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Population Structure and Regeneration Status of *Pinus-Quercus* Mixed Forest in Bhardeu Village, Lalitpur District, Nepal

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Abstract

Understanding population structure and regeneration status reflects the biological and ecological characteristics of the forest. The present study aims to know the population structure and regeneration status of *Pinus-Quercus* mixed forest in Bhardeu village of Lalitpur district, central Nepal. The study was carried out by laying down twenty-eight concentric circular plots of 8.92-meter radius randomly during 2021-2022. Altogether 28 tree species belonging to 24 genera and 17 families are recorded. Five species (*Miliusa velutina*, *Cinnamomum camphora*, *Eriobotrya dubia*, *Maesa chisia* and *Saurauia napaulensis*) were only recorded in adult form. The forest was found to be dominated by the species of *Pinus* and *Quercus* with the important value index (IVI) values ranging from 49.91 to 35.24. The average Simpson's Diversity Index (1/D) is 2.88, Shannon Weiner's Index is 0.85, species evenness is 0.57 and species richness is 1.07. The overall regeneration of the different species was seedlings 6484 individuals/ha., saplings 533 individuals/ha. and adults 1198 individuals/ha. showing fair regeneration. The majority of tree species show fair regeneration status (32.14%) followed by none regeneration (25%), new regeneration (17.85%), poor regeneration (14.28%) and good regeneration status (10.71%). The density diameter curve of the forest shows slightly flat reverse j-shaped structure indicating that majority of tree species were not in good regenerating status. The present analysis thus revealed that the population structure may get altered in future. Those species with none to poor regeneration status should be prioritized for the conservation and the proper management strategies need to be developed for sustainability of tree species in the forest.

Keywords: Circular plots, Family, Girth class, Temperate forest

Introduction

A plant community is a group of plant species that grow in the same area and have a clear relationship (Singh et al., 2016). Understanding the status of tree population, regeneration and diversity for conservation purposes requires an assessment of forest community composition and structures (Das et al., 2021; Malik et al., 2014; Mishra et al., 2013). The ecological qualities of locations, species diversity and species regeneration status all influence the nature of forest communities (Khumbongmayum et al., 2006). The distribution and abundance pattern of species influence plant diversity at any site (Palit et al., 2012). A community's population is a fundamental component and its structure has a direct impact on the community structure, demonstrating the community's trend (Xia et al., 2004). The population structure of tree species reflects their biological and ecological characteristics (Da et al., 2004).

The natural process by which plants replenish or restore themselves by self-sowing seeds or sprouting from stumps, rhizomes, or roots is known as regeneration (Petrie, 1999). It is the process by which plants re-grow or reproduce through their juveniles in order to sustain plant species and increase population in a community over time and space (Acharya & Shrestha, 2011; Bharali et al., 2012). Natural forest tree regeneration is important for biological diversity conservation and maintenance (Cameron et al., 2001; Hossain et al., 2004). The regeneration state of a forest determines its health and vitality and a healthy forest ensures strong future regeneration (Awasthi et al., 2015). The forest structure and composition are determined by the regeneration patterns and the factors that govern them (Wangda, 2003). The regeneration study describes the current state of the forest as well as potential future changes in forest composition (Malik & Bhatt, 2016). Reliable data on regeneration trends are required for successful natural forest management and conservation (Eilu & Obua, 2005). The presence of adequate seedlings, saplings and young trees in the population structure indicates successful regeneration of forest species (Saxena & Singh, 1984). A population with an adequate number of seedlings and saplings indicates satisfactory regeneration, whereas a population with an insufficient number of seedlings and saplings indicates poor forest regeneration (Tripathi & Khan, 2007). Regeneration status identifies poorly regenerating tree species so that effective conservation and management measures can be put in place (Sharma et al., 2018; Zegeye et al., 2011).

A complete ecological study of the forest is essential for determining the community's development trend, species composition and forest stability in the future. However, the knowledge on the structure, composition and regeneration of forest in Nepal are mainly concentrated in Terai region (Acharya & Shrestha, 2011; Aryal et al., 2021; Awasthi et al., 2015; Basyal et al., 2011; Bhatta & Devkota, 2020; Bhatt et al., 2021; Chikanbanjar et al., 2020; Giri et al., 1999; Malla & Acharya, 2018; Napit, 2015; Paudyal, 2013; Timilsina et al., 2007) and is still inadequate study with few exceptions like Shrestha et al. (2004), Shrestha et al. (2007) and Subedi et al. (2009) are found in the forest of central Nepal. Thus, to fulfill this research gap and to analyse the population structure and regeneration status of the *Quercus-Pinus* temperate forest we conducted the current research in Bhardeu village of Lalitpur district Central Nepal.

Materials and Methods

Study area

The study area Bhardeu village, is located in Konjyosom rural municipality of Lalitpur district central Nepal between 27°28'36"N to 27°33'49"N latitude and 85°18'27"E to 85°24'23"E longitude with an altitudinal range from 1053 to 2650 m asl (Figure 1). The study was carried out in Kunnekali and Gupteshwori community managed forest of the village having temperate vegetation (1817 to 2627 m asl). The forest was dominated by *Pinus* spp. (*Pinus roxburghii* and *Pinus wallichiana*) and *Quercus* spp. (*Quercus lanata, Quercus lamellosa* and *Quercus semecarpifolia*) along with *Rhododendron arboreum, Myrica esculenta, Schima wallichii* etc. The study area has a subtropical to temperate monsoon climate with a mean annual rainfall of 1697 mm and four distinct seasons: Winter (December to

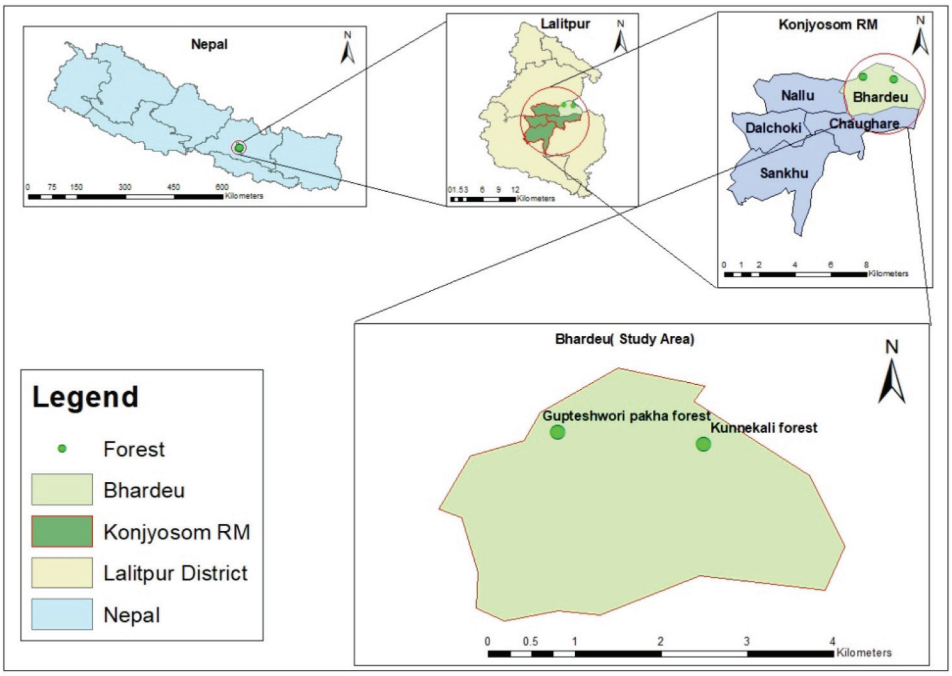

Figure 1: Map showing the study area (ArcGIS10.4.1)

February), Spring (March to May), Summer (June to August) and Autumn (September to November). The temperature variation is high, ranging from 2.3°C (January) to 26.4°C (May) with an average temperature of 14.8°C. The average relative humidity is 50 to 80 % (Source: Konjyosom Rural Municipality, 2019).

Field survey and data collection

The preliminary information about the study area was collected before the field visit from division forest office, Godawari. The field visit was conducted between November 2021 and April 2022. The stratified random sampling design was used for the data collection. The primary data were collected from 28 random Concentric Circular Sampling Plots (CCSPs) with radius 8.92 m for the medium sized trees forest (15 to 40 m^2 area occupied by a tree) according to MacDicken, 1997 (Ministry of Forests and Environment [MoFE], 2014). The DBH (Diameter at Breast Height) of all the tree species >5cm DBH are measured and the number of different species were recorded. For the measurement and number counting of saplings and seedlings the radius of circular plot 5.64 m and 1 m were taken respectively (MoFE, 2014). The regeneration status of forest was determined by the number of seedlings, saplings and adult tree species of the forest. The plant species were collected and locally identified then it is scientifically corrected by experts and cross checking with the herbarium specimens deposited at National Herbarium and Plant Laboratories, Godawari (KATH). Later the valid name of the plant specimens was acquired based on the https://www.catalogueoflife.org.

Data analysis

The primary data of vegetation were analyzed to find out the distribution pattern of trees by calculating Frequency (F), relative frequency (Rf), density (D), relative density (Rd), basal area (BA), relative basal area (RBA) and importance value index IVI) of each species by applying the formula given by Zobel et al. (1987).

1. Frequency (Fi) = frequency is the proportion of sampling units containing the species.

   $$Fi = \frac{ni}{N} \times 100\%$$

   Where,
   Fi = Frequency of species i
   ni = Number of quadrats in which species i present
   N = Total number of quadrats studied

   $$\text{Relative frequency (Rfi)} = \frac{Fi}{F} \times 100\%$$

   Where,
   Rfi = Relative frequency of species i
   Fi = Frequency of species i
   F = sum of frequencies of all species
2. Density (Di) = Density is the total number of individuals in a sample plot.

   $$Di = \frac{ni}{N}$$

   Where, ni = Total numbers of individual of species i
   N = Total number of sample studied

   $$\text{Relative density (RDi)} = \frac{Di}{D} \times 100\%$$

   Where,
   Di = Density of a species
   D = Total densities of all species
3. Basal area (BAi) = Basal area is the total area covered by a tree species.
   $BAi = \pi d^2/4 \times$ number of individuals of species i

   $$\text{Relative basal area (RBAi)} = \frac{BAi}{BA} \times 100\%$$

   Where, BAi = Basal area of species i
   BA = Total basal area of all species
4. Importance Value index (IVI) = The nature of forest is determined by the importance value index (IVI) by summation of relative frequency, relative density and relative basal area and the value is obtained in 300%.
   Importance Value index (IVIi) = RFi + RDi + RBAi
5. Species richness (SER) index indicates the mean number of species per sample (Margalef, 1958) and is expressed as

   $$\text{Species richness (SER)} = \frac{S-1}{1nN}$$

   Where, S = Number of species
   N = Number of individuals of all species

6. Species evenness (SE): Species evenness is given by the formula:

$$\text{Evenness} = \frac{H'}{H\ max}$$

Where, H' = Shannon- Wiener diversity index
H max= Ln S (S= Number of species present)

7. Shannon- Wiener diversity index (H) (Shannon and Wiener, 1963) is calculated according to Michael (1984) as follows:

$$H= -\sum_{i=1}^{n} Pi\ 1n\ Pi$$

Where, H= Shannon-Wiener diversity index
Pi= Number of individuals of species i

8. Simpson diversity index (SD) is calculated as follows according to Simpson (1949):

$$SD=\sum Pi$$

Where,

$Pi=\frac{ni}{N}$ ni= Total number of individuals of each species

N= Total number of trees of all species
The value of SD is expressed either in 1-SD or 1/SD.

Regeneration status

On the basis of DBH, tree species were divided into three growth classes namely seedlings, saplings and trees. Seedlings are the baby plant with less than one centimeter diameter and <137 cm height. A sapling has two-to-five-centimeter DBH and tree has more than five-centimeter DBH (Bhatta & Devkota, 2020; Department of Forest Research and Survey [DFRS], 2014). The densities of seedlings and saplings are considered as the good indicators of vegetation status. The regeneration status was analyzed on the basis of population size of seedlings, saplings and adults. The categorization of regeneration is done following Shankar (2001) and Khumbongmayum et al. (2006).

Good regeneration: If the density of seedlings is more than the saplings and saplings is more than the adults then it is good regeneration (Seedlings>Saplings>Adults).

Fair regeneration: The regeneration status is known to be fair when the density of seedlings is greater than saplings and the density of saplings is less or equal to the density of the adults (Seedlings>Saplings≤Adults).

Poor regeneration: If the species survives in only saplings stage but not as seedlings (though saplings may be less, more or equal to adults).

None regeneration: If species is absent both in saplings and seedlings stage but present in adults only.

New regeneration: If species has no adults but only saplings/or seedlings.

Data analysis

All the data were tabulated in MS excel sheet and was analysed with R analytical tool packages (R Core Team, 2021).

Results and Discussion

Tree species composition

In this study, two community managed forests (Kunnekali and Gupteshwori pakha forest) distributed in same altitudinal distribution and having similar vegetation types were considered as the study site together. A total of 28 different tree species comprising 24 genera and 17 families were recorded. Among the families, Fagaceae (7 spp.) comprises the highest number of species followed by Rosaceae (3 spp.), Pentaphylaceae, Primulaceae and Pinceae (2 spp. in each) and rest of families comprises only one species (Table 1). Five species (*Miliusa velutina*, *Cinnamomum camphora*, *Eriobotrya dubia, Maesa chisia* and *Saurauia napaulensis*) are only recorded in seedlings or saplings form but not in adult form. On the basis of Importance Value Index (IVI), the forest of the study area is *Pinus- Quercus* type (*Pinus roxburghii, Pinus wallichiana, Quercus semecarpifolia* and *Quercus lanata*) with highest IVI value but the *Quercus lamellosa* has lowest (5.05%) IVI value (Figure 3, Table 1 and 2). The distribution pattern of data of ecological parameters (relative frequency, relative density, relative basal area and importance value index) of all species in the study area is shown in the boxplot which indicated non-normal distribution of data (Figure 2).

Table 1: List of plant species in the study area

S.N.	Scientific name	Local name	Family
1	*Lyonia ovalifolia* (Wall.) Drude	Angeri	Ericaceae
2	*Cleyera japonica* Thunb.	Baklepate	Pentaphylaceae
3	*Quercus lanata* Sm.	Banjh	Fagaceae
4	*Schima wallichii* Choisy	Chilaune	Theaceae
5	*Pinus wallichiana* A.B.Jacks.	Gobresallo	Pinaceae
6	*Myrica esculenta* Buch. -Ham. ex D. Don.	Hadekaphal	Myricaceae
7	*Eurya acuminata* DC.	Jhingaine	Pentaphylaceae
8	*Quercus semecarpifolia* Sm.	Khasru	Fagaceae
9	*Pinus roxburghii* Sarg.	Khotesallo	Pinaceae
10	*Rhododendron arboreum* Sm.	Laligurans	Ericaceae
11	*Quercus lamellosa* Sm.	Phalat	Fagaceae
12	*Miliusa velutina* (Dunal) Hook. F.& Thoms	Kalikath	Annonaceae
13	*Cinnamomum camphora* (L.) J.Presl	Kapur	Lauraceae
14	*Prunus cerasoides* Buch.-Ham. ex D.Don	Paiyun	Rosaceae
15	*Maesa chisia* D.Don	Bilaune	Primulaceae
16	*Ficus neriifolia* Sm.	Dudhilo	Moraceae
17	*Saurauia napaulensis* DC.	Gogan	Actinidiaceae
18	*Eriobotrya dubia* (Lindl.) Decne	Jurekaphal	Rosaceae
19	*Pyrus pashia* Buch. -Ham. ex D.Don	Mayal	Rosaceae
20	*Castanopsis tribuloides* (Sm.) A.DC.	Musurekatush	Fagaceae
21	*Rapanea capitellata (*Wall.*)* Mez	Setikath	Primulaceae
22	*Lithocarpus fenestratus (*Roxb.*)* Rehder.	Arkhaulo	Fagaceae
23	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Dhalekatush	Fagaceae
24	*Celtis australis* L.	Khari	Cannabaceae
25	*Fraxinus floribunda* Wall.	Lakuri	Oleaceae
26	*Choerospondias axillaris* (Roxb.) B.L.Burtt. & A.W.Hill	Lapsi	Anacardiaceae
27	*Madhuca longifolia* (J.Koenig ex L.) J.F.Macbr.	Mauwa	Sapotaceae
28	*Ilex excelsa* (Wall.) Hook. f.	Punwale	Aquifoliaceae

Table 2: List of adult trees and their IVI value

S.N.	Scientific name	Local name	IVI value
1	*Lyonia ovalifolia* (Wall.) Drude	Angeri	12.43351
2	*Lithocarpus fenestratus (*Roxb.*)* Rehder.	Arkhaulo	5.357176
3	*Quercus lanata* Sm.	Bajh	40.30583
4	*Cleyera japonica* Thunb.	Baklepate	2.106548
5	*Schima wallichii* Choisy	Chilaune	6.435154
6	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Dhalekatush	1.1081
7	*Ficus neriifolia* Sm.	Dudhilo	1.060126
8	*Pinus wallichiana* A.B.Jacks.	Gobresallo	35.23795
9	*Eurya acuminata* DC.	Jhingane	11.41178
10	*Myrica esculenta* Buch.-Ham. ex D. Don.	Hadekafal	9.356879
11	*Celtis australis* L.	Khari	1.645964
12	*Quercus semecarpifolia* Sm.	Khasru	40.70888
13	*Pinus roxburghii* Sarg.	Khote sallo	49.91303
14	*Fraxinus floribunda* Wall.	Lakuri	22.69654
15	*Rhododendron arboreum* Sm.	Laligurans	17.26363

S.N.	Scientific name	Local name	IVI value
16	*Choerospondias axillaris* (Roxb.) B.L.Burtt. & A.W.Hill	Lapsi	6.274703
17	*Madhuca longifolia* (J.Koenig ex L.) J.F.Macbr.	Mauwa	1.060126
18	*Pyrus pashia* Buch.-Ham. ex D.Don	Mayal	9.307803
19	*Castanopsis tribuloides* (Sm.) A.DC.	Musurekatush	3.600838
20	*Prunus cerasoides* Buch.-Ham. ex D.Don	Paiyun	2.414944
21	*Ilex excelsa* (Wall.) Hook. f.	Punwale	1.605
22	*Quercus lamellosa* Sm.	Phalat	5.045195
23	*Rapanea capitellata (*Wall.*)* Mez	Setikath	10.42735

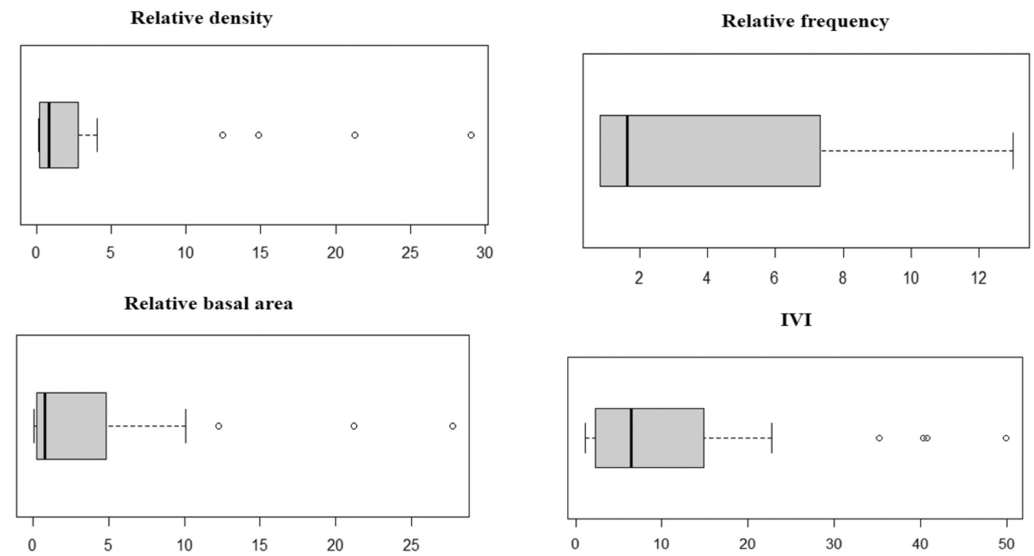

Figure 2: Boxplots of ecological parameters

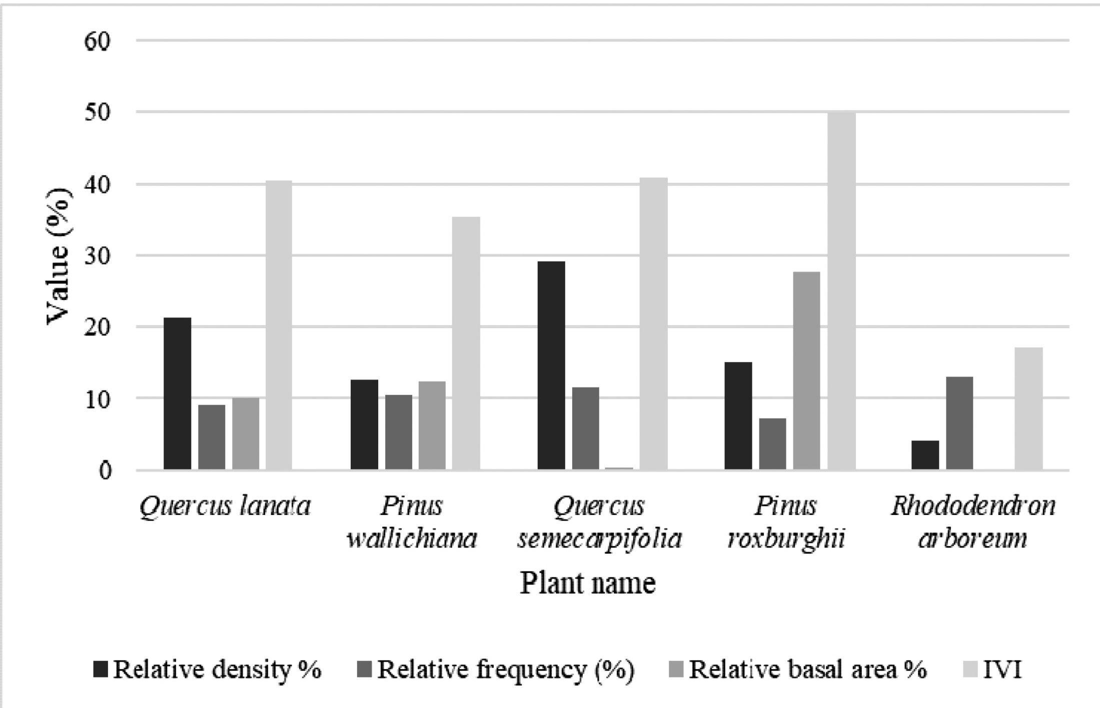

Figure 3: Vegetation characteristics of dominant trees species

Species diversity, species richness and species evenness

The Shannon-Weiner diversity index value of the study area was found 0.85 (0 to 1.92) that the plant diversity of the study area is diverse whereas Simpson diversity index value was 0.56 (0.07 to 1) or 1/D=2.88 (1.12 to 14.53) which represents that the area is dominated by few tree species. The species richness and species evenness were found to be comparatively low in this study, the species richness was found to be 1.07 (0 to 2.7) while the species evenness was found to be 0.57 (0 to 1.11) which could be due to the harvesting and logging practices. The distribution of data for the diversity indices (Shannon index, Simpson index, species richness and evenness) in the study area are shown in the box plots which indicates not normal distribution of data (Figure 4).

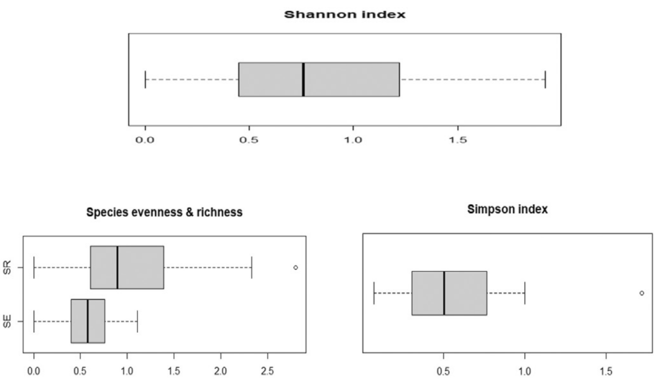

Figure 4: Boxplots of diversity indices

Density diameter relationship

The density DBH curve showed uneven DBH class distribution. Some DBH class had few individuals or completely lacking due to removal of individual trees in that DBH class group for the domestic purposes like fire wood or timber purposes. The tree species like *Quercus lanata* and *Rhododendron arboreum* have some DBH class missing possibly due to selective cuttings of bigger diameter. The study showed that highest number of trees is found in 0-30 cm DBH class group but the number of trees in other DBH class group do not follow any order and are found in uneven distribution pattern (Figure 5 and 6).

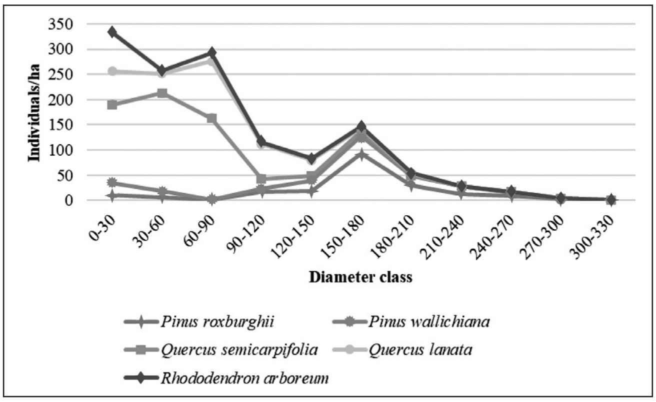

Figure 5: Density DBH curve of five dominant species

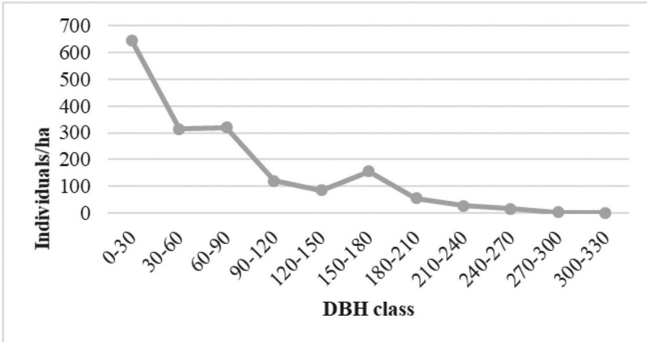

Figure 6: Density DBH curve of total species

Regeneration status

The overall regeneration of the different species in the study area is fairly good (seedlings 6484 individuals/ha, saplings 533 individuals/ha and adults 1198 individuals/ha) due to having good number of seedlings followed by adults and saplings. The majority of tree species (*Quercus lanata*, *Schima wallichii*, *Pinus wallichiana* etc.) show fair regeneration status (32.14%) followed by none regeneration (25%) (*Celtis australis*, *Castanopsis indica*, *Choerospondias axillaris* etc.), new regeneration (17.85%) (*Miliusa velutina*, *Cinnamomum camphora* etc.), poor regeneration (14.28%) (*Ficus neriifolia, pyrus pashia* etc.) and good regeneration status (10.71%) (*Rhododendron arboreum, Lyonia ovalifolia, Eurya acuminata* etc.) (Figure 7, Table 3).

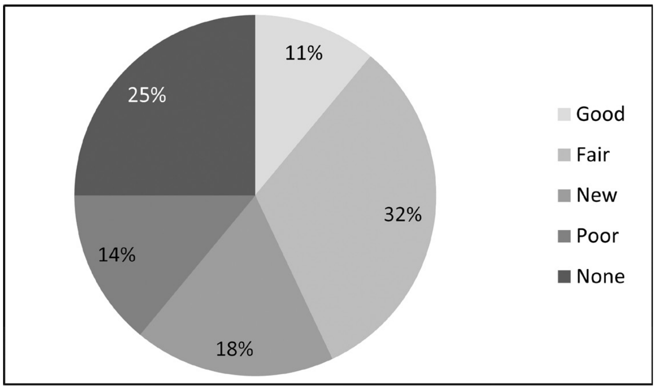

Figure 7: Regeneration status

Quantitative data on tree species composition and distribution is essential for understanding the structure of a forest community and developing a conservation strategy for it (Malik et al., 2014). Tree species variety and regeneration status are important indicators of the forest community's character since they supply resources and habitat for nearly all other forest species (Cannon et al., 1998). The frequency and variety of species found in a given geographic area is referred to as species diversity (Ministry of Forests and Soil Conservation [MoFSC], 2002). The species richness and evenness within an area

Table 3: Regeneration status of tree species

S.N.	Scientific name	Local name	No. of seedlings/ha.	No. of saplings/ha.	No. of trees/ha.	Regeneration status
1	*Lyonia ovalifolia* (Wall.) Drude	Angeri	227.449	60.714	30	Good
2	*Cleyera japonica* Thunb.	Baklepate	113.739	3.571	4.285	Fair
3	*Quercus lanata* Sm.	Banjh	568.698	60.714	267.142	Fair
4	*Schima wallichii* Choisy	Chilaune	454.959	14.285	28.571	Fair
5	*Pinus wallichiana* A.B.Jacks.	Gobresallo	227.479	21.428	125.714	Fair
6	*Myrica esculenta* Buch.-Harm. ex D. Don.	Hadekaphal	454.959	17.857	35.714	Fair
7	*Eurya acuminata* DC.	Jhingaine	454.959	57.142	30	Good
8	*Quercus semecarpifolia* Sm.	Khasru	2502.274	146.428	372.857	Fair
9	*Pinus roxburghii* Sarg.	Khotesallo	227.479	10.714	182.857	Fair
10	*Rhododendron arboreum* Sm.	Laligurans	454.959	60.714	48.571	Good
11	*Quercus lamellosa* Sm.	Phalat	227.479	3.571	8.571	Fair
12	*Miliusa velutina* (Dunal) Hook. F.& Thomson	Kalikath	227.4795	7.1428	0	New
13	*Cinnamomum camphora* (L.) J.Presl	Kapur	113.739	3.571	0	New
14	*Prunus cerasoides* Buch.-Ham. ex D.Don	Paiyun	227.479	3.571	4.2857	Fair
15	*Maesa chisia* Buch.-Ham. ex D. Don	Bilaune	0	3.571	0	new
16	*Ficus neriifolia* Sm.	Dudhilo	0	3.571	1.4285	Poor
17	*Saurauia napaulensis* DC.	Gogan	0	3.571	0	New
18	*Eriobotrya dubia* (Lindl.) Decne	Jurekaphal	0	3.571	0	New
19	*Pyrus pashia* Buch.-Ham. ex D.Don	Mayal	0	39.285	22.8571	Poor
20	*Castanopsis tribuloides* (Sm.) A.DC.	Musurekatush	0	3.571	8.571	Poor
21	*Rapanea capitellata* (Wall.) Mez	Setikath	0	3.571	8.571	Poor
22	*Lithocarpus fenestratus* (Roxb.) Rehder.	Arkhaulo	0	0	1.4285	none
23	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Dhalekatush	0	0	2.847	none
24	*Celtis australis* L.	Khari	0	0	1.4285	none
25	*Fraxinus floribunda* Wall.	Lakuri	0	0	7.1428	none
26	*Choerospondias axillaris* (Roxb.) B.L.Burtt. & A.W.Hill	Lapsi	0	0	1.4285	none
27	*Madhuca longifolia* (J.Koenig ex L.) J.F.Macbr.	Mauwa	0	0	1.4285	none
28	*Ilex excelsa* (Wall.) Hook. f.	Punwale	0	0	1.4285	none

describes the structure of the plant community. *Pinus-Quercus* Forest of Bhardeu village of Lalitpur district comprises 28 trees species belonging to 24 genera and 17 families. The dominant species of the forest are *Pinus roxburghii* (IVI 49.91%), *Quercus semecarpifolia* (IVI 40.70%), *Quercus lanata* (IVI 40.30%), *Pinus wallichiana* (IVI 35.23%), *Fraxinus floribunda* (IVI 22.69%) and *Lyonia ovalifolia* (IVI 12.43%). The number of individuals was found varied plots to plots with the average of 31 individuals. 22 plots (79% plots) were having 35 to 65 number of individual trees and 6 plots (21% plots) were having 16 to 34 individual trees. Shannon-Wiener diversity index of this forest ranged between 0 to 1.92 which is closely comparable to those reported by Napit (2015) in Banke National Park where it was 1.32 and Singh et al. (2016) in *Quercus* Forest of Garhwal Himalaya India where it was 1.49 to 1.86. But the value is higher than the value 0.38 to 0.62 which was reported by Aryal et al. (2021) in *Shorea* forest of Kapilbastu district.

The Simpson index value was ranged from 0.07 to 1 which is less comparable with the value 0.238 given by Dey and Akhtar (2020) from the tropical forest of south eastern Bangladesh and 0.97 given by Rahman et al. (2011) from biodiversity conservation areas of northeastern Bangladesh. Species diversity is the quantity and variety of species found within a given geographic area (MoFSC, 2002). It is used to characterize an area's species richness and evenness, which describes the composition of the local plant community. Greater the number of species, more will be species richness hence stable will be the ecosystem. More species richness will contribute to increase in biodiversity also which is an important aspect biodiversity conservation. The species richness and species evenness were found to be comparatively low in this study, the species richness was found to be 1.07 (0 to 2.7) while the species evenness was found to be 0.57 (0 to 1.11) which could be due to the harvesting and logging practices. These values are less comparable with the value found in Sal dominated forest of Kapilbastu district by Aryal et al. (2021) in which species richness was between 0.77 to 0.96 and species evenness 0.36. Hernandez et al. (2012) suggested that low species richness seems to be associated with the dominance of one or few species.

Total density of tree species in the study was 1198 individuals/ha. which similar to that of the study carried out by Marasini (2003) in which Churiya forest of Rupandehi had 1092-1153 individuals/ha. Similarly, it is higher than 756 individuals/ha. and 346 individuals/ha. in Tamatok forest and Madimulkharka forests in Tinjure-Milke region of eastern Nepal (Koirala, 2004) and 602 individuals/ha in Panchase forest (Chikanbanjar et al., 2020). The basal area is a crucial factor in determining the forest ecosystem's capacity to produce timber (Agrawal, 1992) as well as the maturity/ age group of the forests. The total basal area in the study area ranged from 0.81 to 13.01 m^2/ha. which is less as compared to other results Pande et al. (2001) 56-126 m^2/ha. and Koirala (2004) 56.90 to 69.80 m^2/ha. The reason for the lower basal area values in the present study may be the haphazard cutting down of trees for timber and fire wood by the local people.

The population structure of forests has been represented by the size class distribution of trees (Saxena & Singh, 1984). The size class frequency shown unevenly distributed curve in the present study which is not similar to reverse j-shaped size class distribution those reported in different forest of Nepal (Chikanbanjar et al., 2020; Giri et al., 1999; Napit, 2015; Subedi et al., 2009). Shrestha et al. (2004) found bell shaped density diameter curve in the forest of central Nepal. In the present study, the size class distribution demonstrated the lack of sustainable regeneration and unhealthy population with missing of various diameter classes. Among the different tree species, only the *Quercus semecarpifolia* is found with highest diameter class (300-330 cm). The *Quercus semecarpifolia*, *Pinus wallichiana*, *Quercus lanata* and *Rhododendron arboreum* lacks 210-240, 60-90, 180-210 and 180-210 cm diameter class respectively. In a regenerating forest (which has reverse j-shaped size class diagram), the density decreases with increasing DBH class (Bhatta & Devkota, 2020) but in present study density was found decreasing except the DBH class 60-90cm and 150-180 cm.

Natural regeneration is essential for forest sustainability and dynamics. A population with sufficient number of seedlings and saplings depicts satisfactory regeneration behavior while inadequate number of seedlings and saplings of the species in a forest indicates poor regeneration (Tripathi & Khan, 2007). The future composition of forest depends on the potential regenerative status of tree species within a forest stand in space and time (Henle et al., 2004). The overall regeneration of the *Pinus- Quercus* Forest in this study was in fair status which is much similar with the regeneration status of subtropical forest of Alkanand valley, India where seedling density ranged between 520-1240 seedlings/ha. and sapling density between 400-800 saplings/ha. (Ballabha et al., 2013). Only three species (*Eurya acuminata, Rhododendron arboreum* and *Lyonia ovalifolia*) showed good regeneration status and five species (*Miliusa velutina, Cinnamomum camphora, Eriobotrya dubia, Saurauia napaulensis* and *Maesia chisia*) has new regeneration. In the new regeneration status species are only present in seedling/sapling stage but not in adult stage. Hence the dominant tree species of present will be replaced by these newly regenerating tree species. In the study area the overall regeneration status can predict that the community structure may alter in future due to having none, poor and new regenerating tree species in 61% whereas the good and fair regenerating trees are only in 39%. The present study showed tree density was found 1198 trees/ha. which is much similar with Churiya forest of Rupandehi district i.e., 1092 to 1153 trees/ha. (Marasini, 2003), higher than the tree density (453-550 trees/ha.) in Parroha community forest, Rupandehi district (Acharya & Shrestha, 2011), Bashyal (2005) in tropical forest of Palpa district (654 trees/ha.) and Poudel (2000) in tropical forest of Udayapur district (226.93).

This study reported the abundant numbers of seedlings (6484 $ha.^{-1}$) and very less numbers of saplings (533 $ha.^{-1}$) which is comparable with abundant seedlings number 3807 $ha.^{-1}$ and very less saplings numbers 62 $ha.^{-1}$ of *Quercus semecarpifolia* in Shivapuri Hill, central Nepal (Shrestha et al., 2004). Malik and Bhatt (2016) reported seedling and sapling densities ranging between 1670 individuals/ha. and 7485 individuals/ha. and 1850 individuals/ha. and 5696 individuals/ha. respectively in different altitudes of Garhwal Himalayas, the seedlings density is much comparable with 6484 seedlings/ha. and sapling density much higher than 533 saplings/ha. in this study. In this study seedlings were not found in total six plots among the total plots studied. Out of these six plots five plots were between 2305 m and 2627 m altitude. Sapling density was low (533 $ha.^{-1}$) compared with the numbers of seedlings and trees. It might be due to the unplanned collection of fodder by the local people and invasive characteristics of shrub species like *Lantana camara* and *Ageratina adenophora.* Cutting down of *Quercus semecarpifolia* for the fodder and *Rhododendron arboreum* for the timber purposes was frequently observed during the field visit in the study area.

Conclusion

We have investigated the quantitative characteristics and regeneration status of the *Pinus – Quercus* Forest of Bhardeu village, Lalitpur district in Central Nepal. The study encountered 28 trees species from 24 genera and 17 families. The members of Pinaceae and Fagaceae were dominant with highest IVI values. The density of seedlings was found highest followed by trees and saplings. It indicates that the forest could not be healthy and sustainable in future due to very less density of saplings. The density diameter curve was unevenly distributed showing the unhealthy and unmanaged condition of forest. The overall regeneration status of the forest is fair. The overall study showed the vulnerable condition of the studied forest. To improve the condition of forest in future species with very low IVI values (*Rhododendron arboreum, Eurya acuminata* and *Lyonia ovalifolia*) should be prioritized for conservation. Those species with none to poor regeneration status should be prioritized for the conservation by providing probable mechanism that could promote natural regeneration. Regeneration is manly influenced by soil properties so the detail soil analysis should be recommended for further research. Furthermore, the proper management strategies need to be developed for sustainability and preservation of seedlings and saplings in the study area.

Author Contributions

IS and SJ conceptualized, designed the study, revised and finalized the manuscript. RSG collected and analyzed the data, and prepared first draft of the manuscript.

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