*GR*
8	*Castanopsis tribuloids* (Sm.) A. DC	Cas_tri	Fagaceae	*GR*
9	*Cinnamomum camphora* (L.) J.Presl	Cin_cam	Lauraceae	*GR*
10	*Elaeagnus latifolia* L	Ela_lat	Elaeagnaceae	*PR*
11	*Eriobotrya dubia* (Lindl.) Decne.	Eri_dub	Rosaceae	*FR*
12	*Eurya acuminata* DC.	Eur_acu	Theaceae	*GR*
13	*Fraxinus floribunda* Wall.	Fra_flo	Oleaceae	*GR*
14	*Gaultheria fragrantissima* Wall. Wall.	Gau_fra	Ericaeae	*GR*
15	*Grewia oppositifolia* Ham.-D.Don	Gre_opp	Tiliaceae	*GR*
16	*Hydrangia aspera* D.Don	Hyd_asp	Hydrangiaceae	*GR*
17	*Lecoceptrum canum* Sm.	Lec_can	Labiatae	*GR*
18	*Ligustrum confusum* Dene	Lig_con	Oleaceae	*PR*

19	*Lindera pulcherrima* (Nees.) Benth. ex Hook. F.	Lin_pul	Lauraceae	*GR*
20	*Litsea oblong* (Wall.) Hook. F.	Lit_obl	Lauraceae	*PR*
21	*Luculia gratissima* (Wall.) Sweet	Luc_gra	Rosaceae	*GR*
22	*Lyonia ovalifolia* (Wall.) Drude	Lyo_ova	Ericaceae	*GR*
23	*Maclura cochiachinensis* (Lour.) Corner	Mac_coc	Moraceae	*FR*
24	*Maesa chisia* Buch.-Ham. ex D.Don	Mae_chi	Myrsinaceae	*GR*
25	*Mahonia nepaulensis* DC.	Mah_nep	Berberidaceae	*NN*
26	*Myrica esculenta* Buch.-Ham. ex D.Don	Myr_esc	Myricaceae	*FR*
27	*Myrsine capitelata* Wall.	Myr_cap	Myricaceae	*GR*
28	*Myrsine semiserata* Wall.	Myr_sem	Myrsinaceae	*GR*
29	*Pinus roxburghii* Sargent	Pin_rox	Pinaceae	*PR*
30	*Pinus wallichiana* A.B. Jack	Pin_wal	Pinaceae	*PR*
31	*Princepia utilis* Royle	Pri_uti	Rosaceae	*NN*
32	*Prunus cerasoides* D.Don	Pru_cer	Rosaceae	*FR*
33	*Pyracantha cranulata* (D.Don) Roem	Pyr_cra	Rosaceae	*PR*
34	*Pyrus pashia* Buch.-Ham. ex D.Don	Pyr_pas	Rosaceae	*GR*
35	*Quercus glauca* Thunb.	Que_gla	Fagaceae	*GR*
36	*Quercus lanata* D.Don	Que_lan	Fagaceae	*GR*
37	*Quercus semecarpefolia* Sm.	Que_sem	Fagaceae	*GR*
38	*Rhododendron arboreum* Sm.	Rho_arb	Ericaceae	*GR*
39	*Salix denticulata* And.	Sal_den	Salicaceae	*PR*
40	*Sapium insigne* (Royle) Benth	Sap_ins	Euphorbiaceae	*PR*
41	*Sarcococca coriacea* (Hook.f.) Sewwt	Sar_cor	Buxaceae	*FR*
42	*Schima wallichii* (DC.) Kortch.	Sch_wal	Theaceae	*GR*
43	*Syzygium cumini* (L.) Skeels	Syz_cum	Myrtaceae	*PR*
44	*Taxus wallichiana* Zucc.	Tax_wal	Taxaceae	*NR*
45	*Wendlandia puberula* DC.	Wen_pub	Rosaceae	*NN*
46	*Woodfordia fructicosa* (L.) Kurz	Woo_fru	Lythraceae	*PR*
47	*Zanthoxylem armatum* DC.	Zan_arm	Rutaceae	*PR*

Canonical Correspondence Analysis (CCA)

The variance explained by the CCA ordination diagram (Fig. 5) between tree species and levels of disturbance axes were 54.3% and 31.39% for the first axis and second axis. The eigenvalues were found ranged between 0.54 and 0.31 for both corresponding axes (Table 5). The CCA first axis showed a negative correlation with grazing (-0.4), litter removal (-0.3), forest fire (-0.26) positive correlation with elevation (0.98). While the second axis indicated negative correlation with aspect (-0.58), slope (-0.31) and weak positive correlation with grazing (0.19) and litter removal (0.15) (Table 6).

Table 5. DCA summary

	DCA1	DCA2	DCA3	DCA4
Eigenvalues	0.54	0.31	0.24	0.19
Decorana values	0.55	0.31	0.21	0.17
Axis lengths	3.46	3.76	2.57	2.24

Table 6. Biplot scores for constraining variables of study area

SN	Variables	CCA1	CCA2
1	Elevation (EL)	0.97	0.05
2	North aspect (ASNorth)	-0.12	0.02
3	South (ASSOuth)	-0.31	-0.06
4	West (ASWest)	0.22	-0.33
5	Slope (SL)	0.08	0.29
6	Looping (LP)	-0.02	-0.26
7	Land slide (LS)	0.05	-0.12
8	Grazing (GR)	-0.40	-0.31
9	Forest fire (FF)	-0.25	-0.13
10	Litter removal (LR)	-0.30	-0.37
11	Canopy cover (CC)	0.13	0.69

Among the environmental variables studied, elevation (EL), level of disturbance (DL) and crown coverage (CC) found statistically significant with higher F-values and lower p-values (EL, $F = 5025.4$, $p < 0.001$, DL, $F = 49.05$, $p < 0.001$ and CC, $F = 13.25$, $p < 0.001$). These variables showed the environmental scores with -0.96, 0.04 and 0.12 for the first axis, and -0.06, -0.23 and 0.69 for second axis, respectively. Elevation and Grazing showed the highest environment scores for the first axis (0.97, -0.40), and Canopy coverage and Aspect for second axis (0.69, 0.48).

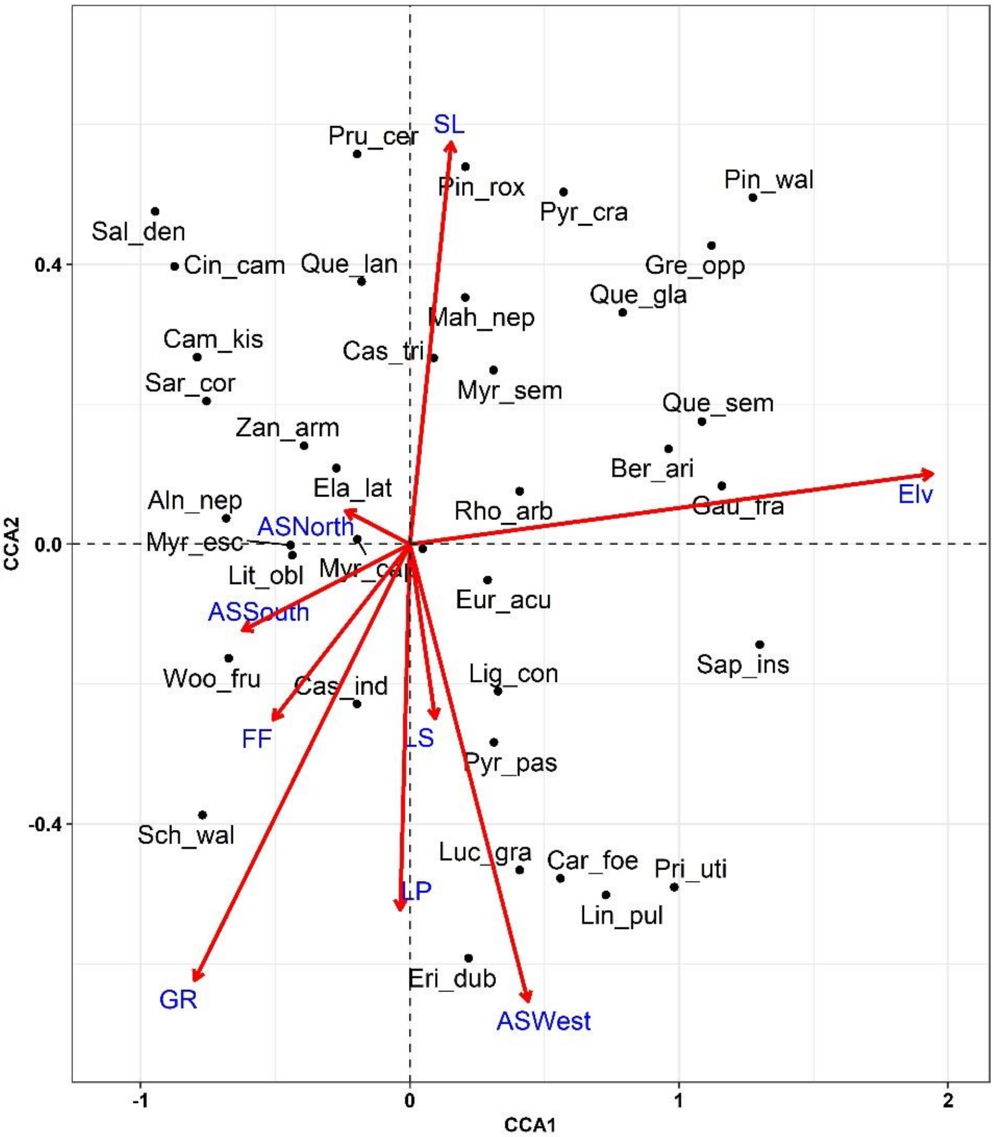

Figure 5. CCA biplot ordination diagram of tree species based on elevation, and categories of disturbance. EV, elevation; ASNorth, North aspect; ASSouth, South aspect; ASWest, West aspect; SL, Slope; LP, lopping; LS, land sliding; SE, soil erosion; FF, forest fire; LR, litter removal; CC, canopy cover (Three letters represents genus and species of plants, for detail species nomenclature see in the table 4 and 7).

Canopy coverage is inversely affected by lopping, land slide, forest fire and slope. The frequency of forest fire was correlated with litter removal and negative affected by looping and landslides.

Most tree species were influenced by elevation. Some tree species like *Berberis aristata*, *Maclura cochiachinensis*, *Lecoceptrum canum*, *Grewia oppositifolia*, *Gaultheria fragrantissima*, *Pinus wallichiana*, *Sapium insigne Princepia utilis*, *Pyracantha cranulata*, *Rhododendron arboreum*, *Quercus glauca*, and *Quercus semecarpefolia* prefered to grow toward upper elevation and *Syzygium cumini*, *Cinnamomum camphora*, *Schima wallichii*, *Alnus nepalensis*, and *Woodfordia fructicosa* toward lower elevation. According to CCA plot and species score, the species toward lower elevation were affected by forest fire, grazing and litter removal while species toward upper elevation were affected by landslides and slope of the area (Fig. 5, Table 7).

Castanopsis tribuloids, *Pyracantha cranulata*, *Eriobotrya dubia*, *Quercus semecarpefolia* prefer to regenerate in higher canopy coverage while *Zanthoxylem armatum*, *Elaeagnus latifolia*, *Quercus lanata*, *Litsea* oblong and Castanopsis indica prefer higher open space for regeneration. *Schima wallichii Woodfordia fructicosa, Alnus nepalensis*, *Myrica esculenta* and *Myrsine semiserata* prefer to regenerate toward higher frequency of grazing and litter removal while the populations of *Pinus roxburghii* were affected by greater landslide and forest fire (Fig. 5, Table 7).

Table 7. Species with their CCA score in the study area

SN	Abbreviation	Species name	CCA1	CCA2
1	Ace_obl	*Acer oblongum*	0.07	-0.07
2	Aln_nep	*Alnus nepalensis*	-0.70	0.07
3	Ber_ari	*Berberis aristata*	0.92	0.24
4	Cam_kis	*Camellia kissi*	-0.79	0.26
5	Car_foe	*Caryopteris foetida*	0.57	-0.48
6	Cas_ind	*Castanopsis indica*	-0.16	-0.31
7	Cas_tri	*Castanopsis tribuloids*	0.07	0.32
8	Cin_cam	*Cinnamomum camphora*	-0.86	0.34
9	Ela_lat	*Elaeagnus latifolia*	-0.26	0.07
10	Eri_dub	*Eriobotrya dubia*	0.20	-0.52
11	Eur_acu	*Eurya acuminata*	0.30	-0.08
12	Fra_flo	*Fraxinus floribunda*	-0.36	-1.17
13	Gau_fra	*Gaultheria fragrantissim*	1.18	0.01
14	Gre_opp	*Grewia oppositifolia*	1.15	0.37
15	Hyd_asp	*Hydrangia aspera*	-1.52	-0.55
16	Lec_can	*Lecoceptrum canum*	0.98	0.60
17	Lig_con	*Ligustrum confusum*	0.36	-0.25
18	Lin_pul	*Lindera pulcherrima*	0.72	-0.49
19	Lit_obl	*Litsea oblong*	-0.41	-0.10
20	Luc_gra	*Luculia gratissima*	0.34	-0.30
21	Lyo_ova	*Lyonia ovalifolia*	0.72	-0.97
22	Mac_coc	*Maclura cochiachinensis*	1.27	0.99
23	Mae_chi	*Maesa chisia*	0.97	-0.94
24	Mah_nep	*Mahonia nepaulensis*	0.18	0.47
25	Myr_esc	*Myrica esculenta*	-0.48	0.06
26	Myr_cap	*Myrsine capitelata*	-0.21	0.04
27	Myr_sem	*Myrsine semiserata*	0.30	0.28
28	Pin_rox	*Pinus roxburghii*	0.22	0.49
29	Pin_wal	*Pinus wallichiana*	1.29	0.47
30	Pri_uti	*Princepia utilis*	0.98	-0.52
31	Pru_cer	*Prunus cerasoides*	-0.20	0.57
32	Pyr_cra	*Pyracantha cranulata*	0.53	0.62
33	Pyr_pas	*Pyrus pashia*	0.32	-0.22
34	Que_gla	*Quercus glauca*	0.75	0.42
35	Que_lan	*Quercus lanat*	-0.17	0.35
36	Que_sem	*Quercus semecarpefolia*	1.09	0.15
37	Rho_arb	*Rhododendron arboreum*	0.42	0.05
38	Sal_den	*Salix deniculata*	-0.99	0.57
39	Sap_ins	*Sapium insigne*	1.29	-0.12
40	Sar_cor	*Sarcococca coriacea*	-0.71	0.06
41	Sch_wal	*Schima wallichii*	-0.78	-0.37
42	Syz_cum	*Syzygium cumini*	-1.17	-0.01
43	Wen_pub	*Woodfordia fructicosa*	0.25	-0.77
44	Woo_fru	*Aesculus indica*	-0.69	-0.09
45	Zan_arm	*Taxus wallichiana*	-0.35	0.04

DISCUSSION

The species diversity, richness and their regeneration were found greatly affected by both biotic (human being) and non-biotic factors (Eshaghi Rad *et al.,* 2018; Takafumi & Hiura, 2009; Zhu *et al.,* 2007). The number of plants species was found greater in case of less disturbed stands as compared to the high disturbed stands, i.e., as the degree of disturbance decreased, the species richness was found to increase as in other researches (Bentsi-Enchill *et al.,* 2022; Eshaghi Rad *et al.,* 2018; Wilson & Gerry, 2000). This increasing species diversity from less disturbed to severely disturbed regions suggested the greater influence of anthropogenic activities on species composition and diversity (Bhuyan *et al.,* 2003; Esther *et al.,* 2014; Majumdar & Datta, 2015; Mishra *et al.,* 2004).

High species richness of trees was found at moderate disturbance region (as intermediate disturbance hypothesis) (Connel, 1978) with lower diversity at severely disturbed and less disturbed area. Higher number of species in moderately disturbed area was due to ample opportunity of species turn over, persistence of higher species richness and colonization (Kumar & Ram, 2005; Molino & Sabatier, 2001; Sharma *et al.,* 2018; Tiwari *et al.,* 2019). Lower tree species richness at severely disturbed area may be due to nearness to human settlement triggering development of microclimate (Esther *et al.,* 2014) higher grazing intensity and litter and biomass removal for compost manuring (Sagar *et al.,* 2003) in lower elevation ranges. Similar results were found in studies done on temperate region of Nepal (Shrestha *et al.,* 2013), India (Singh *et al.,* 2016) and tropical regions of Nepal, India, and South Asian countries (Htun *et al.,* 2011; Mishra *et al.,* 2004; Pandey & Shukla, 2001; Rabha, 2014; Rahman *et al.,* 2009; Sapkota *et al.,* 2010; Timilsina *et al.,* 2007).

While the number of saplings and seedlings species were highest at more disturbed areas and least at lower disturbances. The occurrence of higher density of sapling and seedling towards more disturbed sites might be explained by the susceptibility to invasion (Zimdahl, 2004) and lower canopy coverage (Kumar & Ram, 2005). With increasing canopy gap, the species richness was found increased due to abundant light exposure on forest floor triggering seed germination and increasing ground vegetation coverage but reducing soil moisture which may not be suitable for few species (Dip *et al.,* 2020; Harper *et al.,* 2005). High amount of light exposure on soil surface favored for incursion by newly introduced plant species (Flory & Clay, 2006). It was indicated by the increased species diversity with domination of common invasive species like *Parthenium hysterophorum* and *Eupatorium adenophorum* in the forest area.

Increased density of seedlings, and saplings along increasing disturbances gradient whereas trees species decreased with increasing disturbances. The maximum tree density was observed in lower disturbed sites due to lower frequency of anthropogenic activities like lower firing, litter removal, lopping, grazing, etc. The tree density in study area was found higher (188-563 individual ha^{-1}) as compared to studies viz., Srivastava and Vellend (2005) and lower than the studies of Bharali *et al.* (2011), Sharma *et al.* (2009), Singh *et al.* (2016), Tiwari *et al.* (2019) in similar types of temperate forests.

The result of biodiversity indices (H, D and J') showed significant consequence of disturbance on tree species regeneration. Shannon diversity index (H), and Pileou species evenness index (J') were found highest at moderately disturbed regions for trees and sapling species and lowest for seedling species which contrasts with the study of Peltzer *et al.* (2000). The Shannon index values in this study were lower (3.09 to 3.33) as observed by Gairola *et al.* (2011), and more than the values (1.06-2.80) given by Khera *et al.* (2001) for broad-leaved temperate Himalaya forests. A Similar pattern of Pileou evenness index (J') was found in the study area; greater in moderately disturbed region (0.104) to severely disturbed region (0.051). The lowest evenness index at less disturbed region leads to development of monodominance of the forest composition removing the non-competitive species, and highest values in species evenness in moderately disturbed region reflects the high diversity (Sagar *et al.,* 2003).

Similarly, the result showed the lower Simpsons index (D, concentration of dominance) in highly disturbed region for tree and sapling and highest values for seedling species as found by Gautam *et al.* (2016) indicating the dominance of disturbance tolerant species in these areas. Disparity in diversity and densities of sapling and seedling may be due to changes in many climatic factors including canopy coverage. The governance of one layer of canopy force the alteration of the diversity of other layer (Whittaker, 1975).

Regeneration status

The regeneration potential of the tree species in the study area were identified as good at less disturbed regions, poor in moderate regions and no regeneration in severely disturbed regions. In the study, the majority of the tree species showed different stages of regeneration; among them half of the species showed good regeneration. Only two species, *Aesculus indica* and *Taxus wallichiana* were found near to the agricultural land at lower elevation. The presence of new species at lower elevation range near to human settlement indicated the active anthropogenic activities in forest. Furthermore, four natural species (*Caryopteris foetida*, *Mahonia nepaulensis*, *Princepia utilis* and *Wendlandia puberula*) showed no regeneration, respectively. Unsuccessful in regeneration of few species (8.5%) indicated the presence of non-competitive species and monodominance of species (Sagar *et al.,* 2003; Gautam *et al.,* 2016).

Canonical Correspondence Analysis (CCA)

Present study found that the elevation was the most significant gradient that controls the regeneration of tree species. Similar result also noticed by Behera and

Kushwaha (2007). The grazing intensity was directly correlated with land litter removal and indicating the increasing frequency of gazing could lead to higher litter removal in the study area. Similarly, higher the intensity of looping leads to greater landslides (Shrestha *et al.,* 2013). In the same way, more frequency of forest fire was responsible for lower canopy gaps. Increasing landslides and looping also favoured the canopy coverage. Some species of tree might be sensitive (*Luculia gratissima*) with disturbance gradients, while other no (*Gaultheria fragrantissima* and *Pinus wallichiana*) or little effects (*Acer oblongum* and *Quercus lanata*) (Harper *et al*., 2005).

CONCLUSIONS

The regeneration of tree species and disturbance gradient have a strong relationship in the Chandragiri Forest. The increased anthropogenic disturbances inversely affect the overall species richness and species density. Increasing the intensity of destruction of natural habitat through lopping, cutting, firing, etc. would decrease the species turnover and alter their composition and structure of plant community. Regeneration of some plants like *Acer oblongum, Lyonia ovalifolia* and *Quercus semecarpifolia* showed good potentiality in less disturbed regions while *Alnus nepalensis* and *Schima wallichi* showed quite impressive regeneration in highly disturbed regions. Some typical temperate species like *Quercus lanata*, *Rhododendron arboretum* and *Myrsine semiserrata* showed inadequate seedling abundance. Variation in species diversity and regeneration patterns of individual species along disturbance ranges suggesting the prevailing multiple factors. So, there is need for comprehensive strategies or implementation program for poor regenerating plants for proper conservation and restoration. The result also demands the development of a short-term program for the conservation of severely disturbed regions into moderately or less disturbed regions.

ACKNOWLEDGEMENTS

The authors are thankful to the Department of Botany, Tri-Chandra Multiple Campus, Central Department of Botany, Tribhuvan University for technical assistance. RSD is grateful to University Grants Commission, Nepal for providing faculties Research Fellowship Award. The first author also obliged the local people of Chandragiri Forests for their constant help during field visits.

AUTHORS CONTRIBUTION STATEMENT

RSD innately contributed to the research design, data assembly, data analysis, and manuscript writing. CBB contributed to data analysis, supervision of study, and editing manuscript.

CONFLICT OF INTEREST

The authors do not have any conflict of interest pertinent to this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

REFERENCES

Behera, M.D., & Kushwaha, S.P.S. (2007). An analysis of altitudinal behavior of tree species in Subansiri district, Eastern Himalaya. *Biodiversity and Conservation*, *16*(6), 1851–1865. https://doi.org/10.1007/s10531-006-9083-0

Behera, S.K., Mishra, A.K., Sahu, N., Kumar, A., Singh, N., Kumar, A., Bajpai, O., Chaudhary, L.B., Khare, P.B., & Tuli, R. (2012). The study of microclimate in response to different plant community association in tropical moist deciduous forest from northern India. *Biodiversity and Conservation*, *21*(5), 1159–1176. https://doi.org/10.1007/s10531-012-0230-5

Bennett, L.T., & Adams, M.A. (2004). Assessment of ecological effects due to forest harvesting: Approaches and statistical issues. *Journal of Applied Ecology*, *41*(4), 585–598. https://doi.org/10.1111/j.0021-8901.2004.00924.x

Bentsi-Enchill, F., Damptey, F.G., Pappoe, A.N.M., Ekumah, B., & Akotoye, H.K. (2022). Impact of anthropogenic disturbance on tree species diversity, vegetation structure and carbon storage potential in an upland evergreen forest of Ghana, West Africa. *Trees, Forests and People*, *8*, 100238. https://doi.org/10.1016/j.tfp.2022.100238.

Bharali, S., Paul, A., Khan, M., & Singha, L.B. (2011). Species diversity and community structure of a temperate mixed rhododendron forest along an altitudinal gradient in West Siang District of Arunachal Pradesh, India. *Nature and Science*, *9*, 125–140.

Bhuyan, P., Khan, M.L., & Tripathi, R.S. (2003). Tree Diversity and Population Structure in Undisturbed and Human-Impacted Stands of Tropical Wet Evergreen Forest in Arunachal Pradesh, Eastern Himalayas, India. *Biodiversity and Conservation*, *12*(8), 1753–1773. https://doi.org/10.1023/A:1023619017786.

CBS. (2019). *Environmetntal Statistics of Nepal*. Retrieved 20 October, 2022 from https://unstats.un.org/unsd/environment/Compendia/Nepal_Environment Statistics of Nepal_2019.pdf.

Chapagain, U., Chapagain, B.P., Nepal, S., & Manthey, M. (2021). Impact of disturbances on species diversity and regeneration of Nepalese Sal (*Shorea robusta*) forests managed under different management regimes. *Earth*, *2*(4), 826–844.

https://doi.org/10.3390/earth2040049

Connel, J.H. (1978). Diversity in Tropical Rain Forest and Coral Reefs. *Science*, *199*(4335), 1302–1310. https://doi.org/10.1126/science.199.4335.1302

Connell, J.H., & Lowman, M.D. (1989). Low Diversity Tropical Rain Forests: Some Possible Mechanisms for Their Existence. *American Naturalist*, *134*(1), 88–119. https://doi.org/10.1086/284967

Curtis, J. T., & McIntosh, R. P. (1950). The Interrelations of Certain Analytic and Synthetic Phytosociological Characters. *Ecology*, *31*(3), 434–455. https://doi.org/https://doi.org/10.2307/1931497.

Dip, A.B., Sampietro-Vattuone, M.M., Garey, M.V., & Eleuterio, A.A. (2020). Altitudinal gradient of plant diversity patterns in the Sierra de Quilmes (Monte desert – Argentina). *Journal of Arid Environments*, 182, 104274. https://doi.org/https://doi.org/10.1016/j.jaridenv.2020.104274.

Eilu, G., & Obua, J. (2005). Tree condition and natural regeneration in disturbed sites of Bwindi Impenetrable Forest National Park, Southwestern Uganda. *Tropical Ecology*, *46*(1), 99–111.

Elderd, B.D., & Doak, D.F. (2006). Comparing the direct and community-mediated effects of disturbance on plant population dynamics: Flooding, herbivory and Mimulus guttatus. *Journal of Ecology*, *94*(3), 656–669. https://doi.org/10.1111/j.1365-2745.2006.01115.x.

Eshaghi Rad, J., Valadi, G., Salehzadeh, O., & Maroofi, H. (2018). Effects of Anthropogenic Disturbance on Plant Composition, Plant Diversity and Soil Properties in Oak Forests, Iran. *Journal of Forest Science*, *64*(8), 358–370. https://doi.org/10.17221/13/2018-JFS

Esther, V., Martha, K., Harrison, T., Lenard, O., Charles, K., Stella, W., & Humphrey, N. (2014). The impacts of human activities on tree species richness and diversity in Kakamega Forest, Western Kenya. *International Journal of Biodiversity and Conservation*, *6*(6), 428–435. https://doi.org/10.5897/ijbc2014.0711.

Flory, S.L., & Clay, K. (2006). Invasive Shrub Distribution Varies with Distance to Roads and Stand age in Eastern Deciduous Forests in Indiana, USA. *Plant Ecology*, *184*(1), 131–141. https://doi.org/10.1007/s11258-005-9057-4.

Gairola, S., Sharma, C.M., Suyal, S., & Ghildiyal, S.K. (2011). Composition and diversity of five major forest types in moist temperate climate of the western Himalayas. *Forestry Studies in China*, *13*(2), 139. https://doi.org/10.1007/s11632-011-0207-6.

Gautam, M.K., Manhas, R.K., & Tripathi, A.K. (2016). Patterns of diversity and regeneration in unmanaged moist deciduous forests in response to disturbance in Shiwalik Himalayas, India. *Journal of Asia-Pacific Biodiversity*, *9*(2), 144–151. https://doi.org/10.1016/j.japb.2016.01.004

Good, N.F., & Good, R.E. (1972). Population dynamics of tree seedlings and saplings in a mature Eastern Hardwood Forest. *Bulletin of the Torrey Botanical Club*, *99*(4), 172–178. https://doi.org/10.2307/2484571

Grierson, A.J.C., & Long, D.G. (2003a). *Flora of Bhutan, Vol. 1 (1)*. Royal Botanic Garden Edinburgh.

Grierson, A.J.C., & Long, D.G. (2003b). *Flora of Bhutan: Vol. 1 (2)*. Edinburgh, UK: Royal Botanic Garden Edinburgh.

Grierson, A.J.C., Schäfer-Verwimp, A., & Bates, M. (1999). *Flora of Bhutan Vol. 2 (2)*. Edinburgh, UK: Royal Botanic Garden Edinburgh.

Grierson, A., & Schäfer-Verwimp, A. (1983). *Flora of Bhutan Vol. 1*. Royal Botanic Garden.

Grubb, P.J. (1977). The maintenance of species-richness in plant communities: the importance of the regeneration niche. *Biological Reviews*, *52*(1), 107–145. https://doi.org/10.1111/j.1469-185x.1977.tb01347.x.

Harper, K.A., Macdonald, S.E., Burton, P.J., Chen, J., Roberts, D., Jaiteh, M.S., & Esseen, P.-A. (2005). Edge influence on forest structure and composition in fragmented landscapes. *Conservationa Biology*, *19*(3), 768–782. https://doi.org/10.4018/978-1-59904-099-8.ch010.

Hill, M.O., & Gauch, H.G. (1980). Detrended correspondence analysis: an improved ordination technique. *Vagetatio, 42*, 47–58. https://doi.org/10.1007/978-94-009-9197-2_7.

Htun, N.Z., Mizoue, N., & Yoshida, S. (2011). Tree species composition and diversity at different levels of disturbance in Popa Mountain Park, Myanmar. *Biotropica*, *43*(5), 597–603.

Huston, M.A. (2014). Disturbance, productivity, and species diversity: empiricism versus logic in ecological theory. *Ecological Society of America*, *2*(26).

IPNI. (2022). *International Plant Names Index*. Retrieved October 25, 2022 from http://www.ipni.org.

Kennard, D.K., Gould, K., Putz, F.E., Fredericksen, T.S., & Morales, F. (2002). Effect of disturbance intensity on regeneration mechanisms in a tropical dry forest. *Forest Ecology and Management*, *162*(2–3), 197–208. https://doi.org/10.1016/S0378-1127(01)00506-0.

Kent, M., & Coker, P. (1992). *Vegetation Description and Analysis: A Practical Approach*. New York: John Wiley and Sons.

Khan, M.L., Rai, J.P.N., & Tripathi, R.S. (1986). Regeneration and survival of tree seedlings and sprouts in tropical deciduous and sub-tropical forests of Meghalaya, India. *Forest Ecology and Management*, *14*(4), 293–304. https://doi.org/10.1016/0378-1127(86)90175-1.

Khera, N., Kumar, A., Ram, J., & Tewari, A. (2001). Plant biodiversity assessment in relation to disturbances in mid-elevational forest of Central Himalaya, India. *Tropical Ecology*, *42*(1), 83–95.

Khumbongmayum, A.D., Khan, M.L., & Tripathi, R.S. (2006). Biodiversity conservation in sacred groves of Manipur, northeast India: Population structure and regeneration status of woody species. *Biodiversity and Conservation*, *15*(8), 2439–2456. https://doi.org/10.1007/s10531-004-6901-0.

Kräuchi, N., Brang, P., & Schönenberger, W. (2000). Forests of mountainous regions: Gaps in knowledge and research needs. *Forest Ecology and Management*, *132*(1), 73–82. https://doi.org/10.1016/S0378-1127(00)00382-0

Kumar, A., & Ram, J. (2005). Anthropogenic disturbances and plant biodiversity in forests of Uttaranchal, central Himalaya. *Biodiversity and Conservation*, *14*(2), 309–331. https://doi.org/10.1007/s10531-004-5047-4.

Lemmon, P.E. (1956). A spherical densiometer for estimating forest overstory density. *Forest Science*, *2*, 314–320.

Lemmon, P.E. (1957). A new instrument for measuring forest overstory density. *Journal of Forestry*, 667–669.

Leps, J., & Smilauer, P. (2003). *Multivariate analysis of ecological data using CANOCO*. Cambridge University Press.

Majumdar, K., & Datta, B.K. (2015). Effects of anthropogenic disturbances on vegetation diversity and structure: A case study in the remnant forests surrounding the village ecosystems of Tripura, Northeast India. *Chinese Journal of Population Resources and Environment*, *13*(4), 332–340. https://doi.org/10.1080/10042857.2015.1059791.

Malik, Z.A., Bhat, J.A., & Bhatt, A.B. (2014). Forest resource use pattern in Kedarnath wildlife sanctuary and its fringe areas (a case study from Western Himalaya, India). *Energy Policy*, *67,* 138–145. https://doi.org/10.1016/j.enpol.2013.12.016.

Malik, Z.A., & Bhatt, A.B. (2016). Regeneration status of tree species and survival of their seedlings in kedarnath wildlife sanctuary and its adjoining areas in Western Himalaya, India. *Tropical Ecology*, *57*(4), 677–690.

Mishra, A.K., Bajpai, O., Sahu, N., Kumar, A., Behera, S.K., Mishra, R., & Chaudhary, L.B. (2013). Study of plant regeneration potential in tropical moist deciduous forest in Northern India. *International Journal of Environment*, *2*(1), 153–163. https://doi.org/10.3126/ije.v2i1.9218

Mishra, B.P., Tripathi, O.P., Tripathi, R.S., & Pandey, H.N. (2004). Effects of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, northeast India. *Biodiversity and Conservation*, *13*(2), 421–436. https://doi.org/10.1023/B:BIOC.0000006509.31571.a0.

Molino, J., & Sabatier, D. (2001). Tree diversity in tropical rain forests: A validation of the intermediate disturbance hypothesis. *Science*, *294*(5547), 1702–1704. https://doi.org/10.1126/science.1060284.

Mueller-Dombois, D., & Ellenberg, H. (1974). *Aims and Methods of Vegetation Ecology*. John Wiley and Sons Inc.

Oksanen, J., Legendre, P., O'Hara, B., Stevens, M.H. H., Oksanen, M.J., & Suggests, M. (2007). The vegan package. *Community Ecology Package*, *10*, 631–637.

Pandey, S.K., & Shukla, R.P. (2001). Regeneration strategy and plant diversity status in degraded sal forests. *Current Science*, *81*(1), 95–102.

Peltzer, D.A., Bast, M.L., Wilson, S.D., & Gerry, A.K. (2000). Plant diversity and tree responses following contrasting disturbances in boreal forest. *Forest Ecology and Management*, *127*(1–3), 191–203. https://doi.org/10.1016/S0378-1127(99)00130-9.

Phillips, E. (1959). *Methods of Vegetation Study*. New York: Holt, Rinehart and Winston.

Pielou, E.C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*, *13*, 131–144. https://doi.org/https://doi.org/10.1016/0022-5193(66)90013-0.

Polunin, O., & Stainton, A. (1984). *Flowers of the Himalaya*. Delhi: Oxford University Press.

Press, J.R., Shrestha, K.K., Sutton, D.A. (2000). *Annotated checklist of the flowering plants of Nepal*. London, UK: Natural History Museum Publications.

R Core Team. (2022). *R: A language and environment for statistical computing*. Retrieved October 15, 2022 from https://www.r-project.org/

Rabha, D. (2014). Aboveground biomass and carbon stocks of an undisturbed regenerating Sal (*Shorea robusta* Gaertn. F.) forest of Goalpara District, Assam, Northeast India. *International Journal of Environment*, *3*(4), 147–155. https://doi.org/10.3126/ije.v3i4.11743.

Rahman, M.D.M., Nishat, A., & Vacik, H. (2009). Anthropogenic disturbances and plant diversity of the madhupur sal forests (Shorea robusta C.F. Gaertn) of Bangladesh. *International Journal of Biodiversity Science and Management*, *5*(3), 162–173. https://doi.org/10.1080/17451590903236741.

Rajbhandari, K.R., Rai, S.K., Bhatt, G.D., Chhetri, R., Khatri, S. (2017). *Flowering plants of Nepal: an introduction*. Kathmandu, Nepal: Department of Plant Resources.

Ramírez-Marcial, N., González-Espinosa, M., & Williams-Linera, G. (2001). Anthropogenic disturbance and tree diversity in Montane Rain Forests in Chiapas, Mexico. *Forest Ecology and Management*, *154*(1–2), 311–326. https://doi.org/

10.1016/S0378-1127(00)00639-3.

Raskoti, B. (2009). *The Orchids of Nepal.* Bhakta Bahadur Raskoti and Rita Ale.

Ruprecht, E., Szabó, A., Enyedi, M.Z., & Dengler, J. (2009). Steppe-like grasslands in Transylvania (Romania): characterisation and influence of management on species diversity and composition. *Tuexenia*, *29*, 353–368.

Sagar, R., Raghubanshi, A.S., & Singh, J.S. (2003). Tree species composition, dispersion and diversity along a disturbance gradient in a dry tropical forest region of India. *Forest Ecology and Management*, *186*(1–3), 61–71. https://doi.org/10.1016/S0378-1127(03)00235-4.

Saikia, P., Deka, J., Bharali, S., Kumar, A., Tripathi, O.P., Singha, L.B., Dayanandan, S., & Khan, M.L. (2017). Plant diversity patterns and conservation status of eastern Himalayan forests in Arunachal Pradesh, Northeast India. *Forest Ecosystems*, *4*(1). https://doi.org/10.1186/s40663-017-0117-8.

Sapkota, I.P., Tigabu, M., & Odén, P.C. (2009). Spatial distribution, advanced regeneration and stand structure of Nepalese Sal (Shorea robusta) forests subject to disturbances of different intensities. *Forest Ecology and Management*, *257*(9), 1966–1975. https://doi.org/10.1016/j.foreco.2009.02.008.

Sapkota, I.P., Tigabu, M., & Odén, P.C. (2010). Changes in tree species diversity and dominance across a disturbance gradient in Nepalese Sal (Shorea robusta Gaertn. f.) forests. *Journal of Forestry Research*, *21*(1), 25–32. https://doi.org/10.1007/s11676-010-0004-4.

Sassen, M., & Sheil, D. (2013). Human impacts on forest structure and species richness on the edges of a protected mountain forest in Uganda. *Forest Ecology and Management*, *307*, 206–218. https://doi.org/10.1016/j.foreco.2013.07.010.

Shankar, U. (2001). A case of high tree diversity in a sal (Shorea robusta)-dominated lowland forest of Eastern Himalaya: Floristic composition, regeneration and conservation. *Current Science*, *81*(7), 776–786. Retrieved from http://www.jstor.org/stable/24106397.

Shannon, C.E., & Weaver, W. (1963). The theory of mathematical communication. *International Business*, 131. Retrieved September 10, 2022 from https://pure.mpg.de/rest/items/item_2383164_3/component/file_2383163/content

Sharma, C.M., Suyal, S., Gairola, S., & Ghildiyal, S.K. (2009). Species richness and diversity along an altitudinal gradient in moist temperate forest of Garhwal Himalaya. *Journal of American Science*, *5*(5), 119–128.

Sharma, C.M., Mishra, A.K., Tiwari, O.P., Krishan, R., & Rana, Y.S. (2018). Regeneration patterns of tree species along an elevational gradient in the Garhwal Himalaya. *Mountain Research and Development*, *38*(3), 211–219. https://doi.org/10.1659/MRD-JOURNAL-D-15-00076.1.

Sheil, D., & Burslem, D.F.R.P. (2003). Disturbing hypotheses in tropical forests. *Trends in Ecology and Evolution*, *18*(1), 18–26. https://doi.org/10.1016/S0169-5347(02)00005-8.

Shrestha, K.B., Måren, I.E., Arneberg, E., Sah, J.P., & Vetaas, O.R. (2013). Effect of anthropogenic disturbance on plant species diversity in oak forests in Nepal, Central Himalaya. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *9*(1), 21–29. https://doi.org/10.1080/21513732.2012.749303.

Shrestha, K.K., Bhattarai, S., & Bhandari, P. (2018). *Handbook of flowering plants of Nepal (Volume 1. Gymnosperm and Angiosperms: Cycadaceae - Betulaceae)* (Vol. 1). Jodhapur, India: Scientific Publishers.

Simpson, E.H. (1949). Measurement of diversity. *Nature*, *163*(4148), 688. https://doi.org/10.1038/163688a0.

Singh, N., Tewari, A., & Shah, S. (2019). Tree regeneration pattern and size class distribution in anthropogenically disturbed sub-alpine treeline areas of Indian western Himalaya. *International Journal of Scientific and Technology Research*, *8*(8), 537–546.

Singh, S., Malik, Z.A., & Sharma, C.M. (2016). Tree species richness, diversity, and regeneration status in different oak (*Quercus* spp.) dominated forests of Garhwal Himalaya, India. *Journal of Asia-Pacific Biodiversity*, *9*(3), 293–300. https://doi.org/10.1016/j.japb.2016.06.002.

Srivastava, D.S., & Vellend, M. (2005). Biodiversity-ecosystem function research: is it relevant to conservation? *Annual Review of Ecology, Evolution, and Systematics*, *36*(1), 267–294. https://doi.org/10.1146/annurev.ecolsys.36.102003.152636.

Takafumi, H., & Hiura, T. (2009). Effects of disturbance history and environmental factors on the diversity and productivity of understory vegetation in a cool-temperate forest in Japan. *Forest Ecology and Management*, *257*(3), 843–857. https://doi.org/10.1016/j.foreco.2008.10.020.

ter Braak, C.J.F. (1986). Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology*, *67*(5), 1167–1179. https://doi.org/https://doi.org/10.2307/1938672.

Timilsina, N., Ross, M.S., & Heinen, J.T. (2007). A community analysis of sal (Shorea robusta) forests in the western Terai of Nepal. *Forest Ecology and Management*, *241*(1–3), 223–234. https://doi.org/10.1016/j.foreco.2007.01.012.

Tiwari, O.P., Sharma, C.M., Rana, Y.S., & Krishan, R. (2019). Disturbance, diversity, regeneration and composition in temperate forest of Western Himalaya, India. *Journal of Forest and Environmental Science*, *35*(1), 6–24.

Wangda, P., & Ohsawa, M. (2006). Structure and regeneration dynamics of dominant tree species along altitudinal gradient in a dry valley slopes of the Bhutan Himalaya. *Forest Ecology and Management*, *230*(1–3), 136–150. https://doi.org/10.1016/j.foreco.2006.04.027.

Watson, M.F., Akiyama, S., Ikeda, H., Pendry, C., & A., Rajbhandari, K.R., & Shrestha, K.K. (Eds.). (2011). *Flora of Nepal volume 3 (Magnoliaceae – Rosaceae)*. Edinburgh, UK: Royal Botanic Garden.

Werner, F.A. (2009). Effects of human disturbance on epiphyte assemblages in the Andes of Ecuador Florian André Werner Effects of human disturbance on epiphyte assemblages in the Andes of Ecuador Georg-August-Universität Göttingen. *Biodiversity and Ecology*, *2*(Series B), 160.

White, P.S., & Jentsch, A. (2001). *The search for generality in studies of disturbance and ecosystem dynamics*. *62*, 399–450. https://doi.org/10.1007/978-3-642-56849-7_17.

Whittaker, R.H., & Niering, W.A. (1965). Vegetation of the Santa Catalina Mountains, Arizona: A gradient analysis of the south slope. *Ecology, 46*(4), 429-452. https://doi.org/10.2307/1934875.

Whittaker, R.H. (1975). *Communities and Ecosystems*. New York: Macmillan.

Zhu, J., Mao, Z., Hu, L., & Zhang, J. (2007). Plant diversity of secondary forests in response to anthropogenic disturbance levels in montane regions of northeastern China. *Journal of Forest Research*, *12*(6), 403–416. https://doi.org/10.1007/s10310-007-0033-9.

Zhu, Z.X., Nizamani, M.M., Sahu, S.K., Kunasingam, A., & Wang, H.F. (2019). Tree abundance, richness, and phylogenetic diversity along an elevation gradient in the tropical forest of Diaoluo Mountain in Hainan, China. *Acta Oecologica*, *101*, 103481. https://doi.org/10.1016/j.actao.2019.103481.

Zimdahl, R.L. (2004). *Weed-crop competition: A review*. Oxford: Blackwell Publishing Ltd.