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Effect of anthropogenic disturbance on vegetation characteristics of sub-alpine forests in and around Valley of Flowers National Park, a world heritage site of India

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Abstract: Certain vegetation attributes of three sub-alpine forests, viz., *Betula utilis* (Birch), *Abies pindrow* (Fir) and *Acer* (Maple) mixed forest were studied along a disturbance gradient in and around the Valley of Flowers National Park in Garhwal, western Himalaya, India. The study sites in each forest were classified into non-degraded, semi-degraded and degraded plots based on the intensity of current and past anthropogenic disturbance impacts. In *B. utilis* forest, density and basal area of trees, and density of herbs and shrubs decreased with increasing disturbance. In *Acer* mixed forest, the decrease was for density and basal area of trees, and density of herbs. However, in *A. pindrow* forest, density of trees was highest in the degraded plots and total basal area peaked in the semi-degraded plots. Natural regeneration, expressed in terms of seedling and sapling density in different forest types, revealed the following pattern: (i) in *B. utilis* forest, the highest density of seedlings and saplings was in semi-degraded plots; (ii) in *A. pindrow* and *Acer* mixed forests, the density of seedlings and saplings was highest in the degraded plots. The present study indicates that the compositional attributes of sub-alpine forest communities in western Himalaya are sensitive to anthropogenic disturbances, and the effects varied amongst the forest types and life forms. While compositional attributes of the broadleaved *B. utilis* forest exhibited a greater sensitivity to disturbance than the other two forests, the coniferous *A. pindrow* forest was the most resilient.

Resumen: Algunos atributos de la vegetación de tres bosques subalpinos, a saber, bosques de *Betula utilis* (abedul), de *Abies pindrow* (abeto) y bosque mixto de *Acer* (arce), fueron estudiados a lo largo de un gradiente de disturbio en y alrededor del Parque Nacional Valley of Flowers en Garhwal, Himalaya Occidentales, India. Los sitios de estudio en cada bosque fueron clasificadoscomo parcelas no degradadas, semidegradadas y degradadas con base en la intensidad de los impactos de disturbios antropogénicos actuales y pasados. En el bosque de *B. utilis,* la densidad y el área basal de los árboles, y la densidad de las hierbas y arbustos disminuyó con el aumento de la perturbación. En el bosque mixto de *Acer* se observó una disminuciónde la densidad y el área basal de los árboles, y dela densidad de las hierbas. Sin embargo, en el bosque de *A. pindrowla* densidad de árboles fue mayor en las parcelas degradadas y el área basal total alcanzó su máximo en las parcelas semidegradadas. La regeneración natural, expresada en términos de las densidades de plántulas y plantones en diferentes tipos de bosques, reveló el siguiente patrón: (i) en el bosque de *B. utilis*, la mayor

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densidad de plántulas y plantones fue registrada en parcelas semidegradadas; (ii) en el bosque de *A. pindrow* y los bosques mixtos de *Acer*, las densidades de plántulas y plantones fueron más altas en las parcelas degradadas. El presente estudio indica que los atributos de composición de las comunidades forestales subalpinas en el oeste de los Himalaya son sensibles a los disturbios antropogénicos y que los efectos variaron entre tipos de bosque y formas de vida. Si bien los atributos de composición del bosque latifoliadode *B. utilis* mostraron una mayor sensibilidad a los disturbios que los otros dos bosques, el bosque de coníferas de *A. pindrow* fue el más resiliente.

Resumo: Alguns atributos da vegetação de três florestas subalpinas, a saber: floresta mista de *Betula utilis* (vidoeiro), *Abies pindrow* (abeto) e *Acer* (sicómoro) foram estudados ao longo de um gradiente de perturbação em e em torno do Vale do Parque Nacional das Flores em Garhwal, Himalaiaocidental, Índia. Os locais de estudo em cada floresta foram classificados em parcelas não degradadas, semi-degradadas e degradadas com base na intensidade dos impactes de perturbação antrópicaatuais e passados. Nafloresta de *B. utilis*, a densidade, a área basal das árvores e a densidade das ervas e arbustos diminuíram com o aumento de perturbação. No floresta mista de *Acer*, a redução foi na densidade, na área basal das árvores e na densidade das ervas. No entanto, na floresta de *A. pindrow*, a densidade das árvores foi maior nas parcelas degradadas e a área basal total apresentou um pico nas parcelas semi-degradadas. A regeneração natural, expressa em termos de plântulas e da densidade de plantionos diferentes tipos de floresta, revelou o seguinte padrão: (i) na floresta de *B. utilis*, a maior densidade de plântulas e plantio foi em parcelas semi-degradadas; (ii) nas florestas de A. pindrow e florestas mistas de *Acer*, a densidade de plântulas e de plantas jovens foi maior nas parcelas degradadas. Este estudo indica que os atributos de composição das comunidades florestais subalpinas nos Himalaias ocidentais são sensíveis a perturbações antrópicas e os efeitos variaram entre os tipos de florestas e formas de vida. Enquanto os atributos composicionais da floresta folhosa de *B. utilis* exibiu uma sensibilidade maior à perturbação do que as outras duas florestas, sendo a floresta de coníferas de *A. pindrowa* mais resistente.

Key words: Anthropogenic disturbance, natural regeneration, species diversity, sub-alpine forests.

Introduction

Across the world, human activities have resulted in significant changes in ecosystems. Degradation of vegetation is one of the most critical consequences of such activities (Baithalu *et al.* 2013; Devi *et al.* 2014; Dias & Melo 2010; Gunaga *et al.* 2013). Diverse disturbance factors including harvesting of fuel wood and timber have been reported to greatly influence the diversity of forest communities (Sayer & Whitmore 1991) leading to change in species composition and vegetation structure (Berkmuller *et al.* 1990; Kouki 1994). Uncontrolled grazing by domestic livestock also directly impacts the regeneration processes of forests (Kelt & Valone 1995; Saberwal 1995). In addition to anthropogenic disturbances, natural calamities, and insect and pest damages also affect the biota and ecological processes in forest ecosystems (Attiwill 1994; Frelich 2002).

Anthropogenic disturbances in the upper montane zones of many mountains of the world have been reported to alter the regeneration dynamics of both forest and alpine vegetation communities (Perez 1992; Young 1994). The disturbances have also become widespread in the upper montane zones across the Indian Himalayan region, thereby impacting both composition and functioning of high elevation natural ecosystems (Gairola *et al.* 2009; Rawal *et al.* 2012; Singh & Singh 1992). Birch (*Betula utilis*) and fir (*Abies pindrow*) forests dominate the sub-alpine areas of the western Himalaya (2800 - 3600 m a.s.l.) (Rawal & Pangtey 1994). As such, the sub-alpine forests represent a transition (ecotone) between alpine grasslands and temperate forest ecosystems. Besides functioning as a potential indicator for trends of climatic change, this ecotone is valued as a unique habitat for representative, specialized and sensitive biodiversity elements including distinct biological assemblages, native and endemic floral and faunal species, and economically important species (Dhar 2000; Rawal & Dhar 1997). However, these forests are under anthropogenic pressure resulting in rapid degradation (Dhar 2000; Rai *et al.* 2012; WII 1992). Temporal analysis of imageries revealed an upward shift of timberline vegetation in Nanda Devi Biosphere Reserve (Panigrahy *et al.* 2010) in western Himalaya. Singh (1998) opined that chronic anthropogenic disturbances in the Himalayan forests often lead to their inadequate recovery. Understanding the relationship between disturbance and vegetation structure is important as it helps in predicting the status of species diversity, competition, succession and population dynamics in plant communities (Connell 1978; Clark 1991). Although a few recent studies have highlighted the relationship between disturbance and vegetation structure in selected forest communities in the Himalayan region (Gairola *et al.* 2009; Kumar & Ram 2005; Rawal *et al.* 2012), the need of more such studies has been emphasized by many workers, particularly to find out the impacts of anthropogenic disturbances on timberline vegetation of western Himalaya (Rai *et al.* 2012). Recognizing the overall biodiversity value and change (climatic and anthropogenic) - sensitivity of sub-alpine forests, the present study was carried out to investigate the changes in structural attributes of vegetation along an anthropogenic disturbance gradient in three subalpine forests of western Himalaya.

Materials and methods

Study area

The study was conducted in and around the forested areas of the Valley of Flowers National Park (VOFNP) in Uttarakhand state of India (Fig. 1). The VOFNP (location: 30° 41' - 30° 48' N and 79° 33' - 79° 46' E), famous for its floral diversity and alpine and sub-alpine ecosystems, has been inscribed on the list of world heritage sites by UNESCO (http://whc.unesco.org/en/list/335). The climate of the area is characterized by short cool summer and long severe winter. Mean temperature and rainfall during the peak growing season (July) are 13 °C and 415 mm, respectively (Kala *et al.* 1998). Low temperature and high snow accumulation often shorten the growing season.

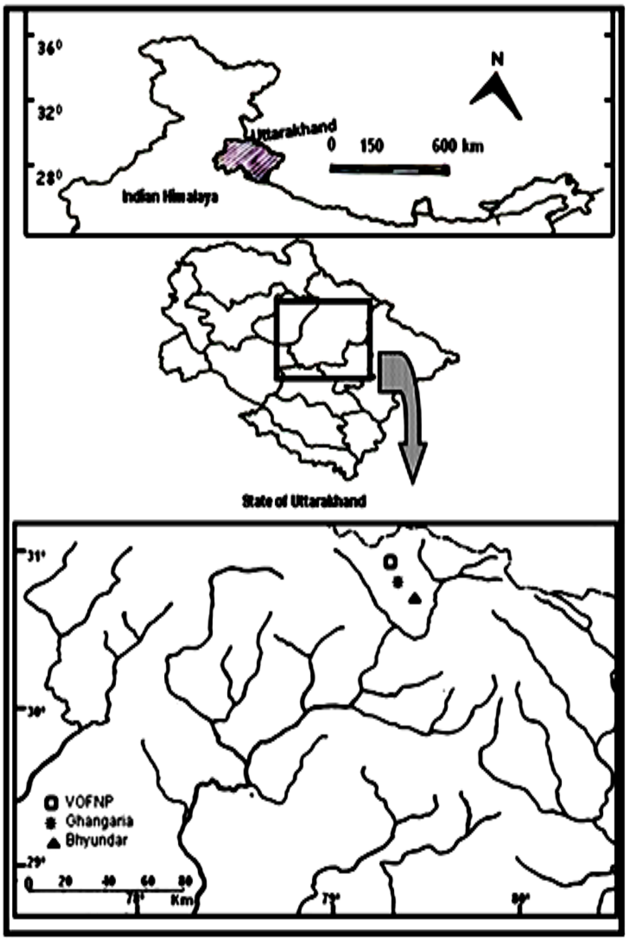

Fig. 1. Location map of the study area.

Three selected study sites viz., VOFNP (within the park representing non-degraded forest stands), Ghangaria (outside the VOFNP representing semi-degraded forest stands), and Bhyundar (outside the VOFNP representing degraded forest stands) (Table 1) with an elevation range of 2750 to 3250 m asl, had all the three forest types viz., broadleaved Birch - *Betula utilis*, coniferous Fir-*Abies pindrow*, and mixed broadleaved Maple-*Acer* mixed (Bharti *et al.* 2011; Gairola *et al.* 2009; Kala & Uniyal 1999). Area of each forest stand under each disturbance category and forest type ranged between 1.5 and 4 ha (Table 1).

Disturbance gradient

The study site selected within the VOFNP was free from any anthropogenic disturbances. The remaining two sites were subjected to grazing (including migratory grazing), felling/lopping of trees for fuel wood, timber, and fodder, and tourist activities. Lopping intensity was calculated as the

Table 1. Description of study sites and sampling locations in and around Valley of Flowers National Park.

Location (Elevation range m asl)	Approximate area (ha) under each surveyed forest	Management and disturbance attributes	Disturbance intensity (cumulative attributes)
Valley of Flowers National Park-VOFNP (3,150-3,250)	*B. utilis* - 3 ha *A. pindrow* - 1.5 ha *Acer* mixed - 1.5 ha	No human disturbance, protected since 1982; inside Valley of Flowers National Park	Non-degraded (No tree felling, No grazing, approximately 3 decades of protection)
Ghangaria (2,950 - 3,150) (outside VOFNP)	*B. utilis* - 2 ha *A. pindrow* - 4 ha *Acer* mixed - 1.5 ha	Away from habitation (> 500 m); distance from cattle camp (> 500 m); tree felling (10 %) and moderate livestock grazing; influx of tourists and pilgrims (May - October)	Semi-degraded (Tree felling/ loping intensity < 10 % , Moderate grazing, distant from habitations and cattle camp, seasonal (May - October) human interventions approximately > 50 years of disturbance history)
Bhyundar (2,750 - 2,950) (outside VOFNP)	*B. utilis* - 1.5 ha *A. pindrow* - 2 ha *Acer* mixed - 2 ha	Near habitation (< 500 m); near to cattle camp (< 500 m); tree felling (> 20 %) and high livestock grazing	Degraded (Tree felling/ loping intensity > 20 %, high grazing, nearer to habitation and cattle camp, round the year human intervention, approximately > 80 years of disturbance history)

Table 2. Vegetation characteristics of sub-alpine forests across disturbance gradients.

Forest types	Disturbance intensity	Tree density (Ind ha^{-1})	Total basal area (m^2 ha^{-1})	Seedling density (Ind ha^{-1})	Sapling density (Ind ha^{-1})	Herb density (Ind ha^{-1})	Shrub density (Ind ha^{-1})
B. utilis	Non-degraded	1208	33.45	2700	500	192667	4806
	Semi-degraded	745	35.98	6600	5833	158133	3627
	Degraded	820	17.87	1000	1966	82700	1360
LSD (< 0.05)		215	2.30	985	2408	42800	2091
F ratio		12.02***	164.66***	77.28***	11.90***	4.20**	6.37**
A. pindrow	Non-degraded	721	62.18	4567	1467	128400	2179
	Semi-degraded	534	86.75	7398	900	194800	2179
	Degraded	728	53.18	11067	5732	73467	627
LSD (< 0.05)		500	42.94	2078	1281	130500	1945
F ratio		0.71	1.49	22.36***	38.66***	1.9	1.93
Acer mixed	Non-degraded	1047	34.28	4134	1933	162267	1191
	Semi-degraded	920	20.35	5566	3400	163733	1973
	Degraded	706	30.53	5669	3800	84000	699
LSD (< 0.05)		235	12.96	3610	2386	47800	415
F ratio		4.85**	2.79*	0.568	1.54	10.8***	21.74***

Significance levels: *** for $P < 0.001$; ** for $P < 0.01$; * for $P < 0.05$ respectively.

ratio of the number of lopped trees to the total number of trees in the plots and expressed as a percentage (Gairola *et al.* 2009). In addition to primary evidences generated through reconnaissance, available past information (e.g., historical records and forest working plans) and information from local people on the study sites was used to get insights into the past disturbance history of the selected sites.

Field sampling and analysis

For vegetation sampling, three plots of size 50 x 50 m were demarcated in each forest type at the three study sites representing three disturbance levels. Thus a total of 9 plots were established. The plots were located at least 50 m apart. In each plot, five 10 × 10 m quadrats were laid randomly for enumerating tree and shrub species (45 quadrats in total). Each 10 × 10 m quadrat was further subdivided into 2 × 2 m sub-quadrats and 4 random sub-quadrats within each 10 × 10 m quadrat were used for enumerating saplings, seedlings and herbs (180 sub-quadrats in total). The sample plots were established and surveyed during the snow-free period (June - October). All individuals of each species were enumerated in the quadrats/sub-quadrats. CBH (circumference at breast height, i.e., 1.37 m above the ground) was measured for each tree. All the woody individuals having ≥ 31.5 cm CBH were considered as trees; individuals with 10.5 to 31.4 cm CBH as saplings; and those with CBH less than 10.5 cm were considered as seedlings (Ralhan *et al.* 1982). Data were analyzed for obtaining density, frequency and total basal area values (Misra 1968; Muller-Dombois & Ellenberg 1974). The density and basal area values were averaged across the plots and expressed on per hectare basis. The species diversity was calculated using the Shannon index of diversity (Shannon & Weaver 1963). Species richness was determined as the total number of species in sampled area for different life forms.

Two-way ANOVA (fixed effect model) was used to test for the difference among disturbance levels and forest types for tree density, total basal area, seedling density, sapling density, shrub density and herb density. The means were compared using Fisher's LSD test (Snedecor & Cocharan 1967). The plant identification was made using the regional floras. The specimens, difficult to identify in the field or with the help of experts, were identified by consulting the Herbaria at Botanical Survey of India, Dehradun and Botany Department, Kumaun University, Nainital, India.

Results

Density and basal area of tree component

Tree density significantly varied across the disturbance levels in broadleaved *B. utilis* forest with highest in non-degraded plots ($F_{2,\ 44} = 12.02$, $P < 0.001$) (Table 2). A similar pattern was observed in the other broadleaved forest (*Acer* mixed). On the contrary, in the coniferous forest (*A. pindrow*), tree density did not vary significantly ($F_{2,\ 44} = 0.71$ $P > 0.05$) across disturbance levels. The density was, however, maximum in degraded plots (728 individuals ha^{-1}).

Total basal area (TBA) of trees varied significantly across the disturbance levels in the broadleaved forests (Table 2). In *B. utilis* forest, mean TBA was higher in the semi-degraded plots than the non-degraded plots but declined sharply with further increase in the level of disturbance ($F_{2,\ 44} = 164.66$, $P < 0.001$). Whereas, *Acer* mixed broadleaved forest exhibited a decline in mean TBA from non-degraded to semi-degraded plots ($F_{2,\ 44} = 2.79$, $P < 0.05$). In the coniferous *A. pindrow* forest, the variation in TBA across disturbance levels was not significant.

The effect of disturbance on natural regeneration, i.e., seedling and sapling density, in different forest types revealed the following: (i) the mean density of seedling ($F_{2,\ 179,} = 77.28$, $P < 0.001$) and sapling ($F_{2,\ 179,} = 11.90$, $P < 0.001$) was significantly higher in semi-degraded plots than the degraded plots in *B. utilis* forest; (ii) degraded plots exhibited significantly higher mean density of seedling ($F_{2,\ 179,} = 22.36$, $P < 0.001$) and sapling ($F_{2,\ 179,} = 38.66$, $P < 0.001$) than the semi-degraded plots in *A. pindrow* forest; and (iii) in *Acer* mixed forest, the density of seedlings and saplings did not show any significant trend in relation to disturbance.

Density of shrub and herb components

ANOVA results showed significant differences in the shrub density across disturbance levels in broadleaved *B. utilis* and *Acer* mixed forests ($F_{2,\ 44} = 6.37$, $P < 0.01$; $F_{2,\ 44} = 21.74$, $P < 0.001$). The mean density of shrubs decreased significantly from non-degraded (4806 individuals ha^{-1}) to degraded plots (1360 individuals ha^{-1}) in *B. utilis* forest. In *Acer* mixed forest, the shrub density was highest in semi-degraded plots. In *A. pindrow* forest, however, shrub density did not show any significant trend in relation to disturbance.

The herb density significantly varied across disturbance levels in *B. utilis* forest ($F_{2,179} = 4.20$, $P < 0.01$). The non-degraded plots of broadleaved *B. utilis* forest exhibited significantly higher density (1,92,667 individual ha^{-1}; $P < 0.05$) than the degraded plots (82,700 individuals ha^{-1}). In *A. pindrow* forest, the semi-degraded plots had the highest density of herbs. In the broadleaved *Acer* mixed forest, both the non-degraded and semi-degraded plots had significantly greater mean herb density than the degraded plots ($F_{2,179} = 10.8$, $P < 0.001$).

Diversity patterns

The non-degraded plots of *B. utilis* forest supported higher herb species diversity than the semi - degraded and degraded plots. In *Acer* mixed forest, highest species richness for herbs was recorded from semi-degraded plots followed by non-degraded and degraded plots. In the non-degraded plots of *A. pindrow* forest, the herbs had highest species richness. Tree species richness and diversity were highest in the degraded plots in all the three forest types (Fig. 2 & Table 3).

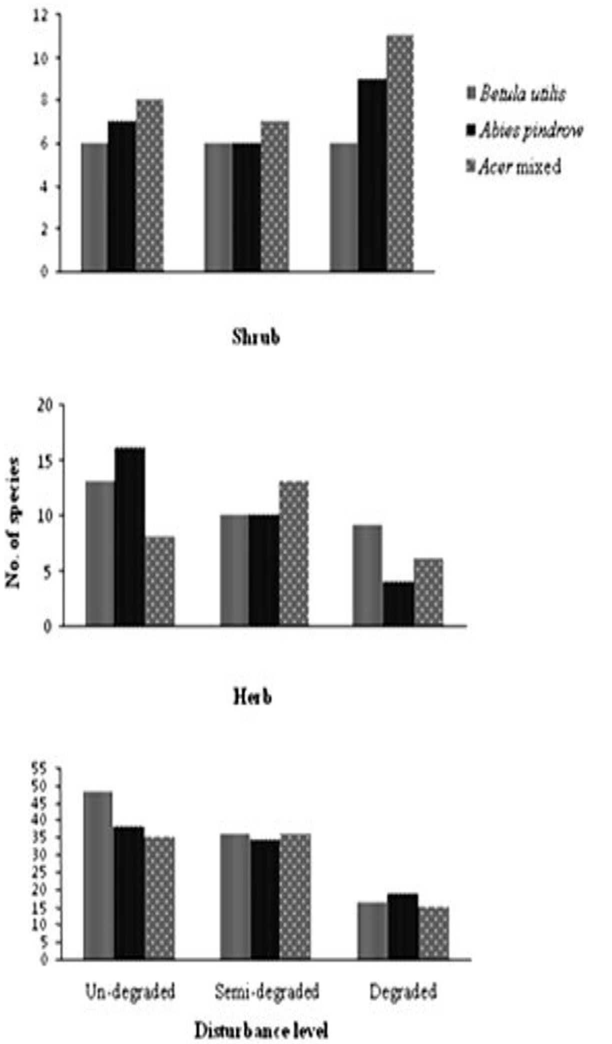

Fig. 2. Species richness of tree, shrub and herb across disturbance gradients in studied forest types.

Discussion

Evidences from different parts of the Indian Himalaya have shown that anthropogenic disturbances greatly influence the diversity and structural characteristics of forest communities in the region (Mishra *et al.* 2004; Rawal *et al.* 2012). Studies from Nepal Himalaya have revealed substantial changes in species composition and community structure of sub-alpine forest on account of human disturbances (Ghimire & Lekhak 2007). Rasingam & Parathasarathy (2009) while comparing patterns of tree species diversity and population structure across disturbance categories in Little Andaman Island reported clear differences in stand structure and species diversity among the undisturbed and disturbed sites. While considering level and frequency of disturbances vis-a-vis forest types, it is often argued that level and frequency of disturbance, and the consequent impacts on forest characteristics either remain site-specific (Htun *et al.* 2011) or forest type specific (Gairola *et al.* 2009; Rawal *et al.* 2012). The varied responses towards disturbance levels amongst the studied forest types in the sub-alpine zone of western Himalaya, therefore, follows the latter argument of forest specific effects of disturbances.

Table 3. Pattern of diversity index (H') value across disturbance gradients.

Forest types	Life form	Non-degraded	Semi-degraded	Degraded
B. utilis	Tree	0.35	0.59	1.01
	Shrub	2.10	1.93	1.69
	Herbs	3.46	3.17	3.07
A. pindrow	Trees	0.80	0.99	1.35
	Shrub	2.29	1.92	1.23
	Herbs	2.85	2.97	3.04
Acer mixed	Tree	1.36	1.22	1.67
	Shrub	1.84	2.4	1.34
	Herbs	2.47	2.73	2.56

The broadleaved forests viz., *B. utilis* and *Acer* mixed exhibited greater sensitivity in terms of tree density and basal area towards anthropogenic disturbances than the coniferous forest. Other studies from different parts of Indian Himalaya revealed that less disturbed stands of both broad leaved and coniferous forests had higher tree density and TBA than more disturbed forests (Anitha *et al.* 2009; Mishra *et al.* 2004; Nath *et al.* 2005; Uniyal *et al.* 2010). Recently, while investigating the responses of Oak (*Quercus* spp.) forests to disturbance, Rawal *et al.* (2012) also reported significant decline in tree density and total basal area in degraded sites of *Q. leucotrichophora* and *Q. semecarpifolia* forests. In *Acer* mixed forest tree density exhibited greater sensitivity to increasing level of disturbance than basal area which remained low at moderate level of disturbance (semi-degraded) indicating that reduced tree density in degraded plots might have provided optimal conditions for accumulating biomass. No significant changes in the tree density and TBA in the coniferous forest (*A. pindrow*) across disturbance levels indicate that tree stocking and biomass in this forest remained resilient to anthropogenic disturbances.

Irrespective of responses of the tree layer towards disturbance level in the studied forests, the density of shrub and herb layers invariably decreased with increasing level of disturbance. This calls for an immediate attention, especially when most of the plans and management prescriptions for the forests in the region are strongly oriented towards the dominant tree species (Rawal *et al.* 2003). Significant negative influence of human disturbance on understorey species, and sensitivity of herbs and shrub layers to increasing intensity of disturbance have been emphasized by Wassie *et al.* (2010) and Rawal *et al.* (2012).

Results of the present study indicate that the level of disturbance does not have uniform effect on natural regeneration expressed in terms of seedling and sapling density. For instance, recruitment in broadleaved *B. utilis* and coniferous *A. pindrow* forests remained sensitive to disturbance level. The recruitment in the broadleaved *Acer* mixed forest, however, remained unaffected by changing level of disturbance. Frequent but low intensity disturbance due to grazing and fuelwood collection seemed to affect forest structure and the tree species could regenerate in such degraded sites. In *B. utilis* forest, the semi-degraded condition seems to favour the natural recruitment. The increase in density of recruits in moderately disturbed forests in the region has also been reported for *Q. floribunda* and *Q. semecarpifolia* forests (Rawal *et al.* 2012). This is in consonance with the reported positive role of mild disturbance in increasing tree regeneration (Barik *et al.* 1996; Khan *et al.* 1998; Maram Kuba & Khan 1998).

This, however, did not hold good for coniferous *A. pindrow* forest which seems to have best recruitment in degraded plots. The ecological attributes of tree species including seed traits, their capacity to reproduce at an early stage and their ability to maintain high growth rates in open habitats might have contributed to high recruitments in the degraded plots. In Temperate mixed conifer forest in the Bhutan Himalaya, Darabant *et al.* (2007) reported that the growth of tree seedlings was considerably higher in grazed plots than the ungrazed plots due to increased light interception. Increase in species richness in degraded forests in the present study suggests that the increased level of canopy disturbance in sub-alpine forests helps to create favourable habitat conditions for the establishment of multiple woody species. Studies elsewhere have also concluded that moderate disturbance provides greater opportunity for species turnover, colonization and maintenance of high species richness in the forests (Mishra *et al.* 2004; Whittaker 1975).

Conclusions

This study provides strong evidences on sensitivity of sub-alpine forests to anthropogenic disturbances. The sensitivity to disturbance varied among the three forests and diverse life forms i.e., trees, shrubs, herbs. Among the three forests studied, the broadleaved *B. utilis* forest appears to be most disturbance-sensitive forest community in the sub-alpine zone of the western Himalaya. This sensitivity needs to be further understood against the perceived notion that these forests are less affected by disturbance due to their special habitats i.e., occurrence along the deep gorges (Rai *et al.* 2012). These forests should, therefore, be given special attention while defining conservation and management priorities for the sub-alpine zones of western Himalaya. The *Acer* mixed broadleaved forest with moderate changes in tree layer and no significant change in recruitment emerged as relatively resilient to disturbance. The composition of coniferous forest of *A. pindrow* broadly remains unaffected to disturbance level. However, the degraded sites of this forest supported high natural recruitment of species other than *A. pindrow,* thereby suggesting future compositional changes in such sites. Results of present study suggest that the three forest types in the region would require different management interventions while addressing the issues of disturbance related effects. The herb and shrub layers, being greatly susceptible to increasing disturbance levels, should deserve special attention of researchers and managers.

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