Research paper

Impacts of Disturbance on the Population Structure and Regeneration Status of Tree Species in a Central Himalayan Mixed-Oak Forest, India

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【Summary】

An attempt was made to study the effects of disturbance on the population structure and regeneration status of tree species in a mixed-oak forest along a disturbance gradient. Population structures were evaluated on the basis of the densities of seedlings, saplings, and trees of different size classes, while the regeneration status was determined from the population sizes of seedlings, saplings, and trees. The population structures of *Quercus leucotrichophora* A. Camus and *Q. floribunda* Lindl. showed frequent reproduction at all sites. However, tree species like *Lyonia ovalifolia* (Wall) Drude, *Acer oblongum* Wall *ex* DC. (at the undisturbed site), and *Cornus macrophylla* Wall *ex* Roxb. (at the moderately disturbed forest) were represented by single size class which indicated their accidental presence. The regeneration pattern suggested that moderate disturbance increased the densities of seedlings and saplings but reduced the tree density. A reverse J-shaped curve indicated a good regeneration status at the undisturbed site, while moderately and highly disturbed sites showed fair regeneration statuses.

Key words: disturbance, regeneration status, population structure, mixed-oak forest, Kumaun Himalaya.

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研究報告

干擾對印度中部喜瑪拉雅山Mixed-Oak森林樹種族群結構與更新狀態之影響

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摘　要

本研究是探討干擾梯度對mixed-oak森林樹種族群結構與更新狀態之影響。族群結構包含幼苗，桿材密度和不同體積大小之林木，更新狀況則取決幼苗，桿材和林木族群之數量。樹種如*Quercus leucotrichophora* A. Camus和*Q. floribunda* Lindl在所有之試驗地上出現經常性之更新，但是樹種如位在未經干擾地上之*Lyonia ovalifolia* (Wall) Drude、*Acer oblongum* Wall ex DC.和輕微干擾地上之*Cornus macrophylla* Wall *ex* Roxb. (undisturbed site)則僅出現單一大小之個體，顯示後者之出現是為偶然之情形。更新型式顯示適度的干擾增加幼苗和桿材之密度，減少林木之數量。倒J分佈形狀顯示出在未甘擾地上有良好之更新狀況，但在中度和強列干擾地上更新狀況則為普通。

關鍵詞：干擾、更新狀況、族群結構、mixed-oak森林、Kumaun Himalaya。

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INTRODUCTION

Population is a basic community component, and the population structure has a direct impact on the community structure, which in turn demonstrates the development trend of the community. Patterns of population dynamics of seedlings, saplings, and trees of a plant species can exhibit the regeneration profile which is used to determine their regeneration status/potential (Teketay 1997). Regeneration is a crucial phase of forest management, because it maintains the desired species composition and stocking and can be predicted by the structure of the population. The population structure, characterized by the presence of sufficient populations of seedlings, saplings, and young trees indicates the successful regeneration of forest species (Khan et al. 1987). Some workers have predicted the regeneration status of tree species based on the age and diameter structure of their populations (Pritts and Hancock 1983). As it is generally infeasible to trace the entire life history from birth to death of a long-lived species, there are several methods to study the regeneration status such as a dominance-diversity curve (Whittaker 1972), a density-diameter curve (Saxena and Singh 1982), and the population structure (Saxena and Singh 1984).

Various changes are appearing in the structure, density, composition, and regeneration in the Himalayan forests due to gradual biotic pressures caused by uncontrolled lopping and felling of trees for fuel, fodder, and grazing (Bargali et al. 1989, Kumar et al. 2004). These biotic pressures play an important role in forest community dynamics (Pickett and White 1985) and regulate the regenerative ability of a species. Due to biotic interference, particularly the lopping of trees, there are reductions in the vigor and rate of seed production that ultimately affect the regeneration status of trees. Physical alterations to habitats such as logging and silvicultural measures are likely to affect pollination, seed production, and seed dispersal, which may in turn change spatial patterns of plant regeneration and may also alter plant diversity (Khan et al. 1987). A thorough understanding of the dynamics of a forest can help to conserve plant diversity (Murali et al. 1996).

The present study describes the population structure and regeneration status of tree species in a mixed-oak forest experiencing varying degrees of disturbance.

MATERIAL AND METHODS

***Study area*:** The study was carried out in a mixed-oak forest located at Nainital, Kumaun Himalaya, Uttarakhand (at 29°19'~29°28'N latitude, 79°22'~79°38'E longitude and 2000~2300 m in elevation). The soil of the study area is residual, derived from dolomite, and sandstone with quartzite and silt. The climate is the monsoon type. The average annual rainfall is 2195 mm, of which 3/4 occurs during the rainy season (mid-June to mid-September). The mean monthly temperature ranges between 17.1 (January) and 26.1℃ (June), and the mean minimum temperature varies between 7.1 and -2℃. Winters are severe, and occasional snowfall occurs.

After repeated field reconnaissance, 3 sample plots were selected on the basis of the degree of disturbance (Table 1). To assess the disturbance level, a disturbance index was calculated using (i) the crown cover (%), (ii) tree density (ha^{-1}) (iii) number of cut stumps (ha^{-1}) (iv) the lopping intensity (%), and (v) the climber-affected trees (ha^{-1}) following Mishra et al. (2004). A high pressure of human activities has been reported in the forests of both disturbed sites. Lopping for fodder is one of the main practices which causes large-scale disturbance in these forests; however, other practices such as logging, browsing, and trampling also occur. The minimum and maximum values of observed disturbance were assessed, and sites were accordingly classified. The ecological niche and seed characteristics of major species present in the studied area are given in Table 2.

On the basis of the disturbance level, these plots were marked as undisturbed, moderately disturbed, and highly disturbed sites. The undisturbed site was located within the Bharat Ratna Pandit Govind Ballabh Pant High Altitude Zoo, Nainital, while the other 2 sites were situated around the Zoo (Fig. 1). At each of the 3 sites, three 1-ha permanent plots were established.

***Sampling*:** The phytosociological data of various tree species were collected by a quadrat method following Saxena and Singh (1982). The different size classes of the tree species were: trees (> 30 cm, circumference at breast height (cbh)); saplings (10~30 cm, cbh), and seedlings (< 10 cm high). Trees

Table 1. Ranges of disturbance indicators used for different disturbance categories

Disturbance indicator	Undisturbed	Moderately disturbed	Highly disturbed
Tree density (ha^{-1})	> 600	450~600	< 450
Crown cover (%)	> 60	30~59	< 30
Lopping (%)	< 10	11~60	> 61
No. of cut stumps (ha^{-1})	< 5	5~15	> 16
Climber-affected trees (ha^{-1})	< 8	8~40	> 41

Table 2. Ecological niche and seed characteristics of the reported species (Source: Troup 1921, Rao 1984, Bisht 1990, Zobel et al. 1995)

Species	Elevational range (m)	Seed fall	Seed weight (mg seed^{-1})	Moisture content (%)	Dispersal mode
Aesculus indica	1200~2700	Oct.-Nov.	7250	134.76	Gravity, mammals
Acer oblongum	1000~2200	July-Oct.	110	18.18	Wind
Cedrus deodara	1200~3000	Oct.-Nov.	3	21	Wind
Cupressus torulosa	1800~2700	Aug.-Nov.	4	25	Wind
Prunus cerasoides	600~300	Apr.-May	523	42	Birds
Lyonia ovalifolia	1200~2300	Apr.-May	22.6	14.16	Wind
Quercus floribunda	2000~2500	Aug.-Oct.	1250.0	61	Gravity, mammals, birds
Q. leucotrichophora	1800~2300	Jan.-Apr.	1463.2	39.10	Gravity, mammals, birds
Rhodondron arboreum	1500~2200	Jan.-Mar.	-	-	Wind

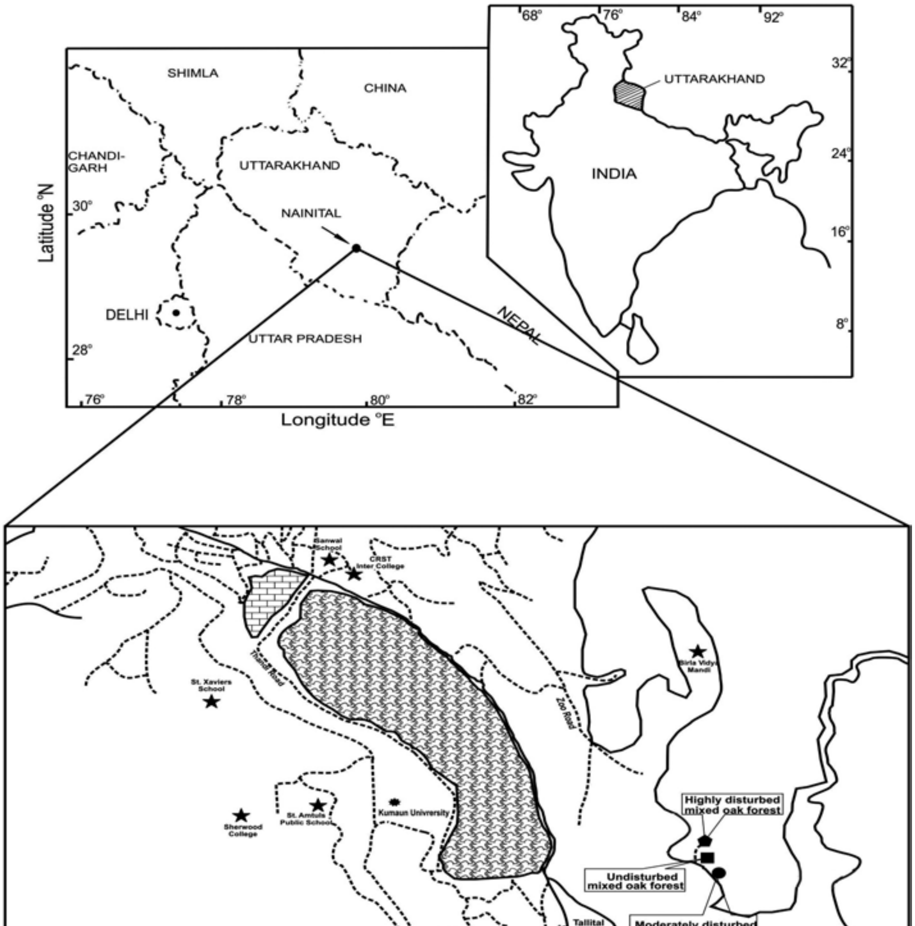

Fig. 1. Map of the study area.

and saplings were sampled using 10×10-m randomly placed quadrats (30 at each site), and for seedlings, 1×1-m quadrats were randomly placed within each 10×10-m quadrat. The phytosociological data were used to prepare the population structure which expresses the regeneration status of individual tree species (Saxena et al. 1984).

Population structure and regeneration

In order to develop the population structure and understand the regeneration of different species, the cbh of individuals was measured with a tape. On the basis of the cbh, trees were arbitrarily classified into 6 classes in addition to seedling and sapling class (Good and Good 1972):

A, seedlings < 10 cm cbh; B, saplings 10~30 cm cbh; trees, < 30 cm cbh; C, 31~60 cm cbh; D, 61~90 cm cbh; E, 91~120 cm cbh; F, 121~150 cm cbh; G, 151~180 cm cbh; and H, 181~210 cm cbh.

The relative proportions of seedlings, saplings, and trees of different size classes to the total density of tree species at each site were calculated to develop the population structure.

The regeneration status of individual tree species was determined on the basis of population sizes of seedlings, saplings, and trees (Uma Shankar 2001). Different categories of regeneration status were designated as:

a. good regeneration, if seedlings > saplings > adults;
b. fair regeneration, if seedlings > saplings ≤ adults;
c. poor regeneration, if the species survives only at the sapling stage, but no seedlings (saplings may be >, <, or = adults);
d. no regeneration, if a species is present only in the adult form; and
e. new regeneration, if the species has no adults but only seedlings or saplings.

RESULTS AND DISCUSSION

Population structure

A logarithmic plot of the number of individuals against diameter classes for the entire study area is given in Fig. 2. With an increasing size class, the number of individual rapidly decreased at first and then slowly and finally became more or less stable. The slight bulge in the middle region of the curve indicates comparatively less mortality or faster growth of trees in the intermediate size class as suggested by West et al. (1981) and Saxena and Singh (1984).

Among the sites, distributions of individuals of *Quercus floribunda*, *Q. leucotrichophora* (at all sites), *Cupressus torulosa*, and *Cedrus deodara* (at undisturbed and moderately disturbed sites) in different size classes showed a more or less reverse-J-shaped curve. Contrary to this, the population structures of *Aesculus indica*, *Acer oblongum*, *Cornus macrophylla* (at undisturbed and moderately disturbed sites), *Lyonia ovalifolia* (at the undisturbed site), and *Rhododendron arboreum* (at the highly disturbed site) showed the complete absence of seedling populations (Fig. 3A~C).

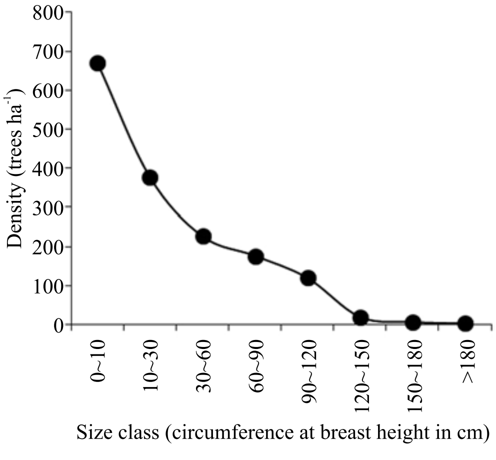

Fig. 2. Density-diameter distribution for all species in the study area.

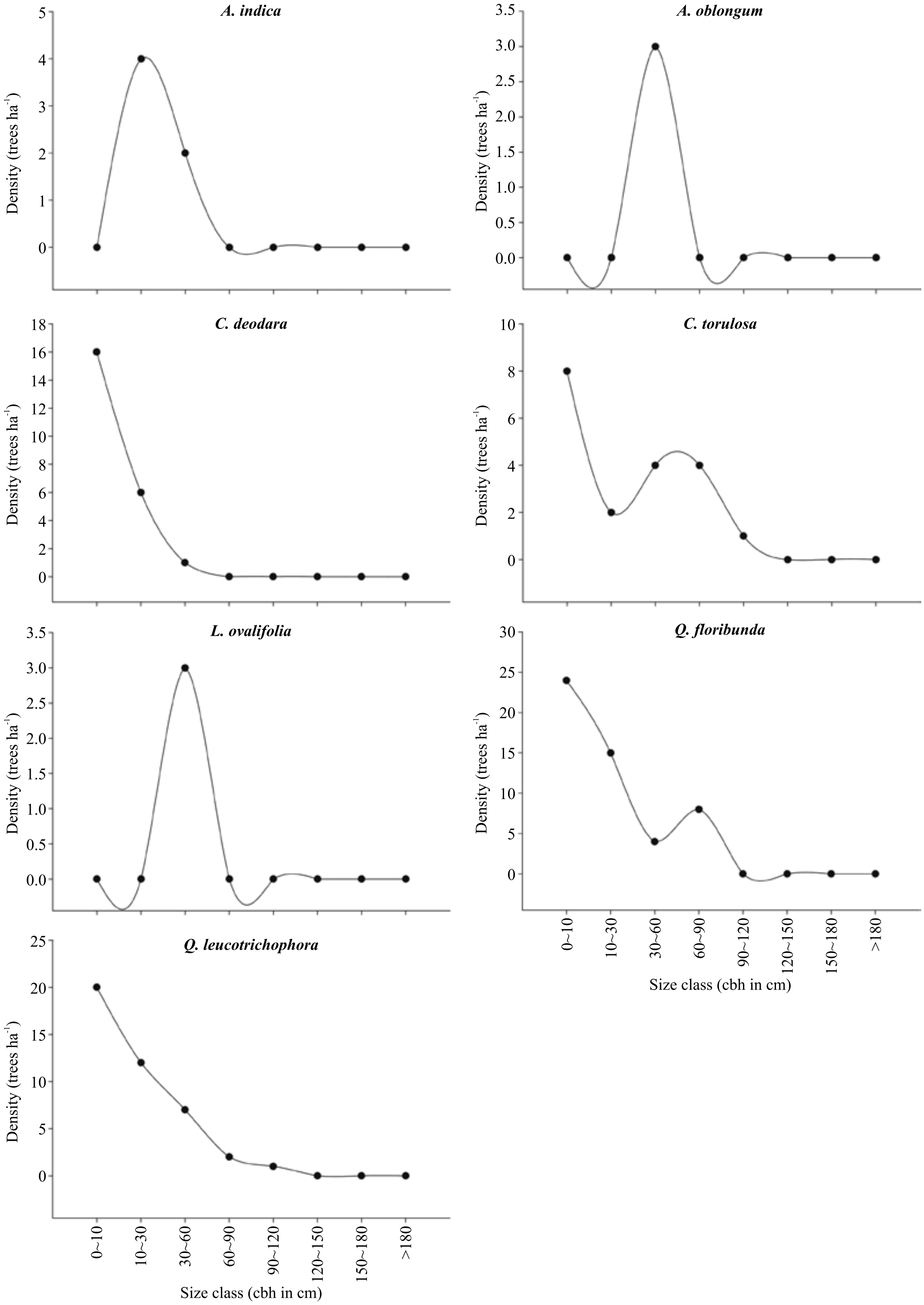

Fig. 3A. Population structures of *Aesculus indica*, *Acer oblongum*, *Cedrus deodara*, *Cupressus torulosa*, *Lyonia ovalifolia*, *Quercus floribunda*, and *Q. leucotrichophora* at the undisturbed site. cbh, circumference at breast height.

Along the disturbance gradient, according to density, the girth class distribution of the population of different tree species indicated a marked variation in the shape of the

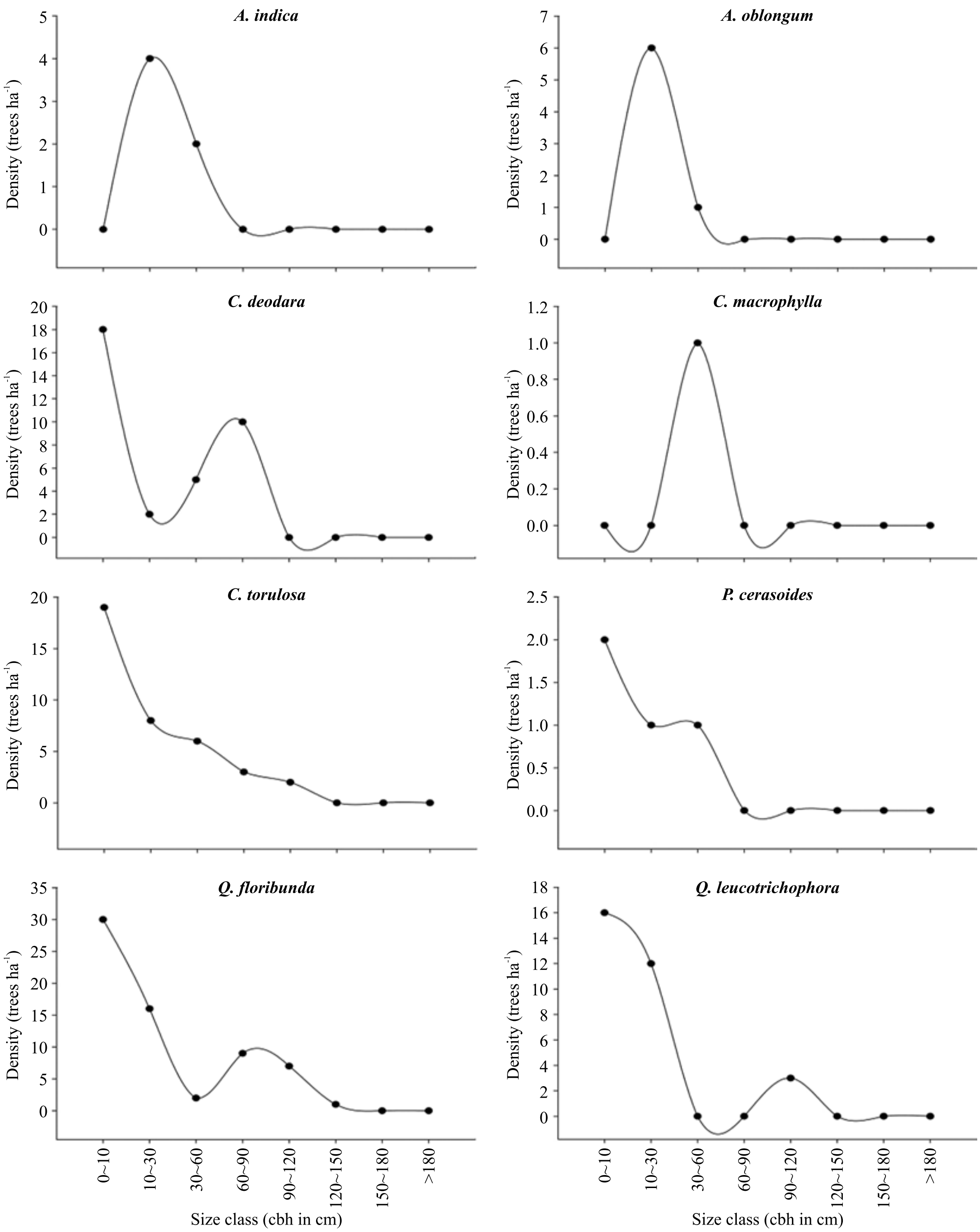

Fig. 3B. Population structures of *Aesculus indica*, *Acer oblongum*, *Cedrus deodara*, *Cornus macrophylla*, *Cupressus torulosa*, *Prunus cerasoides*, *Quercus floribunda*, and *Q. leucotrichophora* at the moderately disturbed site. cbh, circumference at breast height.

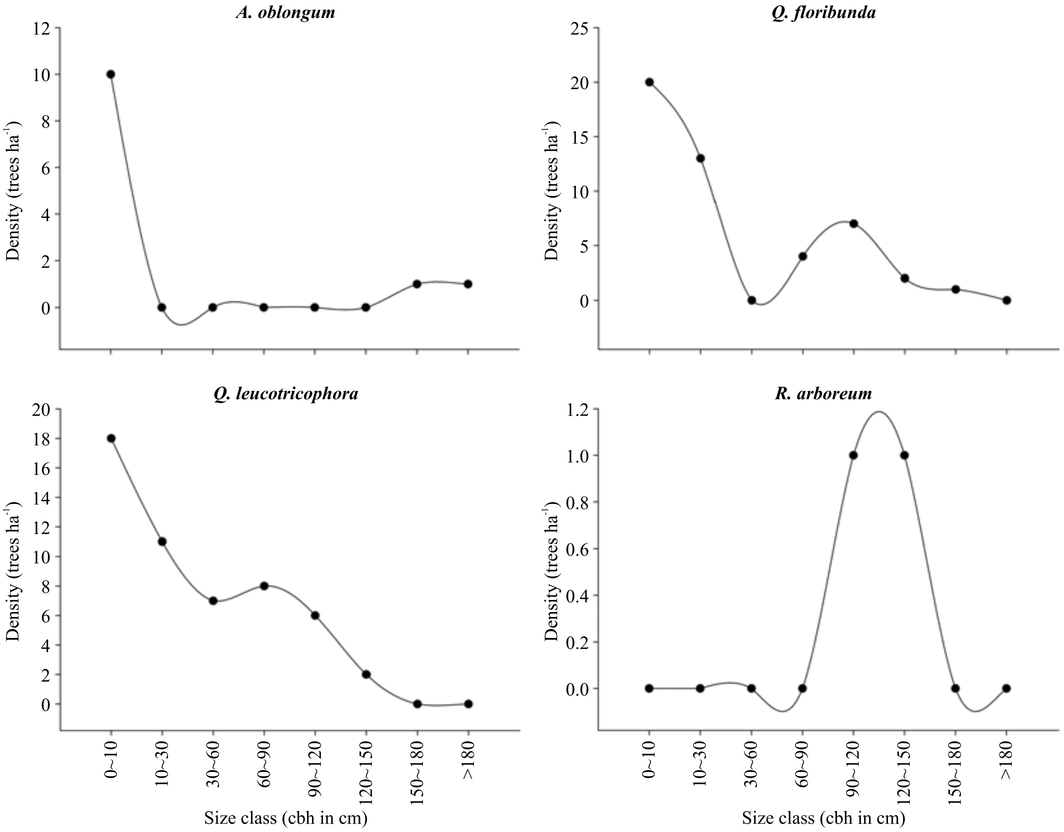

Fig. 3C. Population structures of *Acer oblongum*, *Quercus floribunda*, *Q. leucotrichophora*, and *Rhododendron arboreum* at the highly disturbed site. cbh, circumference at breast height.

population structure. Based on criteria given by Saxena and Singh (1984), the population structure of tree species of the present study may be regarded as follows.

A. The tree species *Q. leucotrichophora* and *Q. floribunda* at all sites and *Ced. deodara*, *Cup. torulosa*, and *Prunus cerasoides* in the moderately disturbed site exhibited higher proportions of individuals in the lower (younger) girth class than the large girth class. An increased number of a younger population of tree species in the population structure indicates that it has the potential for frequent reproduction (Knight 1975, Bargali et al. 1987, 2013).

B. For *Aes. indica*, *Cor. macrophylla*, and *Ac. oblongum*, more individuals (density) were in the intermediate girth class, and numbers declined towards the lower and higher size classes. This pattern of the population structure indicates infrequent reproduction according to Knight (1975). According to Benton and Werner (1976), the population is on the way to extinction if such a trend continues. In Knight's (1975) terminology, such a structure represents infrequent production.

C. There was a lower proportion of established seedlings compared to saplings (e.g., *Aes. indica* and *Cor. macrophylla* at the undisturbed site and *Aes. indica and Ac. oblongum* at the moderately disturbed site). These species can be referred to as fair reproducers, as they reproduced well in the immediate past and continue to do so at present though at a lower rate.

D. There was the absence of established seedlings (e.g., *Aes. indica*, *Ac. oblongum*, *Cor. macrophylla*, and *L. ovalifolia* at the undisturbed site, *Aes. indica*, *Ac. oblongum*, and *Cor. macrophylla* at the moderately disturbed site, and *R. arboreum* at the highly disturbed site). These species reproduced well at first, but at present, their regeneration has stopped.

E. Certain species (e.g., *Ac. oblongum* and *L. ovalifolia* at the undisturbed site and *Cor. macrophylla* at the moderately disturbed site) were represented by only the large girth class each, and were thus either relicts or nomads (Jhariya et al. 2012).

Regeneration status

In general, the seedling density was the highest followed by the tree and sapling densities (Fig. 4). In spite of the presence of high numbers of seedlings and trees, a low sapling population may be attributed to the adverse impacts of biotic and environmental factors prevalent during seedling growth resulting in large-scale death of seedlings/saplings. Similar observations were also reported by Shrestha (2003) for *Q. semecarpifolia* in the Himalayan region. Densities of seedling and sapling were maximum (850 and 490 sapling/ha, respectively) at the moderately disturbed site and minimum (480 and 240 sapling/ha) at the highly disturbed site. However, the tree density was highest at the undisturbed site. Increased densities of seedlings and saplings and a reduced density of trees (Fig. 4) at the moderately disturbed site indicate that moderate disturbance has had a positive impact by increasing the light intensity and temperature and reducing the competition for nutrients and water, thus allowing more seeds to germinate and survive, hence increasing the regeneration potential of species (Oshawa et al. 1986). A few species, like *Ac. oblongum.*, *L. ovalifolia*, and *Cor. macrophylla*, exhibited poor regeneration perhaps due to a low seed germination potential and problems in the establishment of seedlings in the early stages even if favourable conditions prevailed in the

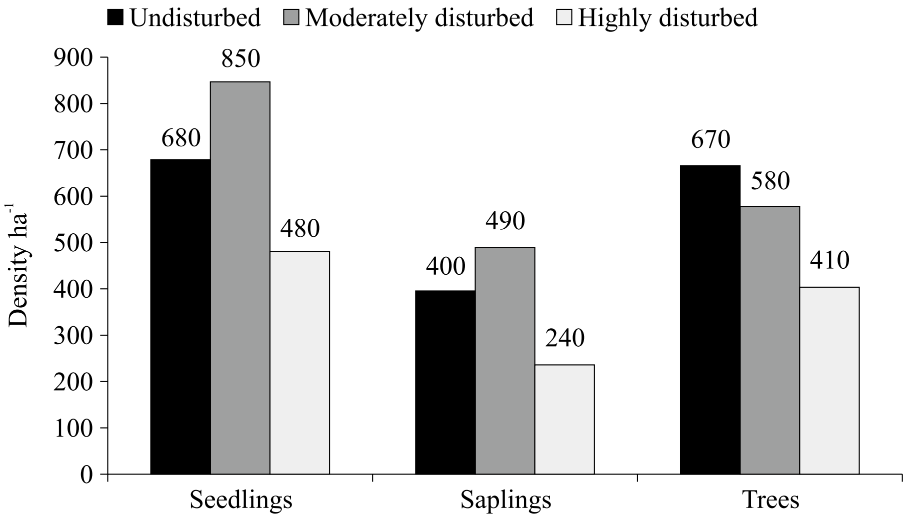

Fig. 4. Variations in densities (ha) of seedlings, saplings, and trees at the 3 study sites.

surroundings. At undisturbed sites, the density of trees was high, as the site is protected and not accessible for fuel and fodder collection. Therefore, seedlings and saplings had a chance to grow and become established.

Regardless of variations in densities of seedlings, saplings, and trees, reverse-J-shaped curves of density-diameter were the distinctive feature (Fig. 5). Shrestha (2003) and Duan et al. (2009) also reported similar curves for different forests. A reverse-J distribution is considered to be an indicator of a stable population structure with a fairly good regeneration status (Teketay 1997, Tesfaye et al. 2010). The density of individuals in the 61~90-cm diameter class (size class D) was maximum at the moderately disturbed site compared to the undisturbed and highly disturbed sites.

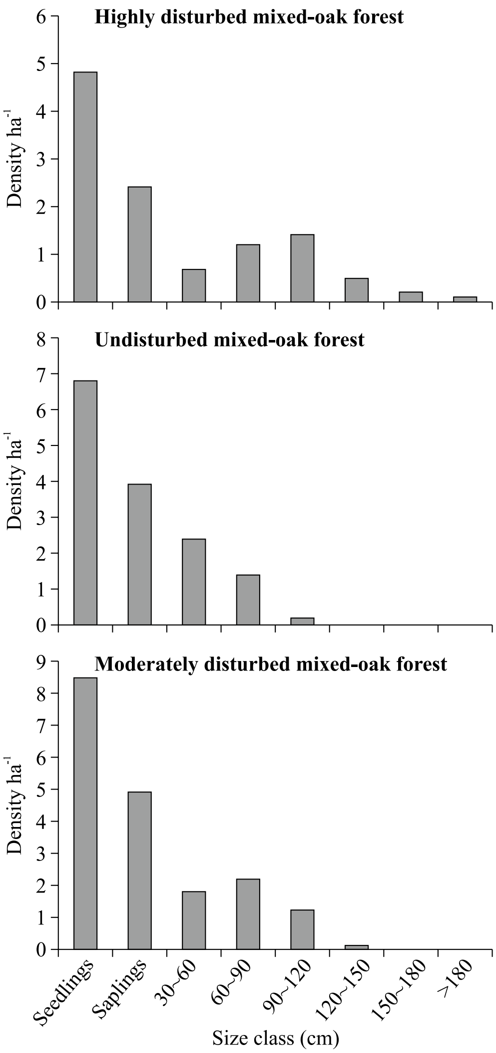

Fig. 5. Density-diameter distributions of tree species in the undisturbed, moderately disturbed, and highly disturbed sites.

Out of 8 species at the undisturbed site, 37.5% of species showed good regeneration (predominance of seedlings and saplings which contributed more to the total density of a species), 12.5% showed fair regeneration, 25% showed poor regeneration, and the remaining 25% showed no regeneration. At the moderately disturbed site out of 8 species, 12.5% showed good regeneration, 50% showed fair regeneration, 25% showed poor regeneration, while 12.5% showed no regeneration. At the highly disturbed site, out of 4 species 75% showed fair regeneration while 25% showed no regeneration (Fig. 6).

Regeneration status of individual tree species

The population structures of *Q. leucotrichophora and Q. floribunda* at all sites indicated good/fair regeneration, as shown by the presence of seedlings and saplings. These 2 species produce large-sized seeds compared to the other species (Table 2). According to Hammond and Brown (1995), large and heavier seeds produce seedlings with greater competitive ability than those of small seeds enabling them to become established and survive under various stresses such as disturbance. Saxena and Singh (1984) suggested that the numbers of seedlings and saplings per unit area can be used as an indicator of the regenerative potential of a species in the forest community. The data on the regeneration status of 2 oaks *Q. leucotrichophora* and

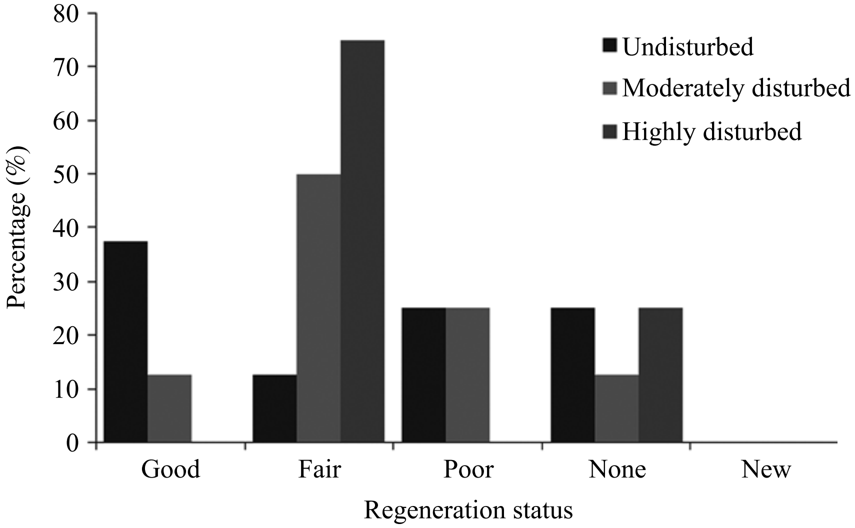

Fig. 6. Regeneration statuses of tree species in the undisturbed, moderately disturbed, and highly disturbed sites.

Q. floribunda of the present study indicated the continuous establishment of seedlings and saplings. This may have been due to the widespread dispersal of seeds (by birds and mammals feeding on them) followed by the germination and establishment of seedlings under preexisting suitable conditions of soil and moisture. The soil moisture and nutrients were greater at the undisturbed site compared to the other 2 disturbed sites (Pande et al. 2012).

Cedrus deodara and *Cup. torulosa* were fair reproducers at the undisturbed and moderately disturbed sites, and are likely to continue as companions of the respective dominants in these forests. In the highly disturbed forest, these species were totally absent. *Acer oblongum* was reproducing fairly well in the highly disturbed forest. According to Khurana et al. (2006), under extreme disturbances, species with small- and medium-sized seeds would benefit by their greater dispersal ability. Seeds of *Ac. oblongum* are winged and are produced in large numbers, therefore, they have an adaptation to facilitate dispersal because of their greater mobility and the large number of offspring they can potentially disperse. In undisturbed and moderately disturbed forests, it was reproducing well in the past, but the absence of seedlings at present indicates infrequent reproduction. *Aesculus indica*, *Cor. macrophylla*, and *L. ovalifolia* in the undisturbed and moderately disturbed forests would persist for some time as indicated by the populations of sapling and young trees, but eventually become extinct as no seedlings were present.

Possible changes in composition

At the undisturbed forest site, the dominant species, *Q. floribunda* and *Q. leucotrichophora*, will likely remain the same, but *Cup. torulosa*, a subordinate species in this forest, will likely remain for some time, but may be replaced by *Ced. deodara* in the near future. *Aesculus indica*, *Ac. oblongum*, and *Cor. macrophylla* at the undisturbed and moderately disturbed forest sites with *L. ovalifolia* in the latter forest site had no seedlings, indicating a possible change in forest composition in the future. Canopy species which may become dominant in this forest are *Q. floribunda* and *Q. leucotrichophora*. Tripathi et al. (1991) reported that oaks can regenerate and revive through their ability to produce unusually large seed crops in oak-dominated sites. In addition to this, oaks have a tremendous ability to regenerate through coppicing (Bargali et al. 2014). In the highly disturbed forest site, the complete absence of seedlings of *R. arboreum* poses a danger of the complete replacement of this species by *Ac. oblongum*. At the highly disturbed site in large openings created by the lopping of trees, *Ac. oblongum* has been able to invade the site as indicated by the presence of its seedlings. Since this site is under continuous disturbance, it seems that the population of *Ac. oblongum* is not able to grow into saplings and trees.

Quercus leucotrichophora and *Q. floribunda* are repeatedly lopped for leaf fodder and fuel (Pandey and Singh 1984). This reduces both the vigor of the plant and seed production. According to Spurr and Barnes (1980), heavy exploitation of a single species can cause the entire structure of the plant community to change. An increasing human population in this zone is also accompanied by an increase in the cattle population. Besides increasing the demand for leaf fodder, cattle heavily browse *Q. leucotrichophora* and *Q. floribunda* saplings and seedlings. Grazing and trampling by cattle also affect the soil structure by compacting it. Because of lower permeability and increased runoff, highly compact soil generally exhibits a lower moisture content. All these conditions may alter the habitat and make it less suitable for the establishment of seedlings.

In the highly disturbed site, the reduction in the number of tree species may be due to either overgrazing or the trampling of herbaceous vegetation including young seedlings and saplings of trees. Interestingly, some species like *Aes. indica*, *Cor.* macrophylla, and *P. cerasoides* had disappeared from the highly disturbed site. The disappearance of the aforesaid species may be attributed to the fact that these species may have a poor regeneration potential, and it is also likely that mature trees are felled by local people for various purposes. For *Aes. indica*, the germination of seeds was reported to be above 80% (Bargali et al. 2003), but the survival of the seedlings appeared to be low. A poor regeneration potential was a causative factor in the disappearance of a species from a site as also reported by Bentan and Werner (1976), Rao et al. (1990), and Gupta and Yadav (2005). Therefore, regeneration studies must be conducted at sites with different disturbance levels in relation to canopy gaps. Long-term study is required to understand the impacts of disturbance activities on the regenerative potential of tree species. This will help in developing proper management strategies by policy makers so that the impacts of a rise in CO_2 can be minimized by afforestation and reforestation programs.

CONCLUSIONS

To conclude, the future community structure and regeneration status of plant species can be predicted from the relative proportions of seedlings, saplings, and trees in the total population of various species in the forest. The overall population structure of tree species at the 3 study sites with varying disturbance levels showed that the contribution of seedlings was the highest to the total population followed by trees and saplings. This difference may have been due to the impacts of biotic and abiotic factors. It was found that biotic interference not only affects the regeneration status but also affects the population structures. The low proportion of saplings compared to seedlings and trees may have been due to the absence of favorable environmental factors for growth and survival and also the size of canopy gaps required for their survival in relation to the availability of light, moisture, nutrients, etc. The results of the present study point out that under continuous biotic pressure, the composition of species within this mixed-oak forest may change, and therefore, sustainable harvesting and management practices would minimize the pressure on these forests.

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