



Stocking Density and DBH Distribution of Community Forests in Nepal

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Abstract

There is a growing concern for sustainable forest management globally, and individual countries have been developing national policies and plans for forest management. This is the case in Nepal, but a large area of national forests is still under protection due to lack of people-centric management guidelines. In this study, diameter (DBH) and height were measured for trees, and frequency was recorded for regenerations (sapling and seedling), in concentric circular plots of 8.92 m, 5.64 m and 1 m radius respectively, in 89 plots from two community forests in the Mid-hills of Western Nepal to analyze whether the forests could be used sustainably. Regression analysis and the Mann–Kendall and Sen’s slope coefficient tests were performed to determine the composition and structure of forests in relationship with elevation which largely determines forests’ type. It was found that seedling density decreases with increasing elevation, but sapling and tree density do not follow any significant pattern for elevation. The DBH size found to be inversely related to stand density for the two dominant tree species (*Shorea robusta* and *Schima wallichii*). In contrast, DBH did not vary significantly with elevation for *Pinus roxburghii* and *Castanopsis indica*. The DBH distribution of all trees (26 species) was found to decline consistently with stand age, indicating that the forests are in good condition to manage sustainably by a simple, people-centric and cost-effective regime of thinning and size-based harvesting. Results suggest that forest managers, forest users and policy-makers need to develop and implement user-friendly forest management directives.

Keywords Forest management · Mann–Kendall test · People-centric · Sen’s slope coefficient · Size-based

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Introduction

Well-managed forests provide multiple economic, socio-cultural and environmental benefits (Upadhyay et al. 2005) which have also been recognized by climate change conferences (including COP15 2009; UN 2015). In Nepal, the government strategy is to hand over accessible forest areas as community forests to forest user groups for protection, management and utilization of forest resources (GoN 2019). To date, more than one-third of the total forested area of the country has been handed over to more than 30,000 forest-dependent communities (Poudel 2018), for which about 1.45 million households or 35% of the total population of Nepal are involved in management through the formation of 22,266 community forests users groups (CFUGs). About 50% of these are in the Mid-hills region (GoN/DoFSC 2018). In this situation, simple and easily applied silviculture systems need to be identified that are suitable for application by ordinary communities (Gilmour 2018).

In Nepal, many CFs are managed in an ad hoc way, involving the removal of dead and dying or diseased and deformed trees (Cedamon et al. 2018). In most situations, detailed growth and yield estimation are not required to assure sustainable take-off of most of the forest to optimize forests goods and services without jeopardizing the long-term benefits from the forests (Gilmour 2018). Recent forest policy promotes the application of sustainable forest management to all productive forests (Khanal and Adhikari 2018), to maximize the benefits from them. This requires further investigation of the structure of managed forests.

Case studies of DBH distributions of Nepalese forest stands have been undertaken by Vetaas (2000), Måren and Vetaas (2007), Awasti et al. (2015), DFRS (2015) and Cedamon et al. (2016). But site-specific studies are required to meet site-specific management objectives. Despite the communities theoretically having plans to guide forest management, the users are, in practice, not able to harvest the wood volumes prescribed in the plan. This is primarily because of the complexity and difficulty of understanding the practical relevance of forest management (Basnyat et al. 2018). In such cases, the silvicultural prescription should not be techno-centric but people-centric and adaptive, with consideration of the local context. Also, there is a demand for suitable silvicultural techniques that can ensure the future economic and ecological sustainability of community-managed forests (Baral et al. 2018). Realizing these facts, this study aims to analyze the trend of stocking density (seedlings, saplings, and trees) and the DBH-class distribution of community-managed forests to explore the stand structure and composition of such forests. Analyses and outcomes of this research will be applicable for preparing people-centric directives, intervention in the management plan and concerns of forests management.

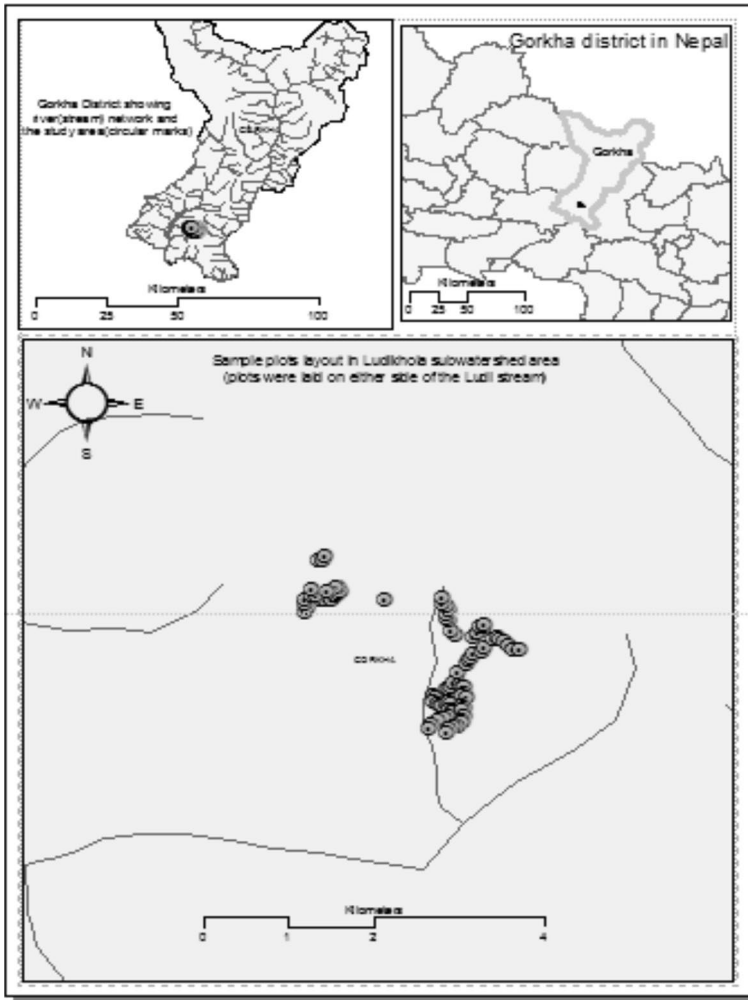


Fig. 1 Maps of the study area. *Note* Top right location of Gorkha district in Nepal's map; top left: the drainage system and the study site within Gorkha district; and bottom map showing the sample plot layout on both sides of Ludikhola stream.

The Study Area

The study was carried out in Gorkha district which extends between $27^{\circ}15' - 28^{\circ}45'N$ latitude and $84^{\circ}27' - 84^{\circ}58'E$ longitude (Fig. 1). The district is located in the Mid-hills and High Mountains of the Gandaki Province of Nepal covering an area of 3614.70 km^2 , with an elevation range of 228–8163 m above sea level (asl). Gorkha district possesses five distinct types of vegetation zones based on the altitudinal range—viz. tropical, subtropical, temperate, sub-alpine, and alpine—offering a wide array of vegetation. The district receives an average

annual rainfall of 1776 mm and average annual maximum and minimum temperatures are 26.1 °C and 15.9 °C respectively (DDC 2011).

The study was concentrated on two CFs, namely Ghaledanda Ranakhola Community Forest (GRCF) and Ludi Damgade Community Forest (LDCF). A total of 269 ha of forest has been studied taking a sampling intensity of 0.83% that covers an area of 2.23 ha. A brief description of CFs is presented here.

Ghaledanda Ranakhola Community Forest

Ghaledanda Ranakhola Community Forest (GRCF) was formally handed over to the Ghaledanda Ranakhola Community Forest Users' Group (GRCFUG) of 459 households in 1998. The GRCFUG consists of a majority of indigenous people (GRCFUG 2008). The GRCF covers an area of 194.2 ha but the study has considered the area which falls under the Ludikhola sub-watershed (181.7 ha). The forest has a sub-tropical climate and characteristics, faces south-east, south and south-west, and has an elevation ranging from approximately 700 m asl to 1100 m asl. The main tree species is *Shorea robusta* (>80% crown dominated) and associates are *Schima wallichii* and *Castanopsis indica*. Some mature but unexploited *Schima wallichii* are also common in this forest.

Ludi Damgade Community Forest

Ludi Damgade Community Forest (LDCF) was handed over to the Ludi Damgade Community Forest Users Group (LDCFUG) in 1993, to 503 households of differing ethnic groups. The total forest area is 270.7 ha, and the elevation ranges between 650 m asl to 1050 m asl (LDCFUG 2008). The forest is mainly covered by four species—*Shorea robusta*, *Schima wallichii* and *Castanopsis indica* as naturally regenerated broad-leaved stands with *Pinus roxburghii* plantation in small patches. Associated common species are *Cleistocalyx species*, *Syzygium cumini*, *Lyonia ovalifolia*, *Wendlandia coriacea*, and *Engelhardtia spicata*. Within this forest, this study has considered an 86.9 ha area which falls under Ludikhola sub-watershed.

Research Method

Sampling Design

A sampling frame was prepared on a map of the study area, and random samples were taken. The geographical coordinates of each sample point were uploaded in the geographical positioning system (GPS) equipment. Then the actual sample plots were routed to locate the sample plots in the field using GPS points. A total of 89 concentric circular sample plots each of area 250 m² were laid at random throughout the forests. The main reason for selecting circular plots is that they are easy for layout, covering a greater area with lesser perimeter, and reduce likely

bias on the border trees that may come during field measurement, as observed by Subedi et al. (2010).

Measurements in Plots

Trees were first marked starting from the forest edge and working inwards to prevent accidental double counting. All trees marked were then numbered from plot centre to edge starting at the north and heading in a clockwise direction. Every tree was recorded, together with its species name. Trees on the border were included if more than 50% of their basal area fell within the plot. Tree diameter was measured if the diameter was greater than 5 cm at 130 cm (breast height) above ground-level on the uphill side and counted if the diameter at breast height was 5 cm or less. Total height was measured using a Vertex IV (an ultrasound instrument system that provides accurate and reliable measurement results in most forest terrains and conditions) and Transponder as described by Subedi et al. (2010). Woody species having a girth less than 16 cm were regarded as regeneration (both saplings and seedlings) and numbers were counted within a 5.64 m radius plots for saplings and within 1 m radius plots for seedlings. Woody species with a height less than 1.30 m were considered as seedlings.

Statistical Tests

An analysis was performed between stocking density with elevation and DBH-size and the number of trees in particular DBH classes. For this purpose, regression analysis, Man–Kendall tests were performed and Sen's slope coefficients were estimated. The Mann–Kendall trend test is a nonparametric and distribution-free rank-based procedure, robust against the influence of extremes. In particular, this technique can be adopted in cases with non-normally distributed gradient data, and data containing outliers and nonlinear trends (Partal and Kahya 2006; Karpouzou et al. 2010). Mann–Kendall tests at the 5% significance level were used as a monotonic trend test. In the testing process, the null hypothesis is that there is no trend of stocking density to elevation and no frequency difference for trees of differing sizes (DBH distribution) in the population from which the dataset is drawn. The alternative hypothesis would test for a variation on tree density with elevation and the frequency of DBH-classes differ. Similarly, the rate of changes of DBH-class density was estimated using Sen's slope coefficient as described by Sen (1968). In this study, the Sen's slope estimator for non-normally distributed and non-parametric equal-spaced DBH-class data was utilized for trend analysis. Unlike the least-square estimators of a regression coefficient which is sensitive to errors, confidence interval and non-normality distribution data, the Mann–Kendall and Sen's slope coefficients tests were performed to avoid these sensitivities (Sen 1968). All the data were analyzed using R (R Core Team 2018) and MS Excel.

Results

Stocking Density

Woody plants include all trees, saplings and seedlings of a woody nature. It is highly important to assess the plant density in terms of number per unit area because this reveals the adjacency of one plant to others in the forest. It also indicates how much space on a site is available for regeneration, i.e. the degree of competition or crowdedness for resources especially sunlight. Of the 26 species, there was an average of 1469 trees, 2696 saplings and 32,522 seedlings per hectare. The highest stocking density was found in the smallest size classes at 800 m asl and the lowest at 1000 m asl (Fig. 2), reflecting a decreasing trend of seedling stock density with increasing elevation.

Linear regression of stand density (y) versus elevation (x) for seedlings of all species had a high degree of trend explanation ($R^2 = 0.8$) by elevation in the function $y = -4671.3x + 46535.9$ (Fig. 2). Among the four dominant species, the regeneration of *Shorea robusta* was profoundly sporadic and *Pinus roxburghii* had no naturally regenerated seedlings and saplings. However, a few saplings of *P. roxburghii* were found, probably regenerated through replanting in the site (Fig. 3).

The test outputs indicate whether the results are statistically significant. For seedling, sapling and tree density separately accounted with elevation, the test found no significant trend (Table 1). However, a significant decreasing trend of tree density with increasing elevation was found for the “all trees” case (Table 1).

The Mann–Kendall test and Sen’s slope coefficient indicate a significant decrease in tree density with increasing elevation from 800 to 1000 m asl collectively (Table 1). But the size-based density of tree, sapling and seedlings did not show a significant trend with elevation in the study area (Table 1).

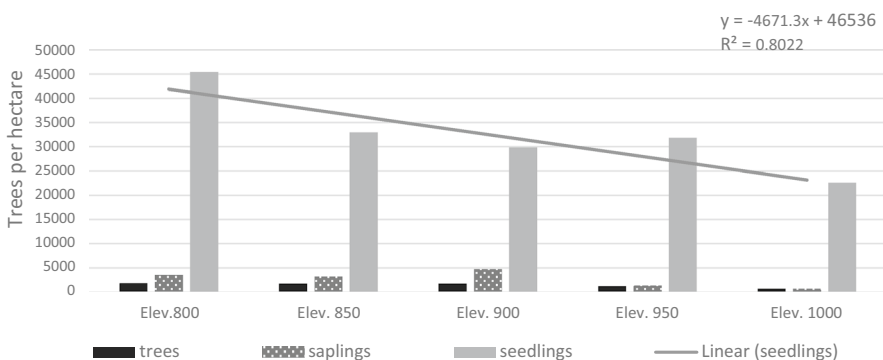


Fig. 2 Bar graphs of tree density with elevation based on tree-habit. *Note* The line is a trend for seedlings density for elevation; y is the regression function, and R^2 is the coefficient of determination for the regression.

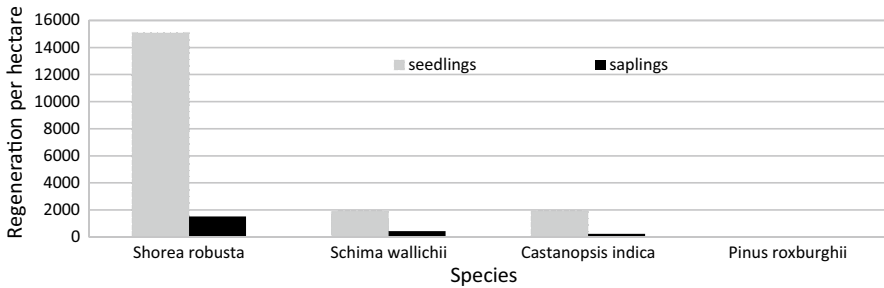


Fig. 3 Graph of seedlings and saplings recruitment density over time for dominant tree species in the study area

DBH Distribution of Dominant Trees

Four tree species—*S. robusta*, *S. wallichii*, *C. indica* and *P. roxburghii*—were accounted as the most dominant species in the study area based on subjective evaluation of crown cover and frequency distribution analysis. The distribution of DBH indicates the assemblage and structure of differing size trees in the forests. The DBH distributions of dominant broadleaved trees were found to have gradually decreasing trend with increasing size (DBH size) (Figs. 4, 5 and 6 of *Shorea robusta*, *Schima wallichii* and *Castanopsis indica* respectively) but not for *Pinus roxburghii* (Fig. 7) for the site.

The variation in DBH distribution graphs indicates that different levels of density occur according to DBH and species (Figs. 4, 5, 6, and 7). Among all the dominant tree species, *S. robusta* consisted of continuous DBH-size trees (Fig. 4), whereas *S. wallichii* had an interrupted DBH profile, having few remaining mature but unharvested trees (Fig. 5). Similarly, *C. indica* stands had very few DBH-classes (only 4) which were of smaller size with hardly any mature trees left behind (Fig. 6). However, regression analysis showed that 90–95% of trees density is explained for broadleaved dominant trees by the given regression power function (Figs. 4, 5 and 6). Unlike the other dominant species, *P. roxburghii* showed a roughly bell-shaped DBH distribution and that the number of trees per hectare explained only 69% by the polynomial regression function (Fig. 7).

Heterogeneous test outputs were found in trend analyses. The trend tests showed a significant decreasing trend (Sen's slope value found negative) of tree density with increasing DBH sized of *S. robusta*, *S. wallichii* and aggregate of 'all trees' in the study area (Table 2). However, DBH- distribution of *C. indica* had a negative with the non-significant trend while *P. roxburghii* had a positive and non-significant trend (Table 2). Meanwhile, a test found a significant negative DBH distribution trend with increasing size of 'all trees' (Table 2).

Table 1 The Mann–Kendall test and Sen's slope coefficient of plant density (number per hectare) with elevation

Variables	p-value	Significance	Sen's slope coefficient	Remarks
Trees	0.086	No	- 266	Analysis based on elevation ranges from 800 m asl to 1000 m asl. The Sen's slope values indicate the rate of decreasing or increasing the trend. If the Sen's slope coefficient is positive, then the variables' trend increases and vice versa
Saplings	0.220	No	- 731.64	
Seedlings	0.086	No	- 4069.08	
All trees	0.027	Yes	- 5828.33	

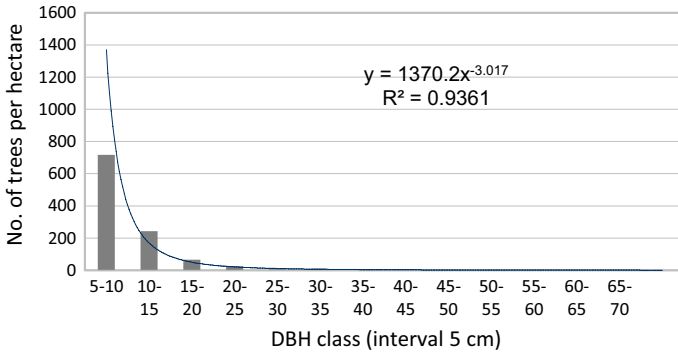


Fig. 4 Bar graphs of the DBH and line indicate DBH distribution trend with a stocking density of *Shorea robusta*; y is the regression function and R² is the coefficient of determination for the regression

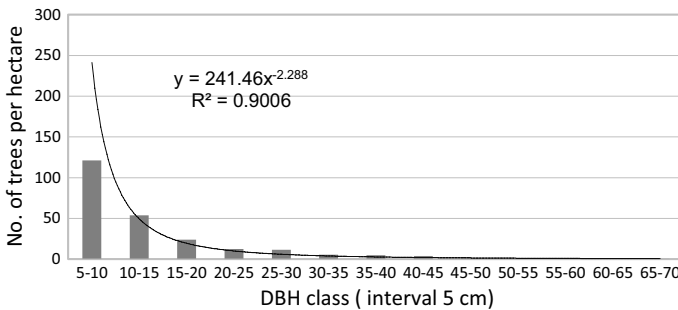
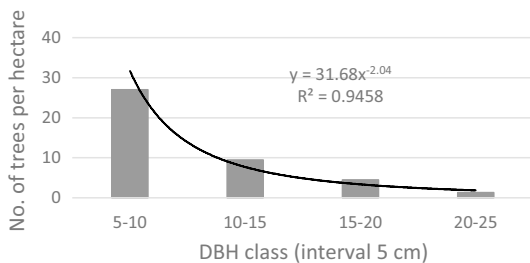


Fig. 5 Bar graphs of the DBH-class and line indicate DBH distribution trend with a stocking density of *Schima wallichii*; y is the regression function and R² is the coefficient of determination for the regression

Fig. 6 Bar graphs of the DBH-class and line graph indicates DBH distribution trend with a stocking density of *Castanopsis indica*; y is the regression function and R² is the coefficient of determination for the regression



DBH-Distribution of All Tree Species

The DBH distribution of all 26 tree species is presented in Fig. 8. The stocking density of ‘all trees’ consistently decreased from smaller size to the larger size. Stocking density decreased drastically to the class 50–55 cm and then had very few unharvested matured trees of size-class 65–70 cm left behind (Fig. 8). The DBH distribution density had a very high R² value (0.92) which indicates the

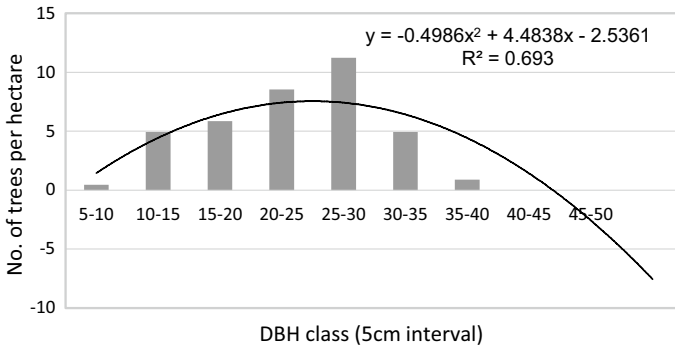


Fig. 7 Bar graphs of DBH-class distribution and a line for regression for size distribution trend of *Pinus roxburghii*; y is the regression function and R² is the coefficient of determination for the regression.

Table 2 The regression analysis and Sen’s slope coefficient test of DBH-classes distribution trend with the frequency of dominant trees

Species	Sen’s slope coefficient	p value	Significance
<i>Shorea robusta</i>	- 3.55	6.32e-05	Yes
<i>Schima wallichii</i>	- 2.44	1.38e-05	Yes
<i>Castanopsis indica</i>	- 15	0.089	No
<i>Pinus roxburghii</i>	2	0.649	No
All tree species	- 9.25	1.38e-05	Yes

A total number of 13 DBH-classes were grouped continuously from 5 cm to 70 cm at an interval of 5 cm

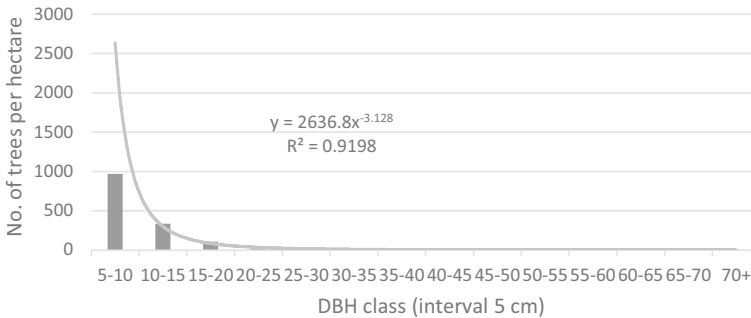


Fig. 8 The bar graphs for DBH and regression line indicates DBH distribution trend with a stocking density of all tree species

very high degree of relationship of DBH density explained by the power regression function (Fig. 8).

Discussion

An average number of 1469 trees was found in the study area, which is approximately equivalent to a 2×3 m rectangular plantation spacing density as identified in Fig. 2. The highest number of saplings indicating crowdedness is in the middle altitude zone (900 m asl) of forests, but lowest sapling density is in the highest elevation. The low crown covers in the mid-elevation might facilitate the profound regeneration of light demander species such as *S. robusta*. The elevation of 1000 m asl is close to the trafficable road adjacent to the villages. This might be because having the highest disturbance causes losses of natural regeneration at the highest elevation of the study site. Very high regeneration of *S. robusta* (15,093 seedlings/ha and 1521 saplings/ha) but very low stocking (no seedlings but 3 saplings/ha) of *P. roxburghii* spread in the whole forests. However, relatively favourable conditions can be seen for regenerations (hence more than 2000 recruits/ha) in the case of *S. wallichii* and *C. indica*. These recruitment densities indicate a healthy regeneration condition of the forests. The co-incident of data collection and the seed fall and germination periods during pre-monsoon season (June–July) in Nepal favoured relatively a high regeneration rate. The very low regeneration of *P. roxburghii* is attributed to frequent fire, a thicket of fallen needles, close canopy, a high degree of anthropogenic disturbances due to proximity and lack of moisture that creates an unfavourable condition for natural regeneration at highest elevation.

The DBH class distribution of dominant woody species indicates a continuous regeneration and heterogeneous population structure (Figs. 3, 4, 5 and 6) for broad-leaved natural forests but discontinuous regeneration (Fig. 3) with roughly bell-shaped DBH distribution and uniform structure for *Pinus* plantation (Fig. 7). Consistent with this result, DBH-distribution of Nepalese forests was found to have a proportional decreasing trend throughout the country (DFRS 2015). This indicates that the forests are in good condition. Similar results were obtained in naturally generated *Quercus semecarpifolia* in Langtang National Park and the Phulchoki Hills (Vetaas 2000). Unlike these, a bell-shaped DBH distribution of trees in Annapurna Conservation Area of Nepal was observed by Måren and Vetaas (2007), which was also found in this study for *Pinus* plantations. Moreover, similar results were obtained for the humid tropics in north-east India's forests that the DBH-class distribution has not an appropriate proportion of DBH class density for plantation forests but the natural forest has the proportional distribution of DBH classes (Baishya et al. 2009). The significant decreasing trend of plant density with increasing elevation (illustrated in Table 1) indicates that the greatest plant density is in the lowest elevation. This result is attributed to the availability of higher soil moisture and relatively higher soil fertility and minerals that may leach or wash from the hillsides to deposit in the lower areas. Also, micro-climatic variables may play a vital role in these differences with elevation because this primarily governs the micro-climatic factors.

Three dominant species of naturally-regenerated trees showed the consistently decreasing stocking density with DBH size. This is further explained by a power regression function obtaining a very high R^2 value (> 0.90) (Figs. 4, 5 and 6), and Sen's slope coefficient value that shows a significant decreasing trend of plant density with increasing size-classes (Table 2). The plantation stand of *P. roxburghii* possesses the highest frequency for trees in the middle classes (20–25 cm and 25–30 cm) trees (Fig. 7). A basic premise of such uneven-age forest management is that the stand should contain in the right proportion trees of different DBH-classes. Then the relationship among different sized-trees would be a continuous proportion. However, many younger trees do not survive because of natural or anthropogenic disturbances and as a result, DBH distribution fails to form the consistent proportion of different-sized trees (Leuschner 1992). This structure is considered as an indicator of equilibrium forest structure, especially at the stand level, but a rotated sigmoid distribution is more characteristic of the old-growth forests (Rubin et al. 2006). This condition provides a sense of good stand structure of forests for practising a selection silviculture system which considers the DBH distribution of the forests (Cedamon et al. 2016). But many community forests in Nepal are managed under an ad hoc selection (Cedamon et al. 2018). Notably, the forests in the study site have a highly consistent proportional size structure of naturally regenerated broadleaved species or 'all trees' that allows exercising size-based harvesting.

The monotonic decreasing trend is observed for tree density with diameter classes (Fig. 8). This is attributed to the high density of young and especially poles-staged trees of naturally regenerated broadleaf species stands. Therefore, thinning at an early stage of stand growth is required that might create a variety of growth patterns which would have a greater option for the growth of seedling and opening of the canopy. Also, thinning allows prior economic and substance returns, and less resource competition for vigorous growth of the remaining trees (Alexandrov 2007). Therefore, natural forest stands or plantation forests having a continuous proportion of stocking density of different DBH classes demand to employ thinning regimes intermittently before final felling of stands.

Improved forest management practices lead the forest towards sustainability. Environmental objectives and anthropocentric ambitions can be achieved through advancing the management system of the forests (Nasi et al. 2011). Cedamon et al. (2018) also emphasized the use of DBH-class distribution in applications of selection silviculture systems in community-managed forests of Nepal. Recognizing this view, improved forest management practice seems essential to maintain the DBH-class distribution towards a negative exponential distribution and the annual increment to a positive exponential pattern. The normal forest would have normal age gradations (all size-classes from regeneration to rotation age) and normal increment (optimal), and as a result, the forests would have a normal growing stock (Parkash 1986). A suitable stand structure of community forests as the research results suggest creates a great opportunity to promote a forest towards normality which allows sustainable management. From such forests, ecosystem services can be ascertained for livelihood and economic returns in addition to providing various environmental services perpetually, including carbon sequestration to mitigate climate change. In this sense, CFs of Nepal have multiple options to get the multiple benefits from the

forests managing sustainably by a simple method of size (DBH measurement) and stand density. These results would be a reference to the manager for technical support to the CF, and for the local communities to manage their forests with a simple and less tedious method in terms of mathematical calculation for stock removal. The policy-makers can be oriented to reform sectoral policy in a people-centric direction rather than issuing technocratic prescriptions to manage the forests, especially for outside protected areas.

Conclusions and Policy Implications

In general terms, DBH distribution and stocking density studies may help to improve forest management. The density and size-based forest management method is probably the simplest and easiest techniques that people also can understand in a community for measuring, counting and managing the forest on size and number. Results signify that the studied CFs are in good condition and that these could be managed sustainably with simple silvicultural operations such as weeding, cleaning, thinning and final harvesting based on log size (DBH) and count. These operations would be beneficial for enhancing carbon, promoting regeneration and reduced resource competition, hence increasing the quality of remaining stands, on the one hand, and gaining intermediate material benefits for livelihood and economic returns, on the other hand. Results also reveal that uni-modal DBH-class stands could be managed sustainably in combination with the stand having a consistent proportion of DBH distribution in the long run. Otherwise, size-gradation requires maintenance within the stand either by enrichment planting or by silvicultural conversion.

The research results suggest that authorities concerned with forestry should develop a common and simple people-centric guideline based on size and number count of trees to manage forests nationally. Also, the findings would be a reference to more than 30,000 community-based forests management models where local communities would be able to manage their forests without intensive guidance and support from the forestry technicians. This would reduce the workload of forestry authorities, and almost all forests in the country could be managed on sustainability principles and a participatory approach to achieve the national and international commitments.

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