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EFFECTS OF GEOGRAPHICAL DIRECTIONS ON PHYTOSOCIOLOGICAL ATTRIBUTES AND BIOMASS AT *TAXUS* OCCURRENCE FOREST, NORTH-WESTERN HIMALAYA

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Abstract

Taxus contorta Griff. is an endangered conifer tree species. It is found in patchy habitats throughout its natural occurrences along with certain altitudinal ranges in the Himalayan region. The present study involves the stand structure, regeneration status and biomass of *Taxus* species in the Narkanda forest that occupies an area of 11.4 km^2 with an altitudinal range of 2400 m to 3000 m a.s.l. in Shimla district of Himachal Pradesh. A total of 24 square plots, each plot of area 0.16 ha, were laid in four main geographical directions (i.e., north, northeast, southwest and southeast) with equal six plots in each slope exposure. The result showed that *T. contorta* is found only in three slopes (north, northeast and southwest) exposures with the main association of *Abies pindrow* (Royle ex D.Don) Royle species. The absence of *Taxus* species occurrences slope exposure (southeast) was dominated by *Quercus semecarpifolia* Sm. Based on the results, this study documented that conservation of an endangered species should be done through silvicultural practices for its sustainable regeneration in northern slope exposure. Additionally, the adult tree of *T. contorta* must be conserved specially for pollination purposes, fertile seed production and dispersion of seeds exposing the open canopy closure through the thinning of common and dominated species. Finally, it is recommended that any kind of human disturbances should be strictly prohibited inside *Taxus* occurrence forest.

Key words: diversity, edaphic parameters, regeneration, shrub habitat.

Introductions

Taxus contorta Griff., known as west Himalayan yew, is an evergreen gymnosperm, dioecious plant with medicinal uses. It belongs to the family Taxaceae with occurrence from Afghanistan to the central part of Nepal (Poudel et al. 2013). Most species of the *Taxus* genus are endangered due to a quantitative decline in its population (>90 %) and the effects of climate change on its habitat (Thomas and Polwart 2003). It is found to have poor seed germination and slow seedlings growth (the girth increment 0.4–1.3 cm·yr^{-1} and average ring 8–12 rings·cm^{-1}) in natural habitats, which shows late growing (García et al. 2000, Linares 2013). Excessive harvesting of *T. contorta* for economical and medicinal purposes has caused substantial environmental concern for its conservation along the north-western Himalaya region (Kunwar et al. 2021, Poudeyal et al. 2021).

The local (biotic and abiotic) factors have limited the regeneration of the *T. contorta* in the Himalayan region. So far, there have been no studies related to the effects of geographical directions on its occurrence in forests that have abiotic factors to control the population of *T. contorta* in this area. However, it is suggested that the major possible threat of decline of its population is overexploitation for domestic, as well as medicinal purposes at the fragile ecosystem in the Himalaya region (Haile et al. 2021, Iqbal 2021, Perdiguero et al. 2021). Furthermore, species regeneration was reduced by birds, rodents and monkeys due to the eating of seeds along with the aril part (Onrubia et al. 2011). The growth of species seedlings under shrub canopy also facilitates the growth and establishment of this species (Kwit et al. 2004, Poudel et al. 2013). Assessment of factors, such as soil parameters, species diversity, community, regeneration status and slope exposures supports the conservation of *T*. *contorta* in the Himalayan region (Masood 2015). The present study was thus undertaken to identify the effects of main geographical directions on regeneration status, the biomass of vegetation and edaphic variables at *Taxus* occurrence hilly temperate forest in the north-western Himalayan region.

Materials and Methods

Study forest

The study was conducted in the Narkanda region of Shimla district, Himachal Pradesh. The Narkanda forest has more than 56 km^2 forest coverage but *Taxus* forest has only an area of 11.4 km^2 at co-ordinates 31.2465° – 31.2548° N and 77.4738° – 77.5344° E with an altitudinal range of 2400–3000 m a.s.l. The annual average temperature varies from -2 ℃ to 18 ℃ and annual precipitation of 1200 mm. The dominant vegetation species were *Cedrus deodara*, *Picea smithiana*, *Quercus* sp. and *T. contorta*. The soil is calcareous and siliceous along with limestone pavement slopes (5–21°). This research was carried out in the government-protected forest (the Indian Forest Act of 1927). The site is easily accessible by the local inhabitants and thus the effects of anthropogenic disturbances could be easily studied at this site. The forest management activities started in the 1950s but active management was started in the 1990s while commercial exploitation of *T. contorta*. Since 2010, the forest department strictly prohibited any kind of illegal activities in the forest as the decline of 90 % of its population was observed.

Survey design

The studies were carried out in October 2020. A total of 24 main square plots with area of 0.16 ha (40×40 m^2) each, were laid for sampling. Six plots were laid on each slope exposure with totally taken four major slope exposures that were north, northeast, southwest and southeast with considering slope length (*SL*) correction. The *SL* is corrected by formula (1):

$$SL = \frac{AL}{\cos\phi}\ , \tag{1}$$

where: *SL* is slope length, m; *AL* is the actual length i.e. 10 m of each subdivided plot and ϕ is the angle between slope line and horizontal line in 1.3 m height of the ground level of each 10 m length.

The main plot was divided into 16 equal squares with an area of 0.01 ha (10×10 m^2) for trees (adults) and the saplings layer. Inside every subplot, there was a quadrat with an area of 0.0025 ha (5×5 m^2) each for seedlings and shrub sampling. Litter biomasses were taken from 0.0625 m^2 (25×25 cm^2) from all 16 plots (Fig. 1). Therefore, a total of 3.84 ha, 0.96 ha and 6 m^2 area were sampled for saplings and adults, seedlings and shrub and litter layer sampling. The soil moisture and soil bulk density were taken from the centre of 16 subplots from the depth of 0–10 cm, 10–20 cm and 20–30 cm, respectively, by stell corer (radius = 2.04 cm) and made the composite sample for lab analysis.

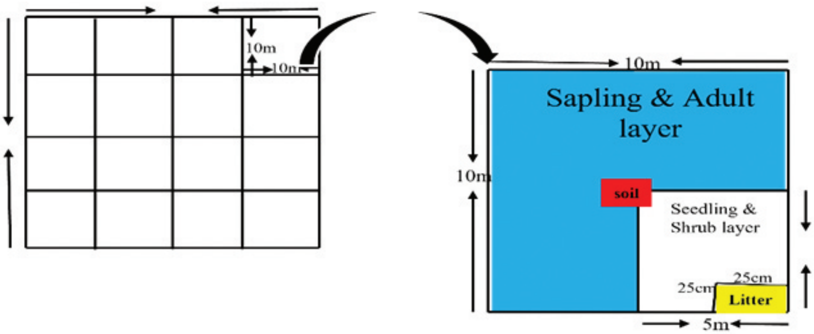

Fig. 1. A nested pattern of squares within each 40×40 m² plot.

Methods

Phytosociological attributes for tree species were calculated through given equations (2 to 9) by Sharma et al. (2018). Similarly, dominance, soil bulk density (*BD*) and soil organic carbon (*SOC*) were calculated through equations (10), (11) and (12) given by Simpson (1949), Alshammary et al. (2020), as well Walkley and Black (1934) and Yigini et al. (2017), respectively.

$$D = \frac{\text{Total number of individual of a species}}{\text{Total number of plant studies} \cdot \text{Area of each quadrat}} \cdot 10000, \quad (2)$$

$$D = \frac{\text{Total number of individual of a species in all quadrat}}{\text{Total number of individual of all species in all quadrat}} \cdot 10000, \quad (3)$$

$$F = \frac{\text{Number of quadrat in which a particular species occurs}}{\text{Total number of all quadrat}}, \quad (4)$$

$$RF = \frac{\text{Number of quadrat in which a particular species occurs}}{\text{Total number of all species in all quadrat}} \cdot 100, \quad (5)$$

$$BA = \frac{\pi \cdot DBH^2}{4}, \quad (6)$$

$$RBA = \frac{\text{Basal area of a particular species in quadrat}}{\text{Total basal area of all species in quadrat}} \cdot 100, \quad (7)$$

$$IVI = RD + RF + RBA, \tag{8}$$

$$H' = -\sum_{i=1}^{N} \frac{n_i}{N} \cdot \ln \frac{n_i}{N}, \tag{9}$$

$$C = \sum \left(\frac{n_i}{N} \right)^2, \tag{10}$$

$$BD = \frac{\text{Ovendry mass}}{\text{Core volume} - \left(\frac{\text{Mass of coarse fragments}}{\text{Density of rock fragments}} \right)}, \tag{11}$$

$$SOC_{stock} = SOC(\%) \cdot BD \cdot SD \cdot 1000, \tag{12}$$

where: D is Density; RD is Relative Density; F is Frequency; RF is Relative Frequency; BA is Basal Area, $m^2 \cdot ha^{-1}$; DBH is Diameter at Breast Height; RBA is Relative Basal Area, $m^2 \cdot ha^{-1}$; IVI is Importance Value Index; H' is Shannon wiener Diversity Index; N is the total number of all available species; n_i is total number of single species; C is Dominance; BD is Bulk Density, $gm \cdot cm^{-3}$; SOC_{stock} is Soil Organic Carbon stock in $t \cdot ha^{-1}$; $SOC(\%)$ is the SOC content percentage; SD is Soil Depth, cm.

The abundance frequency ratio (A/F) was calculated to the category of distribution pattern (DP) of species in the study forest through given equations (13) and (14). If $A/F < 0.025$, species was categorised Regular distribution pattern, if $0.025 < A/F < 0.05$, species was categorized in Random distribution pattern and if $A/F > 0.05$, species was categorised Contagious distribution pattern in community.

$$A = \frac{\text{Total no. of individual of the species}}{\text{No. of quadrate per units in which they occur}} \cdot 100, \tag{13}$$

$$\%F = \frac{\text{No. of units in which the species occurred}}{\text{Total number of all quadrat}} \cdot 100, \tag{14}$$

where: A is Abundance; $\%F$ is percentage frequency.

The fresh weight of soil samples was measured in the field then was carried out in the lab, sieved for the separating purpose of stone. Then, the samples were kept at 105 °C for 24 to 48 h up to constant weight (<0.05 g) in the hot chamber. Finally, BD was calculated depth-wise (Alshammary et al. 2020). For moisture calculation, the dry soil was weighted in the presence of the desiccators and calculated depth-wise method given by Dangal et al. (2017). The fresh weight of the litter biomass was weighted in the field then carried to the lab for heating at 75 °C for 48 h and calculations were done method given by Qin et al. (2020). The soil pH measured given method by Ghazali et al. (2020) of 0–10 cm depth. The soil organic carbon (SOC) was determined accordingly to equation (12).

Regeneration category

The seedlings, saplings and tree density regeneration pattern have given the information about regeneration category by the following formulae (Shankar 2001):

- Good regeneration (GR): when the number of seedlings > saplings > adults;
- Fair regeneration (FR): when the number of seedlings > or < saplings < adults;
- Poor regeneration (PR): when the saplings may be <, > or = adults, but no seedlings;
- No regeneration (NR): if individuals of species are present only in the adult stage;
- New regeneration or not abundant (NA): only occupy in seedlings or saplings.

Biomass and carbon storage

The growing stock volume density (*GSVD*) was estimated using volumetric equations based on the respective species (Sharma et al. 2018). These volume equations were based on basal area, DBH along with height or form factor. In few cases, volume equations for the desired species were not available. The volumes of those species were calculated as per convention by using volume equations of similar species having similar height, form, taper and growth rate. The estimated *GSVD* ($m^3 \cdot ha^{-1}$) was then converted into aboveground biomass density (*AGBD*) of tree components (stem, branches, twigs and leaves), which was calculated by multiplying *GSVD* of the forest with the appropriate biomass expansion factor (*BEF*) (Brown et al. 1999). The *BEF* ($mg \cdot m^{-3}$) is defined as the ratio of *AGBD* of all living trees at diameter at breast height (DBH) ≥ 3.34 cm to *GSVD* for all trees. The *BEF* for hardwood, spruce-fir, and pine were calculated using the following equations (Sharma et al. 2018):

- Hardwood: $BEF = \exp\{1.91 - 0.34 \cdot \ln(GSVD)\}$, for $GSVD \le 200\ m \cdot ha^{-1}$; $BEF = 1.0$, for $GSVD > 200\ m \cdot ha^{-1}$.
- Spruce-fir: $BEF = \exp\{1.77 - 0.34 \cdot \ln(GSVD)\}$, for $GSVD \le 160\ m \cdot ha^{-1}$; BEF = 1.0, for $GSVD > 16\ m \cdot ha^{-1}$.
- Pine: $BEF = 1.68$, for $GSVD < 10\ m \cdot ha^{-1}$; $BEF = 0.95$, for $GSVD$ 10–100 $m \cdot ha^{-1}$; $BEF = 0.85$, for $GSVD > 100\ m \cdot ha^{-1}$.

The below-ground biomass density (*BGBD*, fine and coarse roots) for tree species was estimated using the regression equation (15) in forest association given by Cairns et al. (1997).

$$BGBD = \exp[-1.059 + 0.884 \cdot \ln(AGBD) + 0.284] \quad (15)$$

The *AGBD* and *BGBD* were added to get the total biomass density (*TBD*, $mg \cdot ha^{-1}$). Total carbon density (*TCD*, $mg\ C \cdot ha^{-1}$) was computed using the given equation (16). The C percentage of 46 % was used for forest associations where all conifers together constituted more than 50 % of the forest composition (Negi et al. 2003).

$$TCD = TBD \cdot C,\ \% \quad (16)$$

Statistical analysis

All collected data, such as total individuals of seedling, sapling and adult, as well as carbon storage, were presented per hectare unit. Correlations between the height of the adult and CBH (cm) of girth were analyzed. Data collected in 2020, plant phytosociological attributes were subjected to analysis of variance (ANOVA) within slope exposure. The graphs were presented individual species per hectare with slope exposure. Shapiro-Wilk test was used to analyse distribution of collected data. Tukey’s HSD is used to test differences among diversity among slope exposure. The presented data represent the mean ±SD. Means were considered significantly different at $p < 0.05$.

Results and Discussion

A total of 9 species with a total number of 1176 individuals belonging to a total of 4 families were recorded from the Narkanda forest area. The results in terms of richness of trees, the density of trees, saplings, seedlings and total basal area of study forest were comparable with the KhWLS communities occurrences in the Indian Himalayan Region (Pant and Samant 2008) and similar to Gharwal forest (9–28 species) in the temperate forest, Indian Himalayan region (Rawat et al. 2021). The high richness of trees in the studied forest might be due to the suitable edaphic and climatic factors (Oommen and Shanker 2005). The plant diversity between N and NE slope exposure was found to have significant differences (df = 3, $F = 18.71$, $p = 0.004$) but not always (SW and SE, $p > 0.05$) (Table 1). This indicates that slope exposures have a certain role to play in plant diversity. Geographical direction has significant impact on herb density ($p = 0.001$). *T. contorta* was found to have 'no regeneration category' in its occurrence slope exposures. 'No regeneration category' indicated that the forest required immediate conservation activities for returning the endangered species. Some species were found to have 'new regeneration' category, while most species were found absent in the sapling stage (Table 1).

Table 1. Phytosociological variables of tree species in Narkanda Forest.

Aspect	Species	Seedling, ind.ha^{-1} (mean ±SD)	Sapling, ind.ha^{-1} (mean ±SD)	Adult, ind.ha^{-1} (mean ±SD)	*TBA*, m^2·ha^{-1} (mean ±SD)	*IVI*	*H'* (mean ±SD)
N	*Picea smithiana* (Wall.) Boiss.	162.76 ±142.8	14.5 ±4.91	3.13 ±7.65	3.68 ±5.02	4.43	
	Abies pindrow (Royle ex D.Don) Royle	240.89 ±34.92	null	104.17 ±72.3	35.39 ±25.3	201.4	
	Quercus semecarpifolia Sm.	52.08 ±27.58	null	22.92 ±40.63	6.37 ±12.26	32.25	
	Taxus contorta Griff.	null	null	23.96 ±26.64	2.87 ±1.78	44.09	0.22 ±0.21^{a}
	Aesculus indica (Wall. ex Cambess.) Hook	null	null	5.21 ±12.76	1.74 ±1.82	17.80	
	Pinus wallichiana A.B. Jacks	65.10 ±6.74	null	null			
	Quercus floribunda ex A. Campus	32.55 ±9.75	null	null			
NE	*Picea smithiana* (Wall.) Boiss.	136.72 ±20.41	12.5 ±11.91	20.833 ±28.7	5.97 ±6.09	27.23	
	Abies pindrow (Royle ex D.Don) Royle	260.42 ±80.98	null	112.5 ±44.72	29.19 ±22.6	186.2	0.46 ±0.12^{bc}
	Pinus wallichiana A.B. Jacks	45.57 ±3.81	null	1.04 ±2.55	11.76 ±28.6	1.06	
	Quercus semecarpifolia Sm.	26.04 ±1.89	null	12.5 ±17.72	2.29 ±2.12	19.27	

	Aesculus indica (Wall. Ex Cambess.) Hook	null	null	5.21 ±12.76	1.4 ±1.6	11.34	
	Taxus contorta Griff.	null	null	35.42 ±17.53	2.68 ±2.17	48.97	
	Cedrus deodara (Roxb.) G.Don	null	null	7.29 ±17.86	2.29 ±3.27	5.99	
SW	*Abies pindrow* (Royle ex D.Don) Royle	942.41 ±464.5	112.5 ±111.9	147.92 ±108.52	37.98 ±9.25	181.4	
	Quercus semecarpifolia Sm.	625 ±57.39	12.5 ±2.91	82.29 ±56.1	21.32 ±7.93	85.09	
	Picea smithiana (Wall.) Boiss.	310.33 ±04.33	null	29.167 ±59.4	7.52 ±11.21	26.66	0.32 ±0.14^{ac}
	Taxus contorta Griff.	null	null	7.29 ±10.01	1.41 ±1.55	6.84	
	Quercus floribunda ex A. Campus	45.57 ±1.68	null	null			
SE	*Quercus semecarpifolia* Sm.	943.36 ±562.2	2.5 ±2.91	337.5 ±147.4	36.72 ±3.24	200.7	
	Picea smithiana (Wall.) Boiss.	325.52 ±225.9	16.3 ±5.91	104.17 ±15.6	21.18 ±0.81	43.68	
	Pinus wallichiana A.B. Jacks	221.35 ±298.2	6.3 ±7.91	8.33 ±17.53	3.25 ±0.57	14.76	
	Quercus floribunda ex. A. Campus	45.57 ±93.80	3.3 ±4.91	2.08 ±5.10	2.65 ±0.57	2.35	0.30 ±0.09^{ac}
	Abies pindrow (Royle ex D.Don) Royle	390.63 ±33.58	null	33.33 ±75.69	3.64 ±0.17	36.92	
	Quercus dilatata A. Kein	null	null	8.33 ±2.55	2.1 ±0.81	1.60	
	Cedrus deodara (Roxb.) G.Don	6.51 ±15.95	null	null			

Note: Along the column, different superscript letters indicate significant differences ($p < 0.05$) between geographical directions. Abbreviation: *TBA* is Total Basal Area; *IVI* is Importance Value Index; *H'* is Shannon diversity index.

The spatial distributions of plant species were concentrated in the lower classes of girth, most species concentrated in higher classes in the study site. For example, an endangered species – *T. contorta* was found to have 'no regeneration' or lack of individuals in the lower DBH classes, which may be due to disturbance activities affecting its regeneration (Shankar 2001, Chave et al. 2005, Iqbal et al. 2020, Ghanbari et al. 2021). *Picea smithiana* showed fair regeneration (i.e., number of seedlings > or < saplings < adults) at the northern slope exposure, while *Quercus* spp. and *Abies pindrow* (i.e., number of seedlings > saplings > adults) were described with good regeneration category in southern slope exposure (Table 2). The effects of the regeneration category in between slope exposures have consequences in establishing different community and environmental conditions and sustainability. The DBH and height class distribution relations showed that most species are absent in lower size class, thus should be prioritized for conservation (Molino and Sabatier 2000).

Table 2. Distribution pattern of species in Narkanda forest.

Aspect	Species	Dominance	Richness	Shrubs, ind.ha^{-1}	Herbs, ind.ha^{-1}	*A/F*	RC	DP
N	*Picea smithiana*	0.64 ±0.32^{a}	7	2571.7 ±1839.1^{a}	1649.9 ±1453.2^{a}	0.02	GR	Regular
	Abies pindrow					0.04	FR	Random
	Quercus semecarpifolia					0.01	FR	Regular
	Taxus contorta					0.08	NR	Random
	Aesculus indica					0.13	NR	Contagious
	Pinus wallichiana						NA	
	Quercus floribunda						NA	
NE	*Picea smithiana*	0.44 ±0.14^{a}	7	8668.5 ±7655.6^{ab}	49.28 ±40.714^{bd}	0.09	FR	Contagious
	Abies pindrow					0.04	FR	Random
	Pinus wallichiana					0.03	FR	Random
	Quercus semecarpifolia					0.06	FR	Contagious
	Aesculus indica					0.01	NR	Regular
	Taxus contorta					0.06	NR	Contagious
	Cedrus deodara					0.02	NR	Regular
SW	*Abies pindrow*	0.57 ±0.21^{a}	5	5087.1 ±3990.8^{a}	218.41 ±149.29^{cd}	0.07	FR	Contagious
	Quercus semecarpifolia					0.03	FR	Random
	Picea smithian					0.03	FR	Random
	Taxus contorta					0.04	NR	Random
	Quercus floribunda						NA	
SE	*Quercus semecarpifolia*	0.59 ±0.14^{a}	7	326.9 ±187.6^{ac}	266.68 ±126.69^{ad}	0.06	FR	Contagious
	Picea smithiana					0.03	FR	Random
	Pinus wallichiana					0.05	FR	Contagious
	Quercus floribunda					0.03	GR	Random
	Abies pindrow					0.03	FR	Random
	Quercus dilatata					0.05	NR	Random
	Cedrus deodara						NA	

Note: Different letters in superscript indicate significant differences within geographical directions ($p < 0.05$).

The presence of high diversity in certain slope exposures with high-class girth trees indicated that the forest was mature. It was found that *Aesculus indica* and *Cedrus deodara* density was low may be due to invading recruits of *Quercus* spp. (Lanker et al. 2010). The regeneration status of tree species was determined by the recruitment of saplings and seedlings. Among the identified communities, *Pinus wallichiana, Quercus leucotrichophora* and *Picea smithiana* showed the highest regeneration indicating that these communities were dominant in disturbed habitats (Iszkuło et al. 2012). Even the poor regeneration of the dominant species and no regeneration of endangered species indicate their total replacement by other tree species or the alarm of being endangered of native species more in the coming years (Thomas and Polwart 2003, Farris and Filigheddu 2008).

The relationship between tree height and diameter on main geographical directions of the study forest was presented in Figure 2 and describes the concept in determining ecosystem structure and community also as estimates of biomass and carbon storage in the study forest (Sharma et al. 2018).

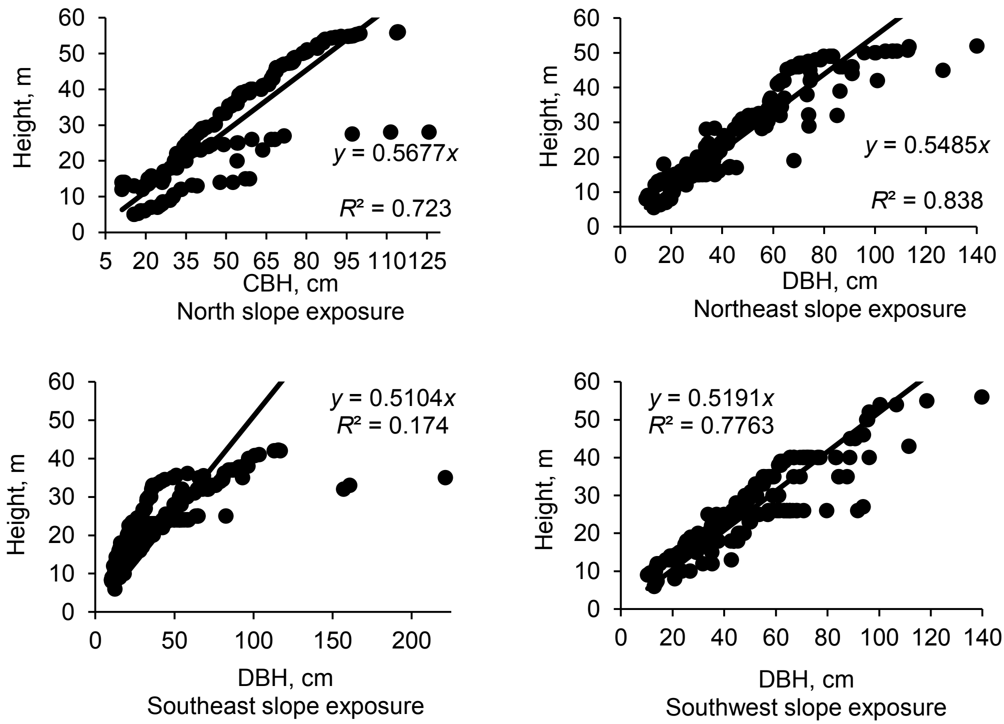

Fig. 2. The relationship between DBH (cm) and height (m) of tree species in study main geographical directions.

The mean tree density varied between different slope exposures and altitudes. It ranges from 425 ±32 ind.ha^{-1} at an altitude ranging from 2400 m to 3100 m a.s.l. to 708 ±153 trees·ha^{-1} at an altitude between 2800 m to 3400 m a.s.l. High density of *Anogeissus latifolia-Spondias pinnata* tree (462 ind.ha^{-1}) association was recorded at moist exposures, i.e. north in Khokhana forest (Sharma et al. 2018). The tree density and total basal cover values were reported as 130–830 trees·ha^{-1} and 6.25–58.88 m^2·ha^{-1} of *Rhododendron arboreum* forest in Garhwal Himalaya and 440–1180 trees·ha^{-1} and total basal cover 18–123 m^2·ha^{-1} in *Rhododendron* *arboreum* mixed broad-leaved Kumaun Himalaya temperate forest (between 2100 and 2800 m a.s.l.) (Gairola et al. 2011). Tree density (1107.29 ind.ha^{-1}) and total basal area (241.39 m^2·ha^{-1}) were reported higher in the study forest than research reported by Gairola et al. (2011) in a study of hilly temperate Himalayan forest for density and total basal area (e.g., 100–860 trees·ha^{-1} and 8.42–59.71 m^2·ha^{-1}, 340–810 trees·ha^{-1} and 30.1–62.2 m^2·ha^{-1} and 337 trees·ha^{-1} and 90.16 m^2·ha^{-1}, respectively). The basal area was considered an important criterion for evaluating timber production in the forest ecosystem and natural fertility. The basal area of trees has been reported higher in the study forest than other temperate forests, i.e., more than 300 m^2·ha^{-1}, Nagarjun hill forest 34.30 m^2·ha^{-1}, and 70.00 m^2·ha^{-1} (Shivapuri National park), which indicates study forest has matured and high contain biomass (Jevšenak and Skudnik 2021).

The density of natural regeneration of *T*. *contorta* was positively correlated with the abundance of shrubs, particularly for small DBH classes (Hulme 1997). The relationship between the recruitment success of *Taxus* species and the presence of shrub vegetation has previously been highlighted in the literature (Linares 2013). The juvenile of the endangered plant was not found in the studied forest, which means that the forest as in unsustainable growth. Diversity index of main geographical directions was obtained lower (0.22, 0.46, 0.32, and 0.30 at N, NE, SW, and SE respectively) than Panthagati conifer forest (1.11) and Gokarna hill temperate forest (1.43) reported by others (Valladares et al. 2016, Dhakal et al. 2021).

Among the study slope exposure, the regeneration curve of species was described in Figure 3. Almost all species were characterized by a lack of juveniles but not adults. New recruitment was found for some of the species, for example *P. wallichiana* in north slope exposure. Estimates of the number of species in a community also can be calculated of species richness. The regeneration curve has been determined to measure the sustainable process of the species and predict the whole forest community (Sharma et al. 2018).

Biomass varied in between species and main geographical directions (Table 3) of the studied forest due to variation in age, size of the tree and tree density. Moreover, it was noticed that micro-climatic variables played a significant role in the amount of carbon stock in the different species of the forest (Gairola et al. 2011).

The carbon stock was found to be more than 260.46 t·ha^{-1} in the studied forest that showed good sequestration of carbon, as previously also reported by Lang et al. (2016) regarding *Pinus roxburghii* Sarg. forest (269.205 t·ha^{-1}) in the mixed broadleaf forest, India. Total carbon stock in the studied forest (720.26 t·ha^{-1}) was found higher than the global boreal forest and temperate forest reported in previous studies (Dangal et al. 2017). Variation of carbon stock with species diversity is shown in Figure 4. The point curve has demonstrated that diversity has a direct relationship with total carbon density, e.g. northeast slope exposures have the highest diversity with the highest carbon density. The continuous curve has cleared that the relationship between them is not infinite in the forest ecosystem.

The total carbon density of vegetation in north and southwest slope exposure was significantly different (p = 0.0255). The herbs carbon stock had a significant difference between N to other slope exposures (Table 4).

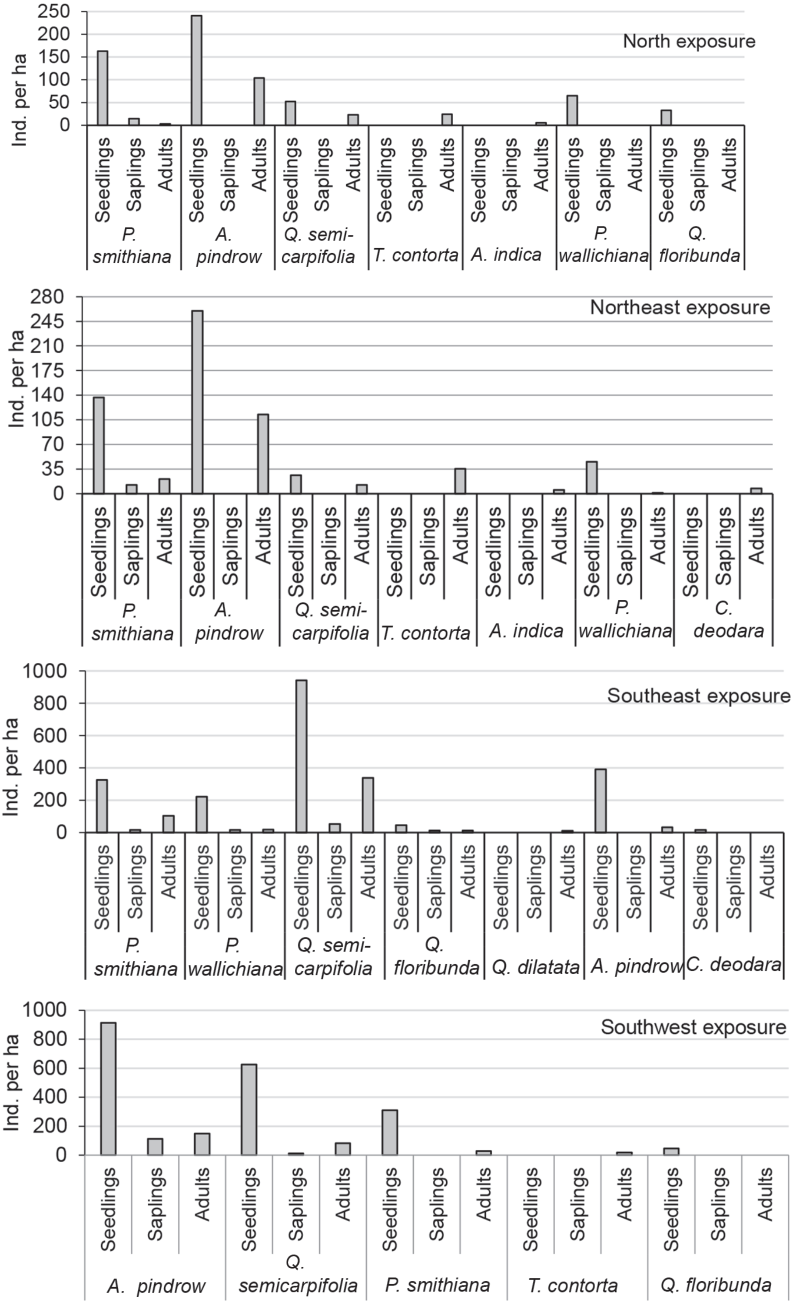

Fig. 3. Regeneration curve of species occurrence in northern and southern slope exposure.

Note: The X-axis belongs to the scientific name of tree species and Y-axis belongs to the number of individuals per ha with regards to species growth form (seedling, sapling and adult) in relative main geographical directions.

Table 3. Species wise biomass in main geographical directions.

Slope exposures	Species	*AGBD*	*BGBD*	*TBD*	*TCD*
		Mg C·ha^{-1}			
North	*Quercus semecarpifolia*	63.0569	17.9633	81.0243	37.2694
	Taxus contorta	11.5889	2.54016	14.1291	6.49943
	Abies pindrow	379.356	87.7605	467.116	214.874
	Picea smithiana	0.42519	0.21636	0.64151	0.29513
	Aesculus indica	3.95258	1.55262	5.50519	2.53244
Total		458.379	110.033	568.412	261.469
Northeast	*Aesculus indica*	3.95258	1.32409	4.62523	2.12761
	Quercus semecarpifolia	22.0522	7.09631	29.1485	13.9913
	Taxus contorta	18.9775	6.21418	25.1916	11.5882
	Abies pindrow	419.078	95.8363	514.914	236.861
	Picea smithiana	68.8153	19.4059	88.2209	40.5813
	Pinus wallichiana	1.54187	0.67554	2.21741	1.02001
	Cedrus deodara	13.4113	4.57198	17.9832	8.27229
Total		521.824	126.704	648.527	298.323
Southwest	*Aesculus pindrow*	365.484	84.9159	450.392	207.181
	Picea smithiana	90.1091	24.6284	114.737	52.7796
	Quercus semecarpifolia	109.834	29.3308	139.134	64.0016
	Taxus contorta	2.27666	0.95337	3.22999	1.48575
Total		567.676	139.828	707.493	325.447
Southeast	*Picea smithiana*	217.454	53.6596	271.109	124.711
	Abies pindrow	43.2852	12.8808	56.1661	25.836
	Quercus semecarpifolia	328.049	77.1813	405.231	213.036
	Quercus dilatata	0.88532	0.41367	1.29899	0.59753
	Pinus wallichiana	34.8465	10.6338	45.4804	20.9209
Total		624.516	154.769	779.286	385.101

Table 4. Total Carbon Density (*TCD*) in main geographical directions.

Slope exposures	Tree	Shrub	Herb	Litter	Soil Organic Carbon
	Mg C·ha^{-1}				
N	261.47 ±52.29^{a}	0.032 ±0.023	0.392 ±0.299^{a}	9.57 ±4.892	7.2 ±2.794^{a}
NE	298.32 ±59.67^{ac}	0.119 ±0.104	0.041 ±0.035^{b}	10.65 ±6.75	6.9 ±1.953^{ac}
SE	385.11 ±77.02^{ac}	0.072 ±0.041	0.005 ±0.003^{b}	6.19 ±2.183	6.04 ±1.44^{bc}
SW	325.45 ±81.36^{bc}	0.071 ±0.054	0.023 ±0.014^{b}	6.92 ±4.154	2.16 ±1.55^{ac}
p-value	< 0.002	0.098	< 0.044	0.078	< 0.043

Note: Different letters in superscript indicate significant differences within the geographical directions ($p < 0.05$).

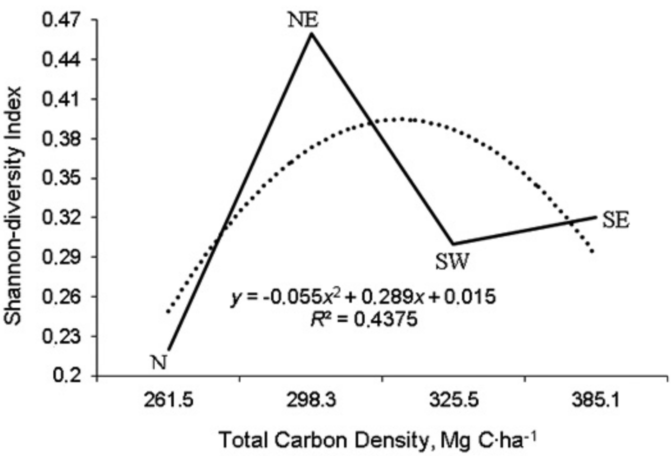

Fig. 4. The relationship of carbon stock density and Shannon diversity Index.

The northern direction of the studied forest was found to have good dominance of the adults of *T. contorta* species, that possessed the ability to survive under north slope exposure due to low temperature, moisture, shady area and acidic soil (Devaney et al. 2018, Pers-Kamczyc et al. 2019, Coughlan et al. 2020). There was a significantly high difference between the northern and southern geographical directions of bulk density (Table 5), i.e. northern to southern ($p = 0.044$) in 0–10 cm depth. But, in the 10–20 cm and 20–30 cm depths there was no evidence of significant difference ($p > 0.05$) between geographical directions. The soil moisture defined as a percent value of the soil moisture content of the soil. In generally, it is the ratio of water volume to soil volume. There was no significant difference ($p > 0.05$) between the northern and southern geographical directions for soil moisture in 0–10 cm depth (Table 5). While, in 10–20 cm and 20–30 cm depth there was found significantly different ($p = 0.031$) and ($p = 0.021$) respectively. The pH was slightly higher in the northern than in the southern main geographical directions (Table 5) but no significantly different ($p > 0.05$).

Poor regeneration of *T. contorta* was found in the study forest with limitations from shade-giving species, leaf litter leachates, high soil compaction and absence of fleshy-fruited shrub that may create its regeneration failure. This finding is consistent with Hulme 1997, García et al. 2000, Thomas and Polwart 2003, Linares 2013, Devaney et al. 2018.

Table 5. Edaphic parameters in main geographical directions.

Soil variables	Depth, cm	N	NE	SW	SE	*p*-value
Bulk	0–10	0.17 ±0.02[a]	0.17 ±0.06[a]	0.22 ±0.05[b]	0.23 ±0.03[b]	0.044
Density,	10–20	0.22 ±0.04	0.23 ±0.13	0.25 ±0.01	0.25 ±0.05	>0.05
g·cm³	20–30	0.18 ±0.02	0.18 ±0.06	0.18 ±0.09	0.19 ±0.07	>0.05
Moisture,	0–10	81.27 ±12.28	80.6 ±19.54	77.21 ±35.52	75.07 ±10.31	>0.05
% by	10–20	51.01 ±24.65[a]	73.33 ±18.56[bc]	59.68 ±29.89[a]	74.72 ±8.01[ac]	0.031
volume	20–30	45.02 ±31.78[bc]	70.8 ±37.35[a]	59.76 ±33.07[ac]	42.12 ±26.95[a]	0.021
pH	0–10	6.3 ±0.3	6.1 ±0.25	6.4 ±0.25	6.8 ±0.28	>0.05

Note: Different letters in superscript indicate significant differences between geographical directions ($p < 0.05$).

Conclusions

It can be concluded that geographical directions change the micro-environment of forests that have effects on diversity. Stand structure, stand species, diversity, the biomass of species, edaphic factors and the vitality of the population depend on geographical directions. *T. contorta* regeneration is found limiting due to less moisture, high soil compaction and disturbance factors in its occurrence of slope exposures. Taking into account the above, immediate actions should be considered for the protection, conservation and restoration of this endangered species in the hilly temperate forest region of the Himalayas.

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