Variation in structure and composition of two pine forests in Kailash Sacred Landscape, Nepal

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Chir pine (*Pinus roxburghii* Sarg.) and blue pine (*Pinus wallichiana* A.B. Jacks.) are two common species found in mid-hill forests of Nepal where households largely depend on forest resources for their livelihoods and subsistence. The management of such forests is supported by our understanding of the dynamics in forest structure and species composition and the relationship between different forest community characteristics. This study was designed to determine the variation in species composition and the relationship between various forest community characteristics in two pine forests of Kailash Sacred Landscape, Nepal.Quadrat sampling was applied to collect information on forest species, forest community structure, and disturbance factors.Data was statistically analyzed using IBM SPSS. There were a total of31 plant species under 28 genera and 20 families in the *P. roxburghii* forest, and 38 plant species under 37 genera and 19 families in the *P. wallichiana* forest. Mean DBH, height and canopy diameter of *P. roxburghii* was 23.98 cm, 12.77 m and 1.97 m, respectively, and that of *P. wallichiana* was 31.5 cm, 11.48 m and 2.79 m, respectively. The relationship between DBH and both height and crown diameter showed strong relationships in the two forest types.In both forests, DBH and height class distribution showed a hump-shaped (unimodal type) distribution with a greater proportion of medium-sized individuals that indicated disruptive forest regeneration. Fire and tree-cut were significant disturbance factors in *P. roxburghii* forest, while grazing and trampling were significant in *P. wallichiana* forest. The extent of these disturbance factors as determinants of regeneration and species recruitment is important to assess for effective forest management.

Key words: Community characteristics, disturbance, forest structure, *Pinus roxburghii, Pinus wallichiana*

The structure of a forest is determined by biotic and abiotic components (Behera *et al*., 2012; Mishra *et al*., 2013), along with human disturbance (Sanderson *et al*., 2002; Kareiva *et al*., 2007). Disturbance and biological processesare significant factors determining forest stand development (Franklin *et al*., 2002). Both forest structure and composition respond to environmental fluctuations and anthropogenic activities (Gairola *et al*., 2008). Moreover, stand structure, tree size and composition are key characteristics for maintaining ecological integrity and dynamics of forest ecosystems and their functions (Elourad *et al*., 1997;Kuuluvainen,

2002;Larsen *et al*., 2005; Merlin *et al*., 2014). These are also the basis for developing forest management and conservation strategies (Gutierrez and Huth, 2012). In mountain areas, forest structure and composition is regulated by slope orientation and elevation which both affect incoming solar radiation in an area (Gallardo-Cruz *et al*., 2009). Topographic variables, such as radiation, in turn affect species composition between slopes due to their influence on small-scale abiotic environmental variables (Ferrer-Castan and Vetaas, 2003; Paudel and Vetaas, 2014).

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Chir pine (*Pinus roxburghii* Sarg.) and blue pine (*Pinus wallichiana* A.B. Jacks.) are two pine species distributed mainly in the western Himalaya while also flourishing in Bhutan (Ohsawa *et al*., 1986). They are commercially important plant species in the Himalaya used for timber, turpentine and several medicinal and cultural purposes (Tiwari, 1994; Siddique *et al*., 2009). Several research studies have been conducted on these pine species from different parts of the Himalaya. A review of *P. roxburghii* was made by Kaushik *et al*. (2013) on ethnobotany and phytopharmacology. Dendrochronological study was carried out to determine the impact of climate change on growth of *P. wallichiana* (Bajwa *et al*., 2015). Similar work was conducted on *P. roxburghii* to understand stand age, structure, soil erosion, disturbance history and tree health (Speer *et al*., 2016). Composition, population structure and diversity of *P. wallichiana* in Garhwal Himalaya with special reference to altitude and aspect was studied by Bhandari (2003). Study on phytosociology of *P. roxburghii* was conducted by Siddique *et al*. (2009) in the lesser Himalaya and Hindukush range of Pakistan. Ghimire *et al*. (2010) carried out research on regeneration of *P. wallichiana* in the trans-Himalayan dry valley of north-central Nepal. Most research conducted in Nepal on these pine species are focused on allometric relationships for biomass prediction (Sharma and Pukkala, 1990), basal area growth model (Gyawali *et al*., 2015), dendrochronology (Schwab *et al.,* 2015) and carbon sequestration (Aryal, 2016).

In Nepal, chir pine and blue pine constitute 8.45% and 3.37%, respectively, of total forest area (DFRS, 2015). The two species are also the major constituents of forests in the midhills of Nepal (DFRS, 2015) where households largely depend on forest resources for their livelihoods and subsistence (Springate-Baginski *et al*., 2003). Long-term studies on forest socio-ecological systems are lacking in Nepal. This study was conducted in two pine-dominated community managed forests of Kailash Sacred Landscape (KSL) in Nepal to collect baseline information as part of a long-term socio-ecological study of forest ecosystems in the landscape. Knowledge on forest structure and composition is important for their management, but such studies are lacking in the landscape. Thus, the findings of this study will contribute to forest management while

also providingbaseline data for long-term forest monitoring.The study addresses the following questions: 1) what are the variations in forest structure and species composition in chir pine and blue pine forests? and 2) what is the relationship between different community characteristics in the two pine forests ?

Materials and method

Study area

The study was carried out in KSL-Nepal (MFSC, 2016) (Fig. 1). The landscape, whichextendsbetween 29° 22' N to 30° 45'N latitude and 80° 15' E to 82° 10' E longitude, covers an area of 13,289 sq. km and comprises the districts of Baitadi, Bajhang, Darchula and Humla.Altitudesin KSL-Nepal range from 390 m to 7,132 m above sea level (masl). The climatic condition of the area is characterized by high rainfall and humidity, with average rainfall of 2,129 mm. Average maximum and minimum temperature is 18.6°C and 7.7°C, respectively. Forests occupy almost 30% of the total area of KSL-Nepal of which subtropical broadleaved forests (with *Shorea robusta*, *Terminalia alata*, and *Pinus roxburghii*) constitute 10% and uppermontane conifer forests (with *Cedrus deodara*, *Cupressus torulosa*, *Tsuga dumosa*, and *Pinus wallichiana*) constitute 3%.
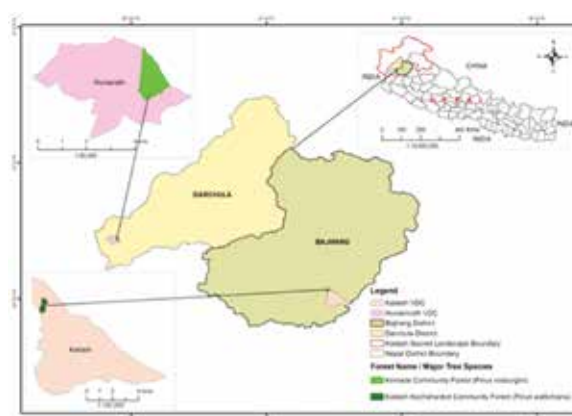

Fig. 1: Map of the study area.

The forest survey was conducted in two community managed forests in the landscape: Kirmadhe Sinnadi in Hunainath Village Development Committee (VDC) of Darchula district and Kailash Kachaharikot Mahila in Kailash VDC of Bajhang district. Kirmadhe

Sinnadi community forest (CF) covers an area of 50.76 hectares (ha). Altitudes in this CF range from 1808 to 1958 m asl and slopes between 5° to 21°with the forest oriented towards east and west. *P. roxburghii* is the dominant tree species while other tree species include *Quercus lanata*, *Rhododendron arboreum* and *Myrica esculenta.* Kailash Kachaharikot Mahila CF covers an area of 20 hectares. Altitudes range from 1800 to 2100 masl and slope between 20° to 35°with the forest oriented towards south and west. *P. wallichiana* is the dominant tree species in this CF.

Field methods

Field work was conducted between May and June 2016 to establish permanent forest monitoring plots in the two pine forests. The boundaries of both forests were delineated using a Global Positioning System (GPS) device - Garmin Oregon 650. The forest boundary was then transferred to Google Earth map where a 20m*25m grid was overlaid. Sample forest plots were then randomly selected and verified in the field. Based on the total size of the CFs, ten permanent plots were established in *P. roxburghii* forest and four in *P. wallichiana* forest. Each plot was further divided into 20 5m*5m subplots to collect data on plant life forms (Fig. 2). The location of each plot was recorded using a GPS device, and topographic variables including altitude, slope and aspect were recorded with an altimeter (Suunto). In each plot, grazing, trampling, cutting, lopping and fire were visually estimated as disturbance variables. They were recorded on a scale ranging from 0 (no visible sign of disturbance) to 3 (high disturbance). Ocular estimate of top canopy (tree crown), mid canopy (canopy of shrubs and saplings) and low canopy (canopy of herbs, forbs and seedlings) was made from the center of each subplot.
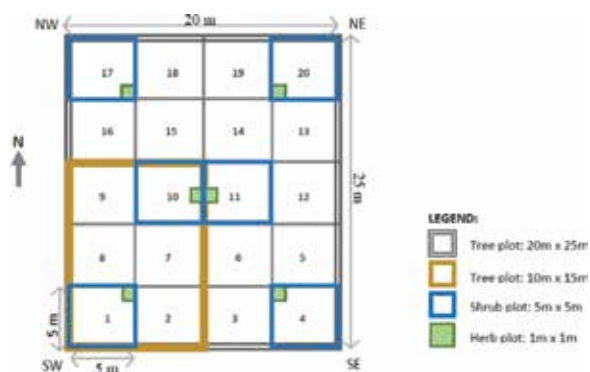

Fig: 2 Vegetation sampling design

Vegetation sampling

Based on diameter at breast height (DBH) and height (H) of the individual, plant species were classified in to three categories, *viz.* tree (>10 DBH), saplings (< 10 cm DBH and H >1.3 m) and seedlings (H<1.3 m) (Newton, 2007). Individual trees were recorded in the entire 20m*25m plot (hereby referred here as 'tree plot'). DBH of each individual tree was measured at 1.3 m height from the ground usingMillion diameter tape(YAMAYO) and its height with a Vertex IV (Haglof Sweden). Canopy of each individual tree was measured in eight directions from the center. Tree saplings were measured in a nested 10m*15 msubplot (sapling plot) within the tree plot. The number and percentage cover of shrubs were recorded in six 5m*5m subplots(shrub plot), four of which were fixed at the corners of the tree plot and two at the center. Similarly six 1m*1m subplots(herb plot) nested within the subplot were used to record herbaceous vegetation. The number of herb species and an ocular estimate of their percent cover was recorded. Most of the plant species were identified in the field withstandard flora (Stainton, 1997; Polunin and Stainton, 2000). Unidentified plant species were collected and later identified usingavailable literature (Sharma and Kachroo, 1983; Stainton, 1997; Polunin and Stainton, 2000) and by consulting herbarium specimens housed at Tribhuvan University Central Herbarium (TUCH) and National Herbarium and Plant Laboratory (KATH). Plant species nomenclature follows Press *et al.* (2000).

Statistical analysis

Spearmen's correlation was used to determine relationships between different characteristics of forest community and environmental variables. Linear regression analysis was performed to determine relationships between different forest community characteristics. The regression coefficients and equationswere obtained through a fitted line on the scattered plot, and F and p valueswere obtained through ANOVA. Before regression analysis,all disturbance variables (grazing, trampling, cut, harvesting and fire) were combined through dimension reduction process in Principle Component Analysis (PCA) to obtain a combined measure of disturbance. IBM SPSS was used for data analysis.

Table 1: Floristic composition in pine forests

Life form	Occurring in only		Common to both forests
	P. roxburghii forest	*P. wallichiana* forest	
Trees	*Alnus nepalensis, Quercus lanata*	*Symplocos paniculata, Viburnum erubescens*	*Lyonia ovalifolia, Rhododendron arboreum*
Shrubs	*Hedysarum kumaonense, Rubus paniculatus*	*Cotoneaster frigidus, Cotoneaster microphyllus, Daphne papyracea, Indigofera heterantha, Inulacappa, Myrsine africana, Prinsepia utilis, Pyracantha crenulata, Smilax aspera, Spiraea bella* and *Viburnum cotinifolium*	*Berberis asiatica, Rubus ellipticus*
Herbs	*Anaphalis busua, Cirsium wallichii, Commelina benghalensis, Curculigo orchioides, Drosera peltata, Fimbristylis dichotoma, Hypericum japonicum, Reinwardtia indica*	*Bidens pilosa, Centella asiatica, Gaultheria nummularioides, Gnaphalium affine, Origanum vulgare, Potentilla sundaica*	*Anaphalis triplinervis, Carex filicina, Erigeron karvinskianus, Flemingia strobilifera, Fragaria indica, Galiu melegans, Gonostegia hirta, Imperata cylindrica,, Micromeria biflora, Oplismenus compositus, Oxalis corniculata, Taraxacum parvulum, Viola serpens, Ageratina adenophora*

Results and discussion

Floristic composition

There were 31 plant species belonging to 28 genera and 20 families in *P. roxburghii* forest, and 38 plant species belonging to 37 genera and 19 families in *P. wallichiana* forest. Based on life forms, 22 herbs, 4 shrubs and 5 trees were recorded in the *P. roxburghii* forest, and 19 herbs, 13 shrubs and 4 tree species were found in *P. wallichiana* forest. 14 herbs, 2 shrubs, and 2 trees were common to both forests while 8 herbs, 2 shrubs and 3 trees were found exclusively in *P. roxburghii* forest and 6 herbs, 11 shrubs and 3 trees exclusively in *P. wallichiana* forest (Table 1).

P. roxburghii is invasive in nature and can easily replace broadleaved species, ultimately leading to monoculture forest development (Bhandari, 2003). It has competitive superiority than other species in obtaining resources (Bargali, 1997). It is a light demanding and fire promoting species. Surface fire causes substantial loss of nitrogen, and this depletion on nitrogen is the major cause of monoculture development of pineforests

(Singh *et al.*, 1984). Phytosociological analysis showed that *P. roxburghii* was generally distributed in pure form (Siddiqui *et al.* 2009). Pine forests are affected by fires especially in the summer season resulting in deterioration of soil fertility and development of new species. Fire reduces total organic matter, phosphorus and potassium (Benerjee and Chand, 1981; Ghotz and Fischer, 1982). In comparison to *P. roxburghii, P. wallichiana* tends to share its habitat with other tree species (Bhandari, 2003) resulting in higher species richness in this study.

Forest structure

The DBH and height class distribution of *P. roxburghii* population is presented in Fig.3 and of *P. wallichiana*in Fig. 4. In both forests,DBH and height class distribution showed hump-shaped (unimodal type) distribution with greater proportion of medium-sized individuals. There was a gradual increase in the proportion of individuals of DBH class up to >20-<30 cm for *P. roxburghii* and >30-<40 for *P. wallichiana*, and height class upto>10-<15 mfor *P. roxburghii* and >15-<20 m for *P. wallichiana* after which height class gradually decreased.
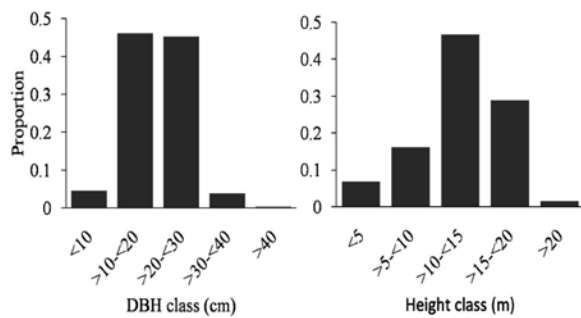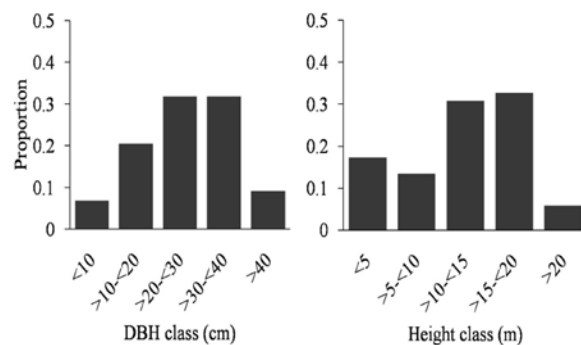
Fig. 3 DBH and height class distribution of *P. roxburghii*

Fig. 4 DBH and height class distribution of *P. wallichiana*

The size distribution of trees is an important indicator for population dynamics and for forest management (Kohira and Ninomiya, 2003; White *et al*., 2007). This study showed that there were fewer juveniles as compared to adults in the two forests indicating disruptive regeneration probably due to disturbance (Condit *et al*., 1998; George *et al*., 2005; Deb and Sundriyal, 2008). A study on *P. roxburghii* in Bhutan showed unimodal distribution resulting from anthropogenic and natural disturbances (Wangda and Ohsawa, 2006). Both forests in KSL-Nepal are used by local communities, especially for extraction of timber, and hence the preference for large-sized trees. While felling such trees, the resulting disturbance on seedlings and saplings could possibly affect their regeneration.

Relationship between forest community characteristics

The forest community characteristics of *P. roxburghii* and *P. wallichiana* are presented in Table 2. Density of pine was high in both forests. Mean DBH, height and canopy diameter of *P.*

roxburghii was 23.98 cm, 12.77 m and 1.97 m, respectively, and that of *P. wallichiana* was 31.5 cm, 11.48 m and 2.79 m, respectively. The mean top and mid canopy cover was higher in *P. wallichiana* forest than in *P. roxburghii* forest, but low canopy cover was highest in the latter forest.

Table 2: Community characteristics of *P. roxburghii* and *P. wallichiana* forest

Variables Mean (SE)		*P. roxburghii*	*P. wallichiana*
		Mean (SE)	
Number of tree species		1.60(0.31)	2.00 (0.45)
Density of Pine (number/**ha**)		168.5 (7.15)	65.00 (3.73)
Mean DBH (cm)		23.99 (1.78)	31.02 (4.70)
Mean height (m)		12.77 (0.83)	11.49 (1.02)
Mean canopy diameter (m)		1.97 (0.19)	2.80 (0.15)
Canopy (%)	Top	27.03 (3.36)	32.75 (3.31)
	Mid	4.25 (0.60)	16.50 (1.96)
	Low	14.59 (1.18)	12.00 (2.61)

The dimension reduction process in PCA resulted in two PCA factors explaining 56.5% of variance: PCA factor 1 (31.32% variance) explained grazing (0.841) and trampling (0.858) as main associated variables; and PCA factor 2 (25.23% variance) explained tree cut (0.807) and fire (0.734) as main associated variables in *P. roxburghii* forest. In *P. wallichiana* forest, two PCA factors were obtained explaining 55.2% of variance: PCA factor 1 (35.25% variance) explained grazing (0.801) and trampling (0.851) as main associated variables, and PCA factor 2 (19.95% variance) explained tree cut (0.782), harvesting (0.517) and fire (0.539) as main associated variables.

The density of *P. roxburghii* was negatively correlated with mean DBH (r = -0.872, p = 0.01) and canopy diameter (r = -0.770, p = 0.01) and positively with disturbance factor 2, *i.e* fire and cut (r =0.792, p = 0.01). Since the local villagers had extracted large sized trees for timber and fire allows regeneration of pine seedlings (Paucas *et al*., 2004), large sized tree with larger DBH were absent in the forest. *P. roxburghii* can tolerate more stress and potentially colonize disturbed and moisture-deficient areas (Singh and Singh,

1992; Ryan and Yoder, 1997). Fire helped liberate seeds from cones allowing their regeneration and monospecific stand development in *Pinus halepensis* (Pausas *et al.,* 2004; Moya *et al.*, 2007). Tang *et al.* (2013) reported that the natural recovery of *Pinus yunnanensis* was more efficient after fire contributing to the density of pine in central Yunan, China. The mean DBH was positively correlated with mean canopy diameter (r = 0.841, p = 0.01). The mean crown radius was the function of stem size, stand density and site productivity and the canopy radius increased linearly with DBH (Avsar and Ayyildiz, 2005; Attocchi and Skovsgaard, 2015).

Strong negative correlation was found with canopy diameter and number of tree species (r=0.987, p = 0.05) in *P. wallichiana* forest. Crown morphology has important implications to compete with other species in a community (Messier, 1996; Messier *et al.*, 1999). High tree canopy cover reduces the amount of solar radiation to the ground while facilitating more litter deposition which is not a favorable condition for seedling establishment (Spanos *et al.*, 2001).

DBH-height relationship

A significant linear relationship (p<0.001) was found between DBH and height (R^2 = 0.571 for *P. roxburghii* and 0.551 for *P. wallichiana*) (Fig. 5 (a) and (b)). The strength in relationship between DBH and height of the two pine forests was not significantly different. The height–diameter relationship of trees are stand specific, site specific, and time specific and also differ within a site due to competition among trees (Trincado *et al.*, 2007; Pretzsch, 2009; Schmidt *et al.*, 2011). Tree diameter has a significant correlation with the height and age of the forest stand and thereby directly affects sustainable volume production (Khan *et al.*, 2016). This correlation depends on the growing environment and stand conditions (Calama and Montero, 2004; Sharma and Zhang, 2004).

DBH-crown diameter relationship

Measurement of crown diameter is usually not carried out in forest inventory but is important to measure some competitive measures and to determine canopy cover (Biging *et al.*, 1995; Gill *et al.*, 2000; Popescu *et al.*, 2003). The R^2

value obtained from regression between DBH and crown diameter in this study was 0.572 in *P. roxburghii* forest and 0.422 in *P. wallichiana* forest (Fig. 5 and 6). Gill *et al.* (2000) developed models for different coniferous trees of California and obtained R^2 values between 0.2691 and 0.6077 where DBH predicted most of the model. Incorporation of crown area into models improved accuracy of the predictions (Nakai *et al.*, 2010; Gonzalez-Benecke *et al.*, 2014).
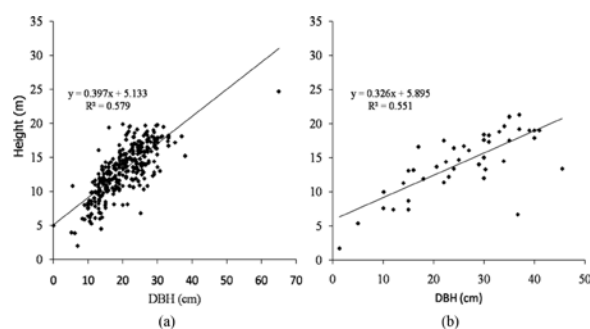

Fig 5 Regression between DBH and height of (a) *P. roxburghii* (b)*P. wallichiana*
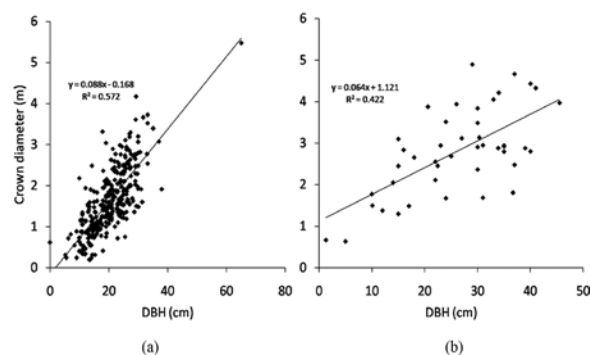

Fig 6 Regression between height and crown diameter of (a) *P. roxburghii* and (b) *P. wallichiana*

Conclusion

Pinus roxburghii and *Pinus wallichiana* are important needleleaved species occurring in subtropical broadleaved and upper montane conifer forests in KSL-Nepal. This study presents the forest structure and species composition of two pine forests selected for conducting long term socio-ecological research in the landscape. Both forests were dominated by the respective tree species, with mean number of tree species being 1.60 (± 0.31) in *P. roxburghii* forests and 2.00 (± 0.45) in *P. wallichiana* forests. Tree density

averaged 168.5 (± 7.15) and 65.0 (± 3.73) stems per ha. in *P. roxburghii* and *P. wallichiana* forests, respectively. Size distribution of trees displayed a unimodal type with greater proportion of medium-sized individuals. The structure of both forests indicates that they are heavily disturbed. Fire and tree cut were significant disturbance factors in *P. roxburghii* forest, while grazing and trampling were significant in *P. wallichiana* forest. The extent of these disturbance factors as determinants of regeneration and species recruitment is important to assess for effective forest management.

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