Trees, Forests and People 8 (2022) 100254

Contents lists available at ScienceDirect

Trees, Forests and People

journal homepage: www.sciencedirect.com/journal/trees-forests-and-people

Dwindling status of a community managed forest in the Dhauladhar mountain range of western Himalaya[☆]

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ARTICLE INFO

Keywords:
Anthropogenic disturbance
Invasion
Regeneration
Soil
Species composition

ABSTRACT

Community managed forest is one of the striking features of Himalayan forest ecosystems that not only help in their conservation but also in nurturing the well-being of adjoining communities. However, during the past few decades, human impacts have affected the sustainability of such ecosystems. Recognizing this, the present study was conducted to assess the ecological status of a community managed '*Bohal spring-shed*' forest in the foothills of Dhauladhar mountain. Stratified random sampling was conducted to collect primary data on plants. Altogether, 61 vascular plant species belonging to 33 families were reported from the area. A marked difference in the distribution of life forms (herb and shrub) was reported between the disturbed and undisturbed sites in the spring-shed forest. Diversity indices revealed that for herbs α-richness, α-diversity, and evenness was significantly higher ($p \leq 0.05$) in undisturbed site whereas for shrubs they were higher in disturbed site. However, tree diversity did not vary significantly between the sites. The percentage cover of *Ageratina adenophora* was significantly higher at the disturbed site ($p \leq 0.05$). The seedlings and saplings revealed a non-significant distribution pattern, however, girth-class distribution revealed a higher frequency of young individuals in the undisturbed site. Similarly, soil properties also varied significantly between disturbed and undisturbed sites ($p \leq 0.05$). Soil pH, bulk density, and available sodium were higher at the disturbed site while the organic matter, available nitrogen, available phosphorus, available potassium, available calcium and available magnesium were high at the undisturbed site. Total biomass and carbon content were also higher in the undisturbed site. The present study concludes that disturbance has led to changed vegetation assemblages in the present area that might affect the ecosystem services rendered by this community managed forest. Therefore, long-term monitoring of the forest is desired with a special focus on alien species.

1. Introduction

Forests represent a key terrestrial ecosystem that not only supports diversity of species but also the livelihood of local communities (Livesley et al., 2016; Thakur et al., 2020). Their degradation, therefore, impacts both the ecosystem and the dependent communities, especially in the mountains regions, which are fragile (Birch et al., 2014; Locher-Krause et al., 2017). Himalaya is no exception to this degradation process. Here the impacts of steadily disappearing forests, land-use changes, and global environmental change (Negi et al., 2019; Thakur et al., 2020) are spotted as adverse effects in the form of alien species invasion, lack of regeneration, species extermination, reduced diversity, erratic weather etc. (Pathak et al., 2019; Kunwar et al., 2020; Negi et al., 2021). Moreover, the ever-growing human population collectively with unsustainable resource use, poor management, and limited investment in conservation further contribute to their degradation and vulnerability. Therefore, in recent times, a need for sustainable forest management involving local communities has been globally put forth (Arts and Koning, 2017; Pathak et al., 2021)

Community managed forests represent a conservation initiative of high importance in the Indian Himalayan region (Germain et al., 2018; Thakur et al., 2020). They involve a quid-pro-quo relationship wherein both the local communities and the surrounding forests are benefitted (Armitage, 2005; Uniyal et al., 2020). The traditional system of forest

☆ This article is part of a special issue entitled: "Ecology of forested ecosystems in mountainous regions: patterns, processes and management implications" published at the journal Trees, Forests and People.

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https://doi.org/10.1016/j.tfp.2022.100254
Received 12 December 2021; Received in revised form 3 April 2022; Accepted 7 April 2022
Available online 9 April 2022

management has long been in practice around the world (Agarwal et al., 2017; Pathak et al., 2021). Nearly 30% of the forested landscape in developing nations is solely managed by ethnic people (Pathak et al., 2021). In Himalaya, there are historical evidences that suggest participatory management of natural resources and their sustainable use has helped in forest conservation since long back (for example Chipko Movement and Van Panchayats) (Chhetri et al., 2013; Pathak et al., 2021; Uniyal et al., 2020). "Van Panchayats" in Uttarakhand which occupy 15% of the total forested area in the state has emerged as one of the effective approaches in community forest management (Pathak et al., 2021).

Community management of forests (CFM) is noted to be an effective approach in the management of forests around the world (Arts and Koning, 2017). Such a mode of natural resource management intends to manage and restore forests through active participation of local communities in decision making that in turn ensures socioecological benefits (i.e. reduce deforestation, maintain biological diversity, supply of good and services) (Niraula et al., 2013; Moktan et al., 2016; Pandey et al., 2016) and improved living condition (Armitage, 2005; Singh et al., 2018).

Success stories of CFM are available from different parts of the world (Antinori and Bray, 2005; Agarawal et al., 2017; Anup et al., 2018). Quantitative plant inventories in the recent past have indeed noted that the community managed forests often perform better than the state managed forests in terms of both ecological diversity and resources generation (Pandey et al., 2014; Paudyal et al., 2015; Agarwal et al., 2017). However, in recent times, land-use changes, and socio-economic and policy transformations are leading to the dwindling status of even the community managed forests thereby affecting the livelihood of the dependent communities (Pandey et al., 2014; Germain et al., 2018; Negi et al., 2019).

Recognizing this, the present study was conducted in a community managed '*Bohal spring-shed'* forest in the Dhauladhar mountain range of lesser Himalaya where reports of its degradation are coming up (Uniyal et al., 2019). The forest is under pressure due to anthropogenic disruptions and also environmental changes (Agarwal et al., 2007; Joshi and Dev, 2016). Over time, the population of the nearby villages and their livestock has increased thereby pressurizing the forest resources (Joshi and Dev, 2016). Unmanaged fodder and fuelwood collection, and livestock grazing are a matter of concern. Along with, slowly but steadily, invasion by alien species in the vicinity of habitations further poses a threat to the forest flora. Therefore, as a primary goal, the study targeted assessing the current status of this forest. It addressed the following research questions: what are the indicators of disturbances, and how do disturbances affect the structure and composition of the forest. Since disturbance alters vegetation composition, we hypothesized a significant shift in plant diversity in areas that were disturbed vis-à-vis that were relatively undisturbed. Consequently, the objectives of the present study were: 1) to compare species composition and regeneration between the disturbed and undisturbed sites and 2) to assess the physicochemical properties of soil between the sites.

2. Materials and methods

2.1. Study area

The present study was conducted in the foothills of Dhauladhar mountain range in district Kangra, Himachal Pradesh (India) (Fig. 1). A community managed '*Bohal spring-shed*' forest in the Palampur tehsil (Kangra) was selected for the sampling (Fig. 2a). The forest encompasses an area of ~160 hectares and lies between 1700-2100 m altitudinal zones (Uniyal et al., 2020). This forest functions as the main recharge zone of Bohal Spring, which fulfills the drinking water needs of the downstream Palampur town. Three villages namely *Bohal, Mandai,* and *Odi* are located in its lower recharge zone and inhabited by the agro-pastoral *Gaddi* community. They depend on the forest for their daily biomass needs. Originally, the forest belonged to the village common land but now it is classified as a "Protected forest", formally under the ownership and control of the forest department (Banihal, 2010). Since the implementation of the payment for water services initiative in October 2010, the Village Forest Development Society (VFDS) is responsible for the management and conservation of this forest (GIZ, 2011).

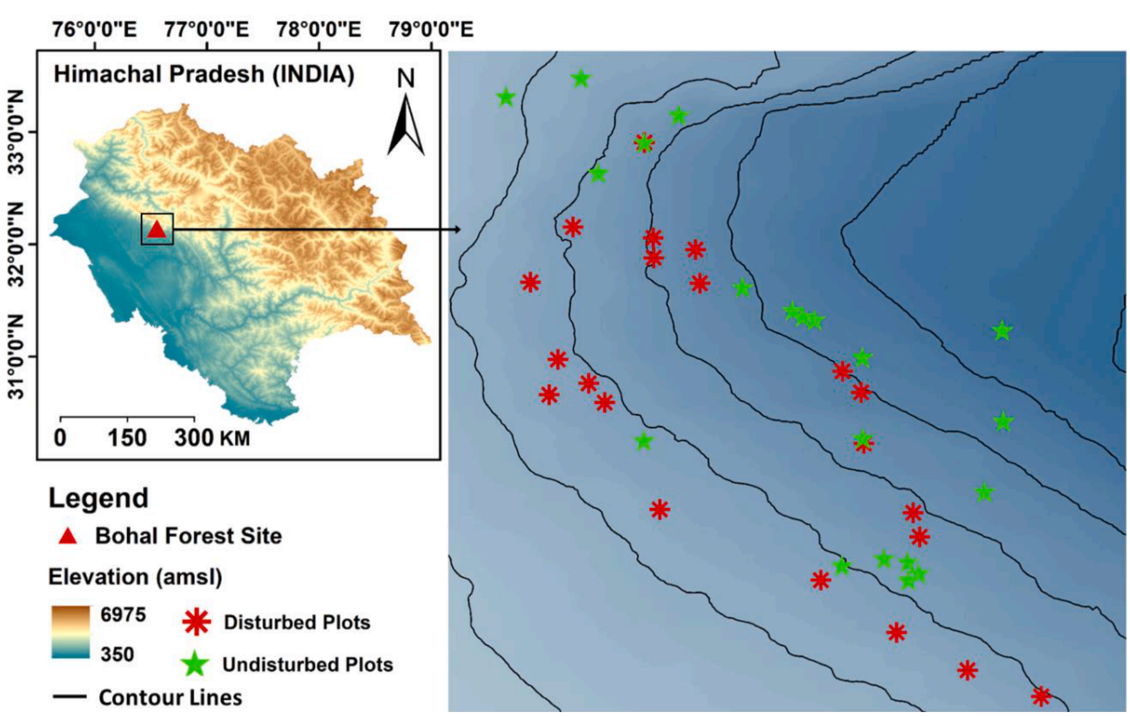

Fig. 1. Map of the study area along with the location of sampled plots.

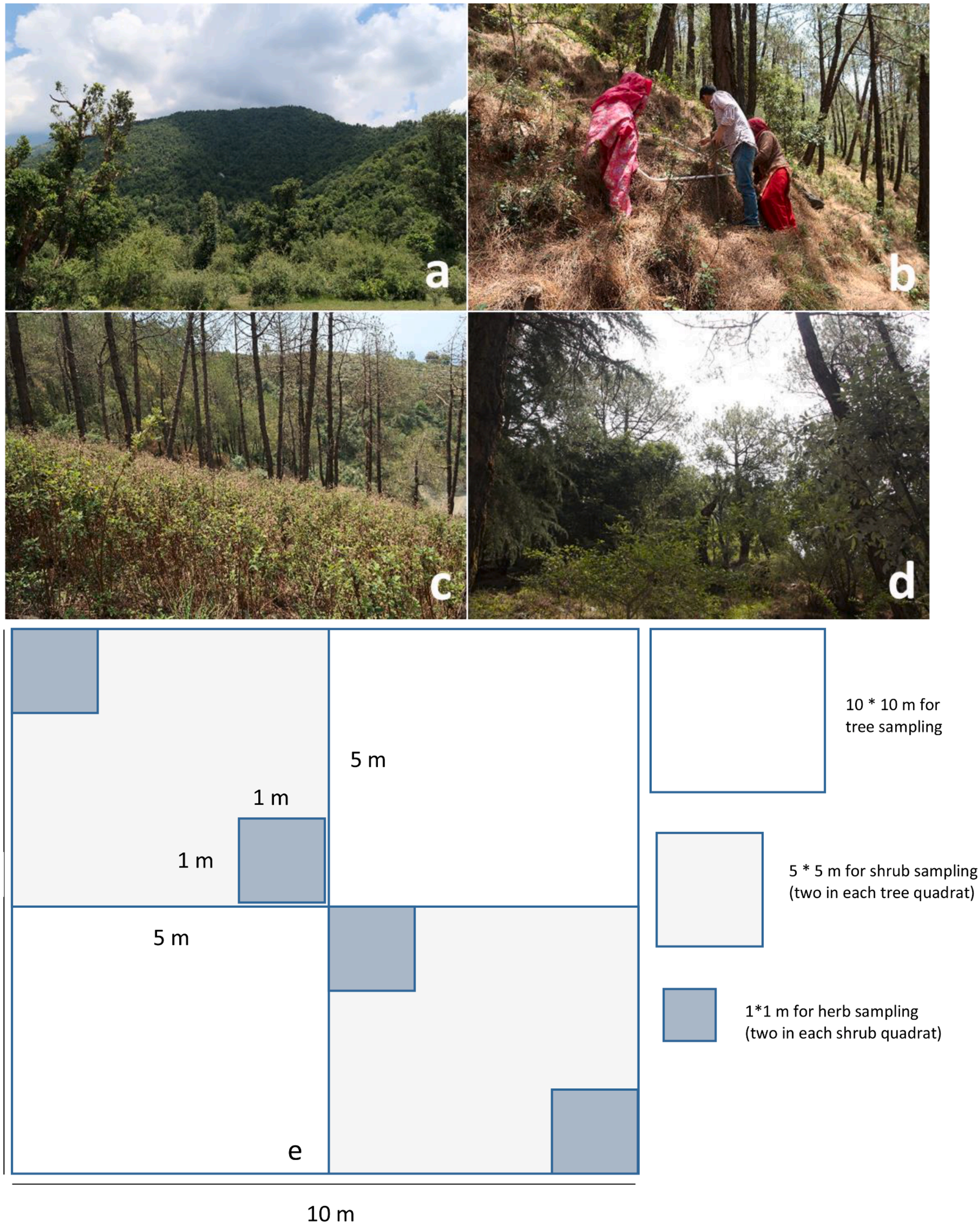

Fig. 2. Photographs clicked during field visit; a view of '*Bohal spring-shed*' forest (a), vegetation sampling (b), disturbed site (c), and undisturbed site (d), schematic representation of a plot showing quadrat sampling layout (e).

2.2. *Forest sampling*

Field surveys were carried out during the growing season in 2016 and 2017. Stratified random sampling was followed to cover all the vegetation types occurring in the area (Fig. 2b). Vegetation sampling was done using nested quadrats of 10 × 10 m (Tree), 5 × 5 m (Shrub), and 1 × 1 m (Herb) (Kunwar et al., 2020; Kumar et al., 2020).

A total of 50 plots that correspond to 350 quadrats were sampled. These include 50 quadrats for trees, 100 for shrubs, and 200 for herbs. Nested inside each tree quadrat were two shrubs quadrats, each of which in turn had two nested quadrats for herb. From each quadrat, information on plant species and their number were noted. Physiognomic attributes like tree height (*h*), and circumference at breast height (*CBH*) were recorded using meter tape. The height of tree individuals greater than 2 m was estimated visually. The percentage cover of dominant alien species was visually estimated from individual quadrats. The presence and absence of disturbance in the form of livestock dung, trails, lopping signs, alien species, and fire signs were also noted in each of the 10 × 10 m plots. Individually, each of the disturbance indicator was scored on a numerical scale of 0 and 1; where 0 represents the absence and 1 the presence of disturbance (Kumar and Shahabuddin, 2005; Cardoso et al., 2013; Sahoo et al., 2020). The values were then summed up to get a final score for each plot. Sampling plots having a score ≤2 were classified as undisturbed and those with a score ≥3 were categorized as disturbed plots. The location of each plot was recorded using a Garmin *etrex* 20x global positioning system (GPS). Further, from each of the 10 × 10 m plots, three random soil samples were collected and mixed to form a composite soil sample. Soil sampling was done at depth of 0-30 cm where majority of the root zone activities take place (Kewlani et al., 2021; Kooch et al., 2021). Altogether, 50 well labelled soil samples were collected from the area in zip lock bags. These were, later, air-dried at room temperature for the soil physiochemical analysis.

2.3. Data processing

Based on the analyses of the above information, the plots were classified as disturbed and undisturbed (Figs. 1 and 2c–e). All the plots classified as disturbed (n=22) represented the disturbed site while the others (n=28 undisturbed plots) represented the undisturbed site. For both the disturbed and undisturbed sites, vegetation parameters such as density, frequency, diversity, evenness, and species richness were calculated using standard methods (Ellenberg and Mueller-Dombois, 1974). Density refers to the number of individuals per unit area, while frequency represents the percent of quadrats in which the species occurred to the total number of quadrats sampled. Species richness refers to the total number of species present in a given site. Evenness depicts how uniformly the species are distributed while diversity represents habitat heterogeneity (Ellenberg and Mueller-Dombois, 1974). The diversity indices were calculated using the '*vegan*' package (Oksanen et al., 2020) in '*R*' [version 4.0.4] (R Core Team, 2021). Altogether, 50 plots for herbs (22 disturbed and 28 undisturbed), followed by 44 plots for shrubs (22 each for disturbed and undisturbed, shrubs were not found in some of the plots laid in grassland areas) and 40 plots for trees (20 each for disturbed and undisturbed, alike shrubs trees were also absent in the plots laid in the grassland areas and also in some of the shrub dominated plots) were analyzed for diversity indices. The plots with no tree (within shrub and grass patches) and shrub species (in grass patches and under canopy of pines) were excluded from respective diversity analyses. The equations for the same are given below:

$$\text{Evenness } (E) = \frac{'H'}{ln\ S} \tag{1}$$

where: *H'* represents Shannon diversity and the *s* represent the number of species

The value of evenness ranges from 0 to 1, a higher value of evenness indicates uniform species distribution and vice-versa.

$$\text{Shannon diversity } ('H') = -\sum_{i=1}^{s} p_i \ln p_i \tag{2}$$

where: *s* represents the number of species, p_i represents the proportion of the *ith* species and lnp_i represents the natural log of p_i. The higher the value of '*H*', more diverse the habitat, and vice-versa.

Above-ground tree biomass was calculated using the allometric equations (Singh and Singh, 1992). The total carbon density (TCD) was computed using formula (IPCC, 2000):

$$\text{Total carbon density} = \text{Biomass} \left(\frac{\text{t}}{\text{ha}}\right) \times 0.5 \tag{3}$$

Soil samples were analyzed for physio-chemical parameters like pH, bulk density (BD), organic matter (OM), available nitrogen (aN), available phosphorus (aP), available potassium (aK), available sodium (Na), available calcium (Ca) and available magnesium (Mg) using the standard protocols (Tandon, 2005).

To statistically test significant differences (significance level at $p \leq 0.05$) between the sites (e.g. diversity indices, canopy cover, and soil parameters etc.), Wilcoxon-test (Wilcoxon rank-sum test); was used (Wilcoxon, 1992). This non-parametric test by-passes the criteria of normal distribution and has been used in vegetation studies (Harris and Hardin, 2013). Whereas, ANOVA was used to compute the significant difference between tree size classes (multiple groups). All the statistical analyses and graphical representation has been done in '*R*' [version 4.0.4] (R Core Team, 2021) using the '*ggplot2*' and '*ggpubr*' packages (Wickham et al., 2021; Kassambara, 2020).

3. Results

Altogether, 61 vascular plant species were recorded from the studied forest. Of these, 36 are herbs, 15 shrubs and 10 tree species (Table 1). These plant species belong to 33 families. Amongst the families, Asteraceae and Rosaceae were the dominant ones with 8 species each, followed by Poaceae (5 species) and Fabaceae (3 species).

3.1. Species composition

Overall, the density of herbs varied from 0.02-53.27 individuals/m^2, that of shrubs between 0.05-8.05 individuals/5m^2, and those of trees between 0.05-11.50 individuals/10m^2 (Table 1). The distribution of herbs and graminoids revealed a high density of *Ageratina adenophora* (53.27 individuals/m^2) followed by *Oplismenus compositus* (16.09 individuals/m^2) at the disturbed site, whereas *Apluda mutica* (29.71 individuals/m^2) reported the highest density at the undisturbed site (Table 1). In the case of shrub species, *Berberis lycium* (3.86 individuals/5m^2) and *Cotoneaster bacillaris* (8.05 individuals/5m^2) had the highest density at the disturbed and undisturbed sites, respectively. With regard to trees, *Quercus leucotrichophora* dominated both the disturbed and undisturbed sites (4.40 and 11.50 individuals/10m^2, respectively).

Concerning species richness, a marked difference was observed (Table 2). The richness of herbs (34 species) and shrubs (13 species) was higher at the undisturbed site as compared to the disturbed site. On the other hand, tree species richness did not vary between the two sites (n=9 each in disturbed and undisturbed sites). Different indices of species diversity revealed a significant variation ($p \leq 0.05$) in the distribution of herbs and shrubs in the disturbed and undisturbed sites, except the species richness of shrubs (Fig. 3). For herbs, α-richness (species richness), α- diversity (Shannon diversity), and evenness was higher in undisturbed site whereas for shrub, the same was higher in disturbed site. No significant difference ($p \leq 0.05$) in the distribution of tree species was reported between the disturbed and undisturbed sites (Table 2).

3.2. Distribution patterns of dominant alien species

The forest was found to be heavily infested with the obnoxious weed *A. adenophora.* The distribution revealed maximum density (53.27 individuals/m^2) and frequency (86.36%) of *A. adenophora* at the disturbed site compared to the undisturbed site (13.89 individuals/m^2 and 67.86%, respectively) (Table 1). The abundance of *A. adenophora* was also higher (61.68/m^2) at the disturbed site compared to the undisturbed site (20.47/m^2). Further, the percentage cover of *A. adenophora* (disturbed site 55%, undisturbed site 25%) significantly varied ($p \leq 0.05$) between the disturbed and undisturbed sites (Fig. 4). It was observed that *A. adenophora* has influenced the distribution of native species in disturbed sites.

3.3. Regeneration potential of forest

The distribution of seedling and saplings revealed a non-significant pattern between the disturbed and undisturbed sites, while the recruitment class (trees) showed a significant difference in their distribution in the two sites ($p \leq 0.05$; Fig. 5). In general, overall seedling, sapling and tree density was higher at the undisturbed site (12727, 3240, and 1190

Table 1
Composition of herb, shrub and tree species reported in the Bohal-spring forest.

Species*	Local Name	Family*	Density (m^2)#		Frequency (%)		Abundance	
Herbs			Dstb	Undstb	Dstb	Undstb	Dstb	Undstb
Achyranthes aspera L.	Puthkanda	Amaranthaceae	0.09	0.12	4.55	3.57	2.00	3.33
Adiantum venustum D.Don	Dhumantuli	Pteridaceae	-	1.25	-	7.14	-	17.50
Ageratina adenophora (Spreng.) R.M. King & H. Rob.	Kalabasuta	Asteraceae	53.27	13.89	86.36	67.86	61.68	20.47
Aleuritopteris sp.	Nachchan	Pteridaceae	-	0.08	-	7.14	-	1.17
Anaphalis busua (Buch. -Ham.) Hand. -Mazz.	Dudhla	Asteraceae	0.03	0.04	9.09	3.57	0.33	1.00
Anaphalis triplinervis (Sims) C.B.Clarke	Khitri	Asteraceae	0.03	0.24	4.55	7.14	0.66	3.33
Apluda mutica L.	Mumri	Poaceae	8.45	29.71	68.18	92.86	12.40	32.00
Arundinella nepalensis Trin.	Kharonkhra	Poaceae	1.98	2.40	9.09	25.00	21.83	9.61
Calamintha sp.	Kapti	Lamiaceae	0.02	0.04	4.55	3.57	0.33	1.00
Cissampelos pareira L.	Angaari	Menispermaceae	-	0.74	-	17.86	-	4.13
Clematis grata Wall.	Kakrubel	Ranunculaceae	0.02	-	4.55	-	0.33	-
Cyperus niveus Retz.	Krass grass	Cyperaceae	0.76	10.75	4.55	35.71	16.66	30.10
Desmodium microphyllum (Thunb.) DC.	Jangli maah	Fabaceae	-	0.07	-	3.57	-	2.00
Dicliptera roxburghiana Nees	Jangalaru	Acanthaceae	-	0.06	-	3.57	-	1.66
Diplazium esculentum (Retz.) Sw.	Lingru	Athyriaceae	-	0.11	-	3.57	-	3.00
Echinops echinatus Roxb.	Basuara ghass	Asteraceae	-	0.36	-	3.57	-	10.00
Elatostema sessile J.R. Forst. & G. Forst.	Bangadi bel	Urticaceae	-	0.07	-	7.14	-	1.00
Eragrostis tenella (L.) P. Beauv.	Dhauli grass	Poaceae	0.02	5.36	4.55	10.71	0.33	50.00
Erianthus sp.	Khajjar	Poaceae	6.36	9.15	18.18	25.00	35.00	36.61
Fragaria indica Andrews	Ankhen	Rosaceae	-	0.14	-	3.57	-	4.00
Gerbera gossypina (Royle) Beauverd	Masela	Asteraceae	0.03	0.23	9.09	7.14	0.33	3.17
Gerbera sp.	Tuta	Asteraceae	-	0.04	-	3.57	-	1.00
Gnaphalium affine D.Don	Bhujnu	Asteraceae	0.09	0.04	4.55	3.57	2.00	1.00
Gypsophila cerastioides D.Don	Chotkali	Caryophyllaceae	0.11	0.25	4.55	3.57	2.33	7.00
Hypoxis aurea Lour.	Masreen	Hypoxidaceae	0.61	2.75	13.64	21.43	4.44	12.83
Ichnocarpus frutescens (L.) R. Br.	Belu	Apocynaceae	-	0.04	-	7.14	-	0.50
Impatiens roylei Klotzsch	Baslini	Balsaminaceae	0.30	-	4.55	-	6.66	-
Inula cappa (Buch.-Ham. ex D.Don) DC.	Durla	Asteraceae	0.02	0.04	4.55	3.57	0.33	1.00
Micromeria biflora (Buch.-Ham. ex D.Don) Benth.	Van ajwain	Lamiaceae	1.64	1.09	27.27	32.14	6.00	3.40
Oplismenus compositus (L.) P.Beauv.	Nalu	Poaceae	16.09	5.47	63.64	57.14	25.28	9.58
Origanum vulgare L.	Van Bhambri	Lamiaceae	1.11	2.01	13.64	17.86	8.11	11.26
Oxalis corniculata L.	Khatti malori	Oxalidaceae	0.32	0.04	4.55	3.57	7.00	1.00
Plumbago zeylanica L.	Chich grass	Plumbaginaceae	-	0.48	-	3.57	-	13.33
Persicaria capitata (Buch.-Ham. ex D. Don) H. Gross	Khatta amlu	Polygonaceae	1.44	0.52	22.73	10.71	6.33	4.89
Polygonum hydropiper L.	Ghaniri	Polygonaceae	-	1.57	-	14.29	-	11.00
Potentilla supina L.	Ronkda	Rosaceae	-	0.06	-	3.57	-	1.66
Shrub								
Berberis lycium Royle	Kashmal	Berberidaceae	3.86	5.27	86.36	75.00	4.47	5.52
Cotoneaster bacillaris Wall. ex Lindl.	Jhanjretu	Rosaceae	2.59	8.05	68.18	78.57	3.80	8.05
Daphne papyracea Wall. ex G.Don	Gandri	Thymelaeaceae	-	0.09	-	7.14	-	1.00
Debregeasia longifolia (Burm.f.) Wedd.	Syanru	Urticaceae	0.05	-	4.55	-	1.00	-
Hedera nepalensis K.Koch	Balakadi bel	Araliaceae	-	0.05	-	4.55	-	1.00
Hydrangea altissima Wall.	Dhullen bel	Hydrangeaceae	-	0.15	-	7.14	-	2.17
Indigofera gerardiana Graham	Kalikathi	Fabaceae	0.59	0.27	4.55	14.29	13.00	1.50
Lantana camara L.	Phulunu	Verbenaceae	0.50	-	27.27	-	1.83	-
Lonicera angustifolia Wall. ex DC.	Lot	Caprifoliaceae	0.14	0.27	9.09	3.57	1.50	6.00
Prinsepia utilis Royle	Bhikal	Rosaceae	0.36	0.23	22.73	14.29	1.60	1.25
Rosa sericea Lindl.	Gulabari	Rosaceae	0.32	0.36	22.73	25.00	1.40	1.14
Rubus ellipticus Sm.	Peeli Ankhen	Rosaceae	2.36	1.73	68.18	46.43	3.47	2.92
Sarcococca saligna (D.Don) Müll.Arg.	Nara	Buxaceae	-	0.32	-	14.29	-	1.75
Wikstroemia canescens Wall. ex Meisn.	Joldar	Thymelaeaceae	0.23	1.00	4.55	7.14	5.00	11.00
Zanthoxylum armatum DC.	Timru	Rutaceae	0.23	0.27	18.18	14.29	1.25	1.50
Tree								
Albizia julibrissin Durazz.	Kurmuru	Fabaceae	-	0.05	-	5.00	-	1.00
Cedrus deodara (Roxb. ex D.Don) G.Don	Diyar	Pinaceae	2.15	2.90	35.00	50.00	6.14	5.80
Ficus palmata Forssk.	Dhudhla	Moraceae	0.15	0.15	10.00	15.00	1.50	1.00
Lyonia ovalifolia (Wall.) Drude	Allan	Ericaceae	0.55	0.40	10.00	20.00	5.50	2.00
Pinus roxburghii Sarg.	Chil	Pinaceae	2.25	3.05	30.00	55.00	7.50	5.55
Prunus cerasoides Buch.-Ham. ex D.Don	Pajja	Rosaceae	0.20	0.05	20.00	5.00	1.00	1.00
Pyrus pashia Buch. -Ham. ex D. Don	Kainth	Rosaceae	0.95	1.15	30.00	25.00	3.17	4.60
Quercus leucotrichophora A. Camus	Ban	Fagaceae	4.40	11.50	50.00	60.00	8.80	19.17
Rhododendron arboreum Sm.	Burans	Ericaceae	3.05	2.00	40.00	40.00	7.63	5.00
Salix alba L.	Biuns	Salicaceae	0.05	-	5.00	-	1.00	-

* species name and family are based on Tropicos database (https://www.tropicos.org/home).
# Herb (1 m^2), shrub (5 m^2), and tree (10 m^2).

individuals/ha, respectively) as compared to the disturbed site (10000, 2440, and 950 individuals/ha; respectively) (Table 3). At the disturbed site, the average tree girth (CBH) was 54.86±39.34 cm whereas the same was 51.27±38.40 cm in the undisturbed site. The density distribution curve also revealed a relatively higher number of individuals in the small girth class (young trees) at the undisturbed site than at the disturbed site. Girth-class distribution reported a higher frequency of young individuals in the undisturbed site as compared to the disturbed site (Fig. 6) revealing better recruitment in the undisturbed site in near future.

Table 2
Summary of different life forms reported from the study area.

Life form/Site	Disturbed	Undisturbed
Herb	22	34
Shrub	11	13
Tree	9	9

3.4. Soil properties, total biomass, and carbon content

Overall, soil properties varied significantly between the sites (Fig. 7; p≤0.05). Soil parameters namely soil pH, bulk density (BD), available nitrogen (aN), available potassium (aK), sodium (Na), calcium (Ca) and magnesium (Mg) showed significant variations between the disturbed and undisturbed sites, whereas organic matter (OM) and available phosphorus (aP) did not vary significantly between the two sites (p≤0.05; Fig. 7). The soil pH, BD and Na reported higher values at the disturbed site, while values of OM, aN, aP, aK, Ca and Mg were higher at the undisturbed site. At the same time, total biomass and carbon content were also high at the undisturbed site compared to the disturbed site (Table 4).

4. Discussion

The present study revealed significant vegetation differences between the disturbed and undisturbed sites (Table 1 and Fig. 3). It was revealed that the species richness of herbs was higher at the undisturbed site compared to the disturbed one (Table 2). This indicates that herbaceous species are more prone to anthropogenic disturbances like grazing and trampling. It has been reported that even a small-scale disturbance in an ecosystem could lead to alteration in ground-layer vegetation like herb and shrub species (Vetaas et al., 2021; Kumar et al., 2020). The occurrence of shrubs was more at the disturbed site possibly because of the distribution of the thorny *Berberis lycium*, which escapes extraction. Likewise, Tiwari et al. (2019) have also reported a high density of herbaceous species in the less disturbed sites of Garhwal Himalaya in comparison to disturbed sites. Whereas, Mestre et al. (2017) reported that the diversity of understory vegetation (herbs) depends on the canopy layer tree composition. They reported high species diversity in the broad-leaf forests. In the present study also, *Q. leucotrichophora* dominated the undisturbed site and might, therefore, be responsible for diverse understory composition. Though, floristic diversity in an ecosystem is governed by multitudes of factors like altitudinal gradient,

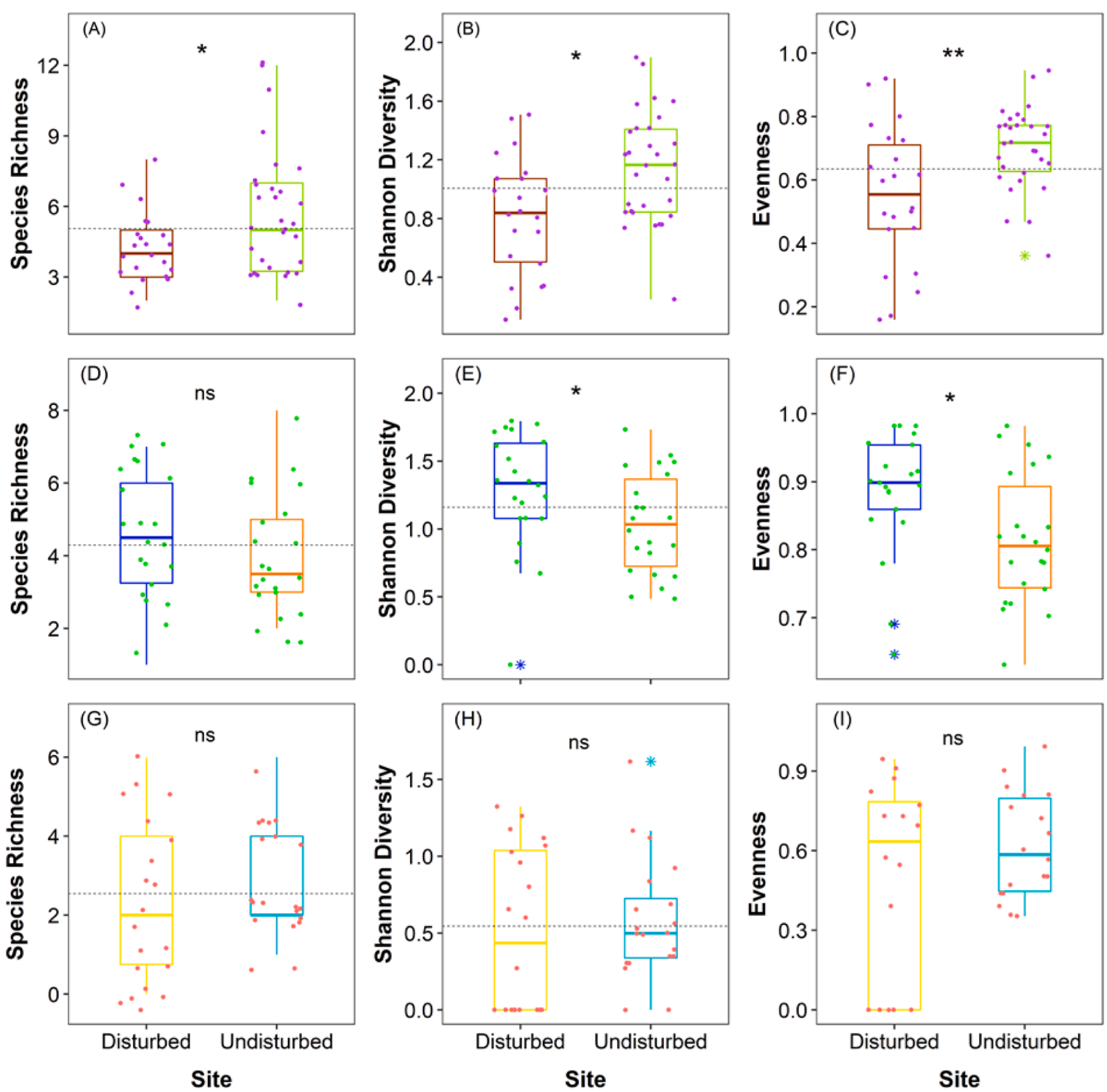

Fig. 3. Comparison of diversity indices for herb, shrub, and tree between disturbed and undisturbed sites (where; A-C for herbs [n=22, n=28], D-F for shrub [n=22 each], G-I for Tree [n=20 each] and * represents the level of significance at, * =p ≤0.05, **=p≤0.01, ns=non-significant).

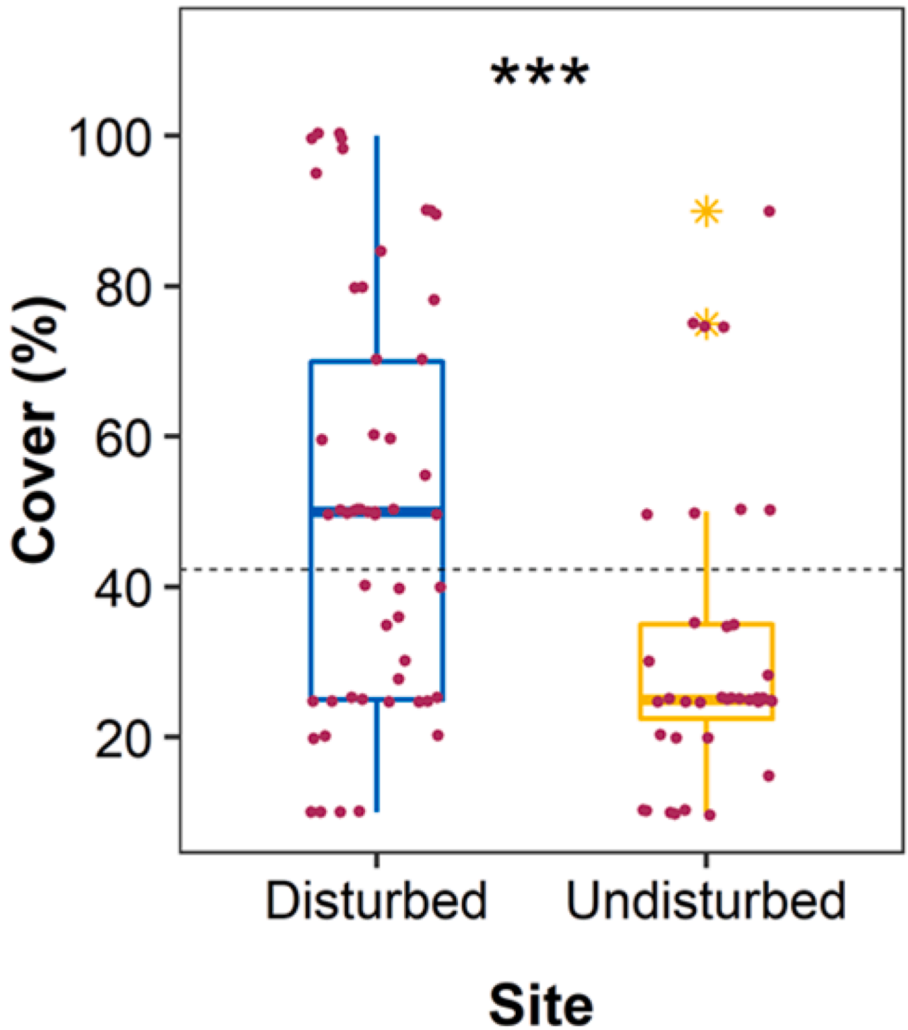

Fig. 4. Percent cover of *Ageratina adenophora* in the disturbed [*n*=53] and undisturbed [*n*=39] site (where; * represents the level of significance at, ***=p≤0.001).

topography, climate and land-use practices (Hofmeister et al., 2009; Dar and Parthasarathy, 2022), edaphic factors and human disturbances also have a role to play (Niu et al., 2007; Thakur et al., 2020). In the present study too, both the sites varied with regards to disturbance and also edaphic characteristics (Fig. 7).

Tree species richness was similar at the disturbed and undisturbed sites (9 species each). This is because; trees sustain populations for a longer time and hence immediate effects of disturbances might not be visible (Munné-Bosch, 2018; Caron et al., 2021). However, the tree density varied between both sites with the undisturbed site reporting higher tree density (Fig. 5 and Table 3). The findings of the present studies are in agreement with the results of other studies carried out in Himalaya (Borah et al., 2014; Chapagain et al., 2021). Borah et al. (2014) reported significantly higher tree density at the undisturbed sites (708.67 trees ha^{-1}) compared to disturbed sites (433.33 trees ha^{-1}) in the Assam Himalaya. In the present area, size-class distribution also suggests a lower population of younger individuals at the disturbed site when compared to the undisturbed one. Agarwal et al. (2017) have also reported similar patterns from Vidharba, eastern Maharashtra. Similalry, Chapagain et al. (2021) reported a high proportion of young individuals in buffer zone community forest in Nepal Himalaya. This implies the good regeneration potential of these forests. Caron et al. (2021) in tropical Amazon forests suggested active conservation of mature trees to circumvent retrogressive succession. The diversity of tree assemblages in a forest ecosystem is a measure of its floristic richness, available biomass and availability of natural resources for supporting the livelihood of local communities (Chapagain et al., 2021; Vetaas et al., 2021). The low population of tree individuals in the disturbed site indicates reduced socio-ecological benefits from the forest. Therefore, adequate management policies that focus on sustainable forest management, awareness creation, and plantation drives that include multipurpose species should be prioritized to rejuvenate the degraded forest areas. It has been reported that local communities are motivated to conserve forests that meet their livelihood requirements (Germain et al., 2018; Singh et al., 2018).

Also, the herb and shrub diversity varied significantly between the disturbed and undisturbed sites (Fig. 3). Diversity indices for herb reported higher values at the undisturbed site. Uniyal et al. (2010) have also reported higher species diversity of herbs in undisturbed sites from Garhwal Himalaya while Kumar et al. (2020) reported a reduction in herb species due to *Lantana camara* and *Ageratina adenophora* invasion in Uttarakhand. In our study also, *A. adenophora* reported a significantly higher cover percentage at the disturbed site as compared to the undisturbed one (Fig. 4). The heavy infestation by alien species not only affects the ecology of native species but also the livelihood of locals (Pyšek et al., 2020; Rai and Singh, 2020). Although, the population of *A. adenophora* in the present area is low when compared to some sites in Kumaon Himalaya (Negi, 2016), the emergence of this species is an indication of possible future changes in vegetation composition in the forest that might affect the overall ecosystem and services flowing from it. Joshi and Dev (2016) have also reported heavy infestation by weeds as a serious concern for forest resource management. Structural changes

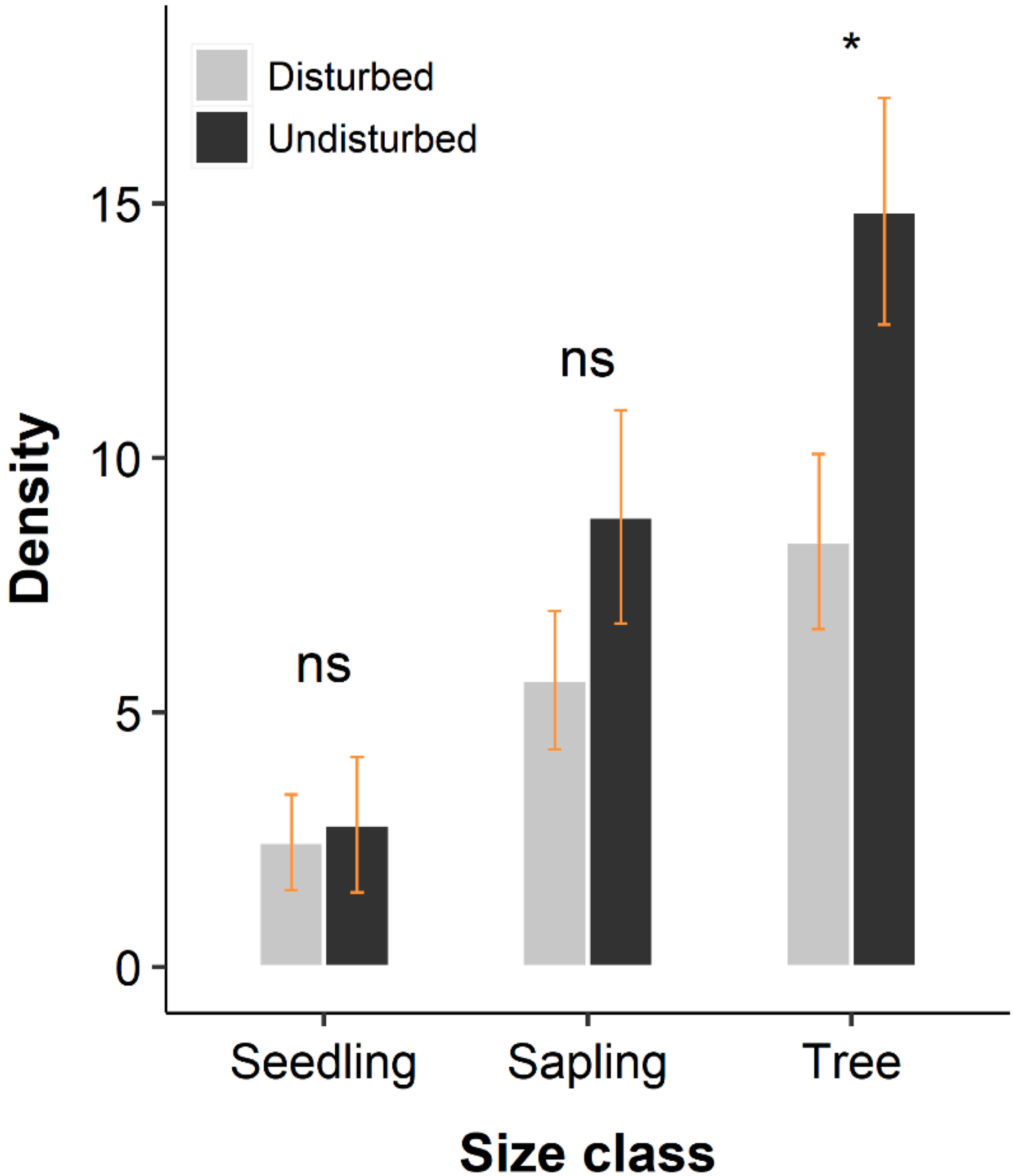

Fig. 5. Comparison of tree growth forms at disturbed [n=20] and undisturbed site [n=20] (where; * represents the level of significance at, * =p ≤0.05 and ns=non-significant).

Table 3
Density of different tree growth in the studied forest.

Growth form/Site	Disturbed	Undisturbed
Seedling/ha	10000	12727
Sapling/ha	2440	3240
Tree/ha	950	1190

in invaded plant communities typically cause a reduction in native species richness and diversity including that of faunal communities (Choudaj and Wankhade, 2021). Not only the vegetation composition but invasive species also modify the soil characteristics to suit their establishment and dominance (Dassonville et al., 2008; Pathak et al., 2019).

At the same time, diversity indices of shrub reported higher values in the disturbed site. This indicates that habitat deterioration due to anthropogenic activities like grazing, fodder and fuelwood collection may promote the spread of opportunistic shrubs. The studies by Manral et al. (2017) and Huebner (2021) have reported a higher abundance of shrubs at disturbed sites compared to the undisturbed sites. In the case of trees, their richness and diversity did not vary between the sites in the present area. This may be attributed to a ban on cutting trees in the area as per rules framed by VFDS. The study reported non-significant variations in the seedling and sapling density between the two sites (Fig. 5). However, tree density significantly varied between the disturbed and undisturbed sites. Anthropogenic disturbance (grazing, fodder and

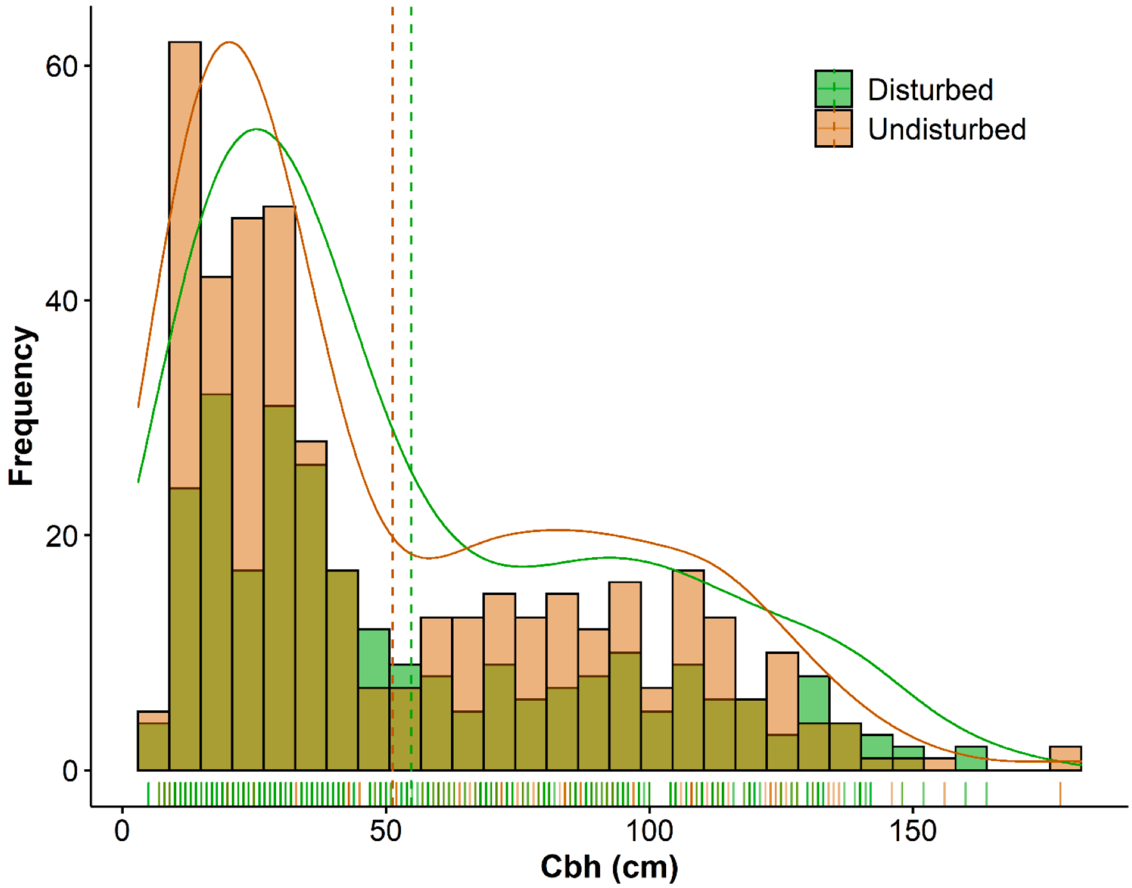

Fig. 6. Distribution of tree individual girth-class with density curve (vertical dotted line represents the mean tree girth).

fuelwood collection) may be responsible for the low seedling and sapling density at the disturbed site while there was a high frequency of juveniles at the undisturbed site. This signifies good regeneration potential at the undisturbed site which is also evident through girth class distribution (Fig. 6) and also implies a better recruitment rate at the undisturbed site. In their study in the sub-alpine forest of Tungnath (Uttrakhand), Gairola et al. (2014) also reported a high population of only adult trees at the disturbed site and attributed it to long-sustained harvesting of forest resources. This indicates that the tree population at the disturbed site might decline in near future due to the low conversion rate of saplings to tree individuals. In the present study area, high tree density in the undisturbed site contributes to higher biomass (t/ha) and subsequently to high carbon content (t/ha) compared to the disturbed site further enhancing its global value through carbon capture. Continuous human disruption and environmental changes, pose a serious threat to carbon capturing potential of community managed forests (Walker et al. 2020).

Alike vegetation characteristics, the majority of the soil parameters significantly varied between the sites (Fig. 7). High nutrient availability in the undisturbed site indicates its importance in nutrient cycling and vegetation growth whereas the low availability of nutrients at disturbed site might limit the ecosystem processes and services. The soils of disturbed site had higher bulk density and were more acidic but had low available nitrogen and poor organic matter content (Fig. 7). Niu et al. (2007) have also reported similar findings while Comole et al. (2021) reported a high concentration of available Na, Ca and Mg in alien invaded sites compared to uninvaded ones. It is pertinent to mention that in the present study area disturbed site had heavy infestation of *A. adenophora*. However, the impact and extent of alien invasion on soil nutrients varies with species and site-specific factors. For example, Dassonville et al. (2008) reported a high concentration of soil nutrients in the invaded areas compared to non-invaded areas and attributed it to the functional traits of the dominant alien species in the area. Similarly, Saggar et al. (1999), Kourtev et al. (2003), and Mandal and Joshi (2015) reported that invasive plant species can modify physical and chemical attributes of soil, including nutrient cycling, pH and soil organic matter, resulting in conditions unsuitable for the survival of the native species.

The studied community managed forest supports a multitude of ecosystem services and supports excellent carbon stock (Uniyal and Rawat, 2018a). The forest not only supplies basic provisioning services to more than 250 rural people residing in its vicinity but also forms the upper recharge zone of the Bohal spring that fulfills the drinking water needs of > 5000 downstream population of Palampur town (Uniyal and Rawat, 2018b, 2018c). The water discharge from Bohal spring was reported to be 7-8 litre per second (l/s) in 1950's which was later reduced to 1-2 l/s by the end of 2000 (Agarwal et al., 2007; Joshi and Dev, 2016). This became a serious concern for all the beneficiaries. Later, recognizing the decline in spring water discharge and the role of forests in improving it, a joint venture of the forest department and VFDS worked on forest conservation, and by 2009 the water discharge increased to 2-3 l/s (Joshi and Dev, 2016). Therefore, the dwindling status of the forest would certainly affect the flow of these services (Agarwal et al., 2007). It is thus important that scientific management of the Bohal spring-shed, especially invasive species control is prioritized.

5. Conclusions

The present study revealed altered species composition and their distribution at '*Bohal spring-shed*' forest. Similarly, soil properties also varied significantly between the disturbed and the undisturbed site ($p \leq 0.05$). The disturbed site was highly infested with *A. adenophora* which would certainly affect the distribution of native species. Lack of

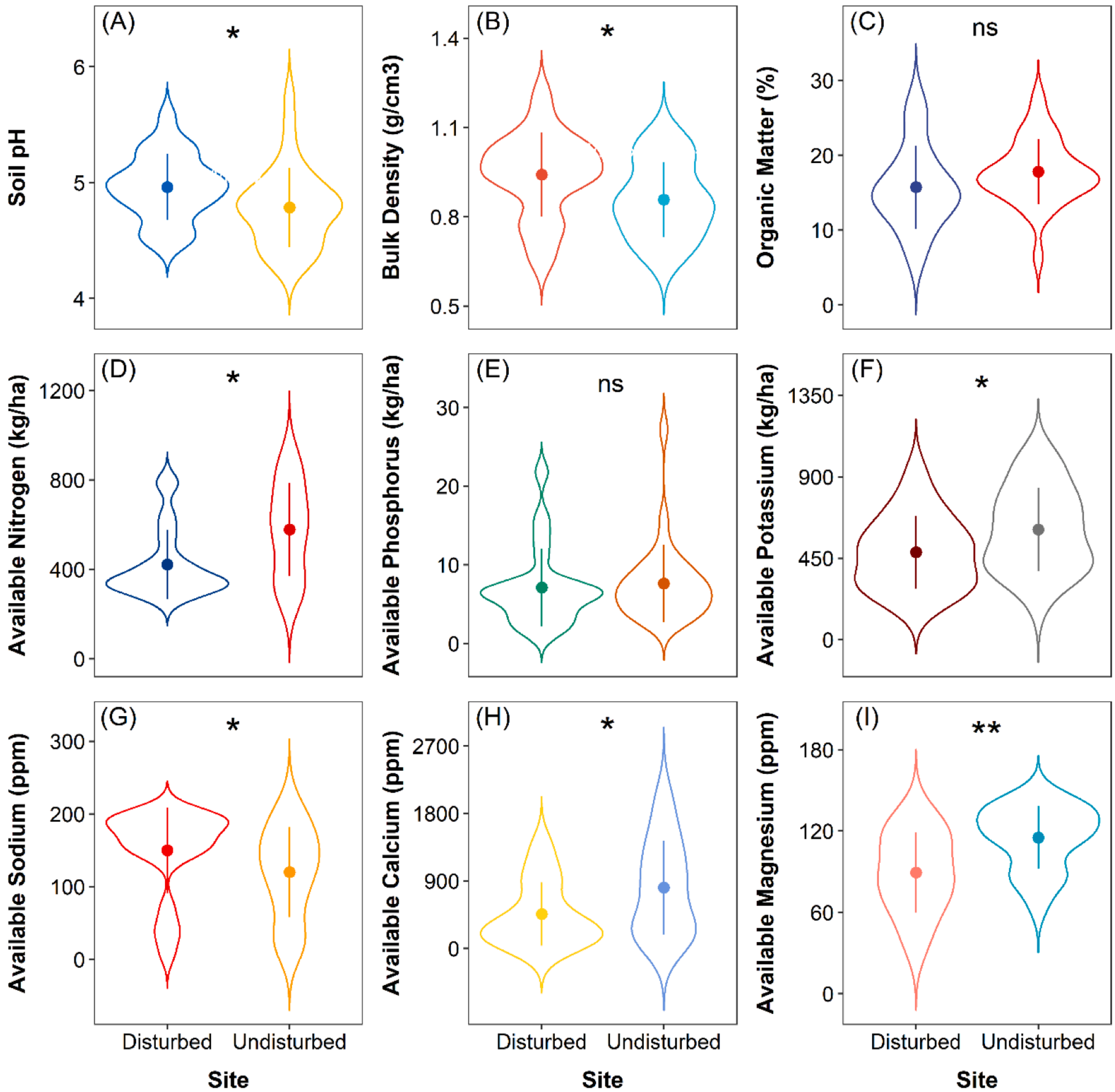

Fig. 7. Comparison of soil parameters between disturbed [n=22] and undisturbed sites [n=28] (Violin plots represents the density distribution and point range define the upper and lower limits of data from mean [where; * represents the level of significance at, * =p ≤0.05, **=p≤0.01 and ns=non-significant]).

Table 4
Estimated biomass and total carbon content (with ±standard deviations) at the studied forest.

Estimate/Site	Disturbed	Undisturbed
Biomass (t/ha)	307.54±90.74	372.60±75.48
Carbon (t/ha)	153.77±45.37	186.30±37.74

recruitment in the disturbed site and the spread of *A. adenophora* is expected to lead to an altered forest structure in due course of time. In nutshell, the disturbance has led to changed vegetation assemblages in the present area that might affect the ecosystem services rendered by this community managed forest. Moreover, the age-old quid-pro-quo relationship between stakeholders seems to be weakening and calls for immediate attention. Awareness programs focused on sustainable forest management, and community involvement in decision making should be effectively implemented. Long-term ecological monitoring of the forest with a focus on alien species should be prioritized.

CRediT authorship contribution statement

Rohit Sharma: Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft. **Anjali Uniyal:** Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Gopal S. Rawat:** Project administration, Supervision, Writing – review & editing. **Sanjay Kr Uniyal:** Conceptualization, Resources, Funding acquisition, Supervision, Writing – review & editing.

Declaration of Competing Interest

None.

Acknowledgements

We thank the Director CSIR-IHBT and the Director Wildlife Institute of India for the support and facilities. We would like to thank the Ministry of Environment, Forest and Climate Change (India) and GB Pant National Institute of Himalayan Environment for funding the study through the National Mission on Himalayan Studies. We are thankful to Forest Department (H.P) and Palampur Municipal Council for their cooperation. Thanks also due to Ms. Deepika, Ms. Medhavi and Ms. Manju for their help in various ways. Mr. Pajju ram, Mr. Daghuram, Mr. Ishwar Das, Ms. Mallika Devi and Ms. Rani from village Bohal are acknowledged for their assistance during field visits. We thank the Editor-in-Chief and the anonymous reviewers whose comments helped in improving the manuscript.

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