Habitat Characterization and Spatial Distribution of *Quercus lanata* Sm. in the Kumaon Himalaya

by

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Dissertation Thesis

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Master of Science
in
Wildlife Science

Under the supervision of

Dr. Amit Kumar (Scientist-D, WII)
Dr. G.S. Rawat (Former Director & Dean, WII)

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DECLARATION

I hereby declare that the work conducted under the thesis entitled **"Habitat Characterization and Spatial Distribution of *Quercus lanata* Sm. in the Kumaon Himalaya"**, is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Master's in Wildlife Science** at the **Academy of Scientific and Innovative Research**. This research work has been carried out under the guidance and supervision of **Dr. Amit Kumar, Scientist-D** and **Dr. G.S. Rawat, Former Director & Dean** of Wildlife Institute of India, Dehradun. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge.

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CERTIFICATE

This is to certify that the thesis by **Shikhar Kaushik** entitled "**Habitat Characterization and Spatial Distribution of *Quercus lanata* Sm. in the Kumaon Himalaya**" is an original and independent research work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master's in Wildlife Science**.

Shikhar Kaushik has put one semester of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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No: WII/Herbarium/2025/0001 **Date: 24th June 2025**

Certificate of Specimens Identification

This is to certify that Mr. Shikhar Kaushik has submitted 26 plant specimens to the Herbarium of Wildlife Institute of India dated 22nd April 2025. The specimens after identification have been assigned accession numbers from WII006385 to WII006410.

The list of specimens is provided below:

S.no.	Species	Location	Collection No.	Accession No.
01.	*Quercus lanata* Sm.	Dehradun	33044	WII006385
02.	*Quercus lanata* Sm.	Kilbury	33045	WII006386
03.	*Quercus lanata* Sm.	Bhowali, (Pines)	33046	WII006387
04.	*Quercus lanata* Sm.	Mukteshwar	33047	WII006388
05.	*Quercus lanata* Sm.	Ramgarh	33048	WII006389
06.	*Quercus lanata* Sm.	Okhalkanda	33049	WII006390
07.	*Quercus lanata* Sm.	Sundarkhal	33050	WII006391
08.	*Quercus lanata* Sm.	Binsar	33051	WII006392
09.	*Quercus lanata* Sm.	Liti	33052	WII006393
10.	*Quercus lanata* Sm.	Manch	33053	WII006394
11.	*Quercus lanata* Sm.	Kranteshwar	33054	WII006395
12.	*Quercus lanata* Sm.	Gangolihat	33055	WII006396
13.	*Quercus lanata* Sm.	Lamkeshwar	33056	WII006397
14.	*Quercus lanata* Sm.	Sandev	33057	WII006398
15.	*Quercus lanata* Sm.	Askot	33058	WII006399
16.	*Quercus lanata* Sm.	Thalkedar	33059	WII006400
17.	*Quercus lanata* Sm.	Chaukodi	33060	WII006401
18.	*Taxus contorta* Griff.	Liti	33062	WII006402
19.	*Quercus glauca* Thunb.	Liti	33063	WII006403
20.	*Ulmus* × *brandisiana* C.K.Schneid.	Manch	33065	WII006404
21.	*Symplocos ramosissima* Wall. ex G.Don	Kilbury	33080	WII006405
22.	*Symplocos theifolia* D.Don	Kilbury	33081	WII006406
23.	*Machilus duthiei* King ex Hook.f.	Manch	33083	WII006407
24.	*Arundinella nepalensis* Trin.	Binsar WLS	33087	WII006408
25.	*Chrysopogon gryllus* (L.) Trin.	Lamkeshwar	33088	WII006409
26.	*Themeda anathera* (Nees ex Steud.) Hack.	Lamkeshwar	33089	WII006410

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“An infinity of forest lies dormant within the dreams on one acorn”

- Wayne W. Dyer

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To the forests, mountains, and people of the Himalaya, thank you for being a beautiful part of this journey and offering me a space to learn and grow and lastly to my 113cc scooter Yamaha Cygnus for making this possible.

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Executive Summary

Oaks are climax species which evolved around 56 million years ago. India is home to around 35 species of oaks out of which only 5 species are native to Uttarakhand. In Western Himalaya 3 species make extensive continuous forests which includes Banj oak forest, Moru oak forest and Kharsu oak forest. They show gregarious nature and provide countless ecological and economic benefits to the country. The other two species, *Quercus glauca* and *Quercus lanata* are patchy is distribution. For *Quercus lanata* the Kumaon Himalaya is the western most limit and therefore thet species is patchy and shows disjunct population. This study aimed to understand the population, regeneration, habitat characterisation and distribution of *Quercus lanata* in Kumaon. Descriptive analysis was used to understand the population structure and associate species and maxent modelling was used to develop habitat suitability model. The overall population of *Quercus lanata* (Rianj) in Kumaon shows a stable and gradually growing trend. *Quercus lanata* shows a diverse preference to habitat which ranges from northerns moist slopes to drier southern slopes. The significant values from analysed data suggest that its preference at southern slope is comparatively higher. It occurs with *Quercus leucotrichophora* as well as with Pinus roxburghii. The major co-occurring species with *Quercus lanata* are Rhododendron arboreum and Myrica esculenta. The developed habitat suitability and generalised linear models helped to understand that elevation and aspect play a significant role in distribution of *Quercus lanata*. The demand of *Quercus lanata* for fodder and fuelwood in village area is quite high and therefore requires sustainable practices. As of now *Quercus lanata* is classified under either Banj oak forest or Moru oak forest which reduces the level of conservation and management this species require.

1. Introduction

1.1 Background

Oaks evolved around 56 million years ago in the American continent and dispersed from North America to Europe followed by Asia (Kremer et al. 2019). Oaks are diverse in North and Central America where they made their way from southeast Canada to the Columbiana Andes (Menitsky, 2005). Oak diversity is poor in Europe and the Mediterranean and is completely absent in Siberia, and central Russia. In Eurasia, the northern limit of the natural range of oak passes through Scandinavia (Denisov, 1970). The natural boundary does not extend beyond Sunda land. There are approximately six hundred species of oaks found worldwide that belong to the Fagaceae family which is native to the Northern Hemisphere of the globe and includes deciduous and evergreen species extending from cool temperate to tropical latitudes in America, Asia, Europe, and North Africa (Hogan, 2012). The ancestors of oaks were more related to Lithorcarpus (stone oak) than *Castanea*, as *Lithocarpus* is characterised by entire toothed evergreen leaves with few widely spaced veins. (Krassilnikov, 1962). The first fossil remains of deciduous oaks, found in the so-called Arctic floras of the Early Paleogene (Paleocene–Eocene) of North America and the Far East, are highly specialized macrophyllous forms adapted to the constant humid and cold climate of higher latitudes (Menitsky, 2005). Oaks are hardwood tree species that are highly adaptable to various climatic conditions, from temperate to subtropical environments (Holmes et al., 2008). Oaks are divided into groups of ring-vessel and diffuse-vessel species. Oaks belonging to the group ring-vessel are deciduous while the others belonging to diffuse-vessel are evergreen. Deciduous oaks are distributed in countries with temperate climates or tropical and subtropical regions with a winter inhibition of vegetative growth and leaf fall. The branching pattern of deciduous oaks differs from that of

evergreens. The branches appear sharp and angular due to tree's high requirement of sunlight whereas in evergreen the branches are wider apart without sharp angles. (Menitsky, 2005). In the subgenus Heterobalanus, original primitive type of leaf is represented by *Quercus incana* (*syn. Quercus leucotrichophora*) and *Quercus lanata*, which have the largest leaf dimensions within the group *Quercus* (Menitsky, 2005).

Out of the six hundred species of oaks around the world, around one hundred and forty species of *Quercus* are found in Asia. Himalaya is home to thirty-five species of oaks which occur from Northwest Himalaya to Northeast at an average elevation of 1200-3500m in the Northwest and 600-1800m in the Northeast (Amarnath et al. 2021). There are sixteen species of oaks distributed in India. The eastern Himalayan oaks include *Quercus dealbata* Griff., *Quercus griffithii* Hook.f. & Thomson, *Quercus lamellosa* Sm., *Quercus lappacea* Klotzsch, *Quercus lineata* Blume, *Quercus pachyphylla* A. Camus, *Quercus serrata* Murray, *Quercus semiserrata* Roxb., *Quercus spicata* Sm., and *Quercus xyocarpa* Lobb ex Steud. The western Himalayan oaks include *Quercus baloot* Griff., *Quercus floribunda* Lindl., *Quercus glauca* Thunb., *Quercus lanata* Sm., *Quercus leucotrichophora* A.Camus and *Quercus semecarpifolia* Sm. (Thakur, 2018). Oaks are dominant, evergreen, tree species of Himalayan temperate forest forming an essential part of the climax community which forms extensive forests in the temperate regions of the world. (Troup, 1921). Oak forests occupy approximately 20,000 Km^2 areas in the Central Himalayan region with an average elevation gradient of 1000-3000m (Joshi et al. 2017). According to Champion and Seth (1968), in the Himalayan temperate forest, *Quercus leucotricophora, Quercus floribunda* and *Quercus semecarpifolia* form extensive forest patches, namely Ban oak forest ($12/C_{1a}$) which occurs from 1800 to 2300m of elevation and Moru oak forest ($12/C_{1b}$) which occurs from 2000 to 2500m of elevation in the Lower western Himalayan temperate forest($12/C_1$) and Kharsu oak forest ($12/C_{2a}$) which occurs from 2500 to 3300m of elevation in the Upper western Himalayan temperate forest ($12/C_2$). Except

for *Quercus glauca* and *Quercus lanata*, other three species of *Quercus*. are widely distributed in the western Himalaya species are widely distributed and form extensive patches in the Garhwal Himalaya (Singh and Singh, 1992). Uttarakhand is home to five native species of oaks *Quercus floribunda*, *Quercus glauca*, *Quercus lanata*, *Quercus leucotrichophora* and *Quercus semecarpifolia*. Some introduced species of oaks in Uttarakhand are *Quercus acutissima, Quercus griffithii* and *Quercus serrata*.

Quercus lanata Sm., in A.Rees, Cycl. 29: n.° 27. 1814. *Quercus lanuginosa* D.Don in Prodr. Fl. Nepal.: 57. 1825. nom. illeg.; Osmaston in For. Fl. Kumaon 526. 1927; Troup in Silviculture of Indian Trees 3: 935. 1921.

Vern. Rianj, Rai-Banj, Latuwa-Banj. Common name. Woolly-Leaved Oak.

It is a large evergreen tree with a girth of up to 10 feet and 80 feet in height with numerous low branches. The bark of the tree is pale grey to ashy-brown with visible lenticels appearing as a rough texture. The outer bark appears as woody plates which remain semidetached to trunk but fall easily. The blaze is hard and fibrous pink in appearance. Young leaves and other parts have dense wool or densely tomentose. Mature leaves with persistent woolly hairs present on the underside of the leaf. The leaves are alternate and midrib is clearly visible. Veins are clearly visible, 7-9 pairs, sometimes 11-13 pairs. Leaves are large in comparison to all other native oaks. Young leaves show variety of shapes and as they mature, they can reach up to the size of 20-25cm in length. (refer to Plate no. 1,2,3) Male catkins are 2-5 inches long, while female flowers are solitary or in pairs. Acorns are 8 inches long with one-third to half enclosed by campanulate cup when they ripe. The flowers appear in April along with new leaves (Osmaston, 1927). On old age tree, bark often forms horizontal raised rings-like structure. The wood is very hard and commonly used for fuelwood purpose. The shedding of leaves is around October, while the immature acorns are visible by September, they mature and ripen in the

latter half of December to January which is around eight months from pollination. Acorns are usually in clusters of 2-5 bearing woolly hair on their tip. This species of oak is light-demanding, coppices well and has a massive root system making it highly wind resistant. Under natural conditions, seeds remain on the ground throughout the summer and germinate on the arrival of rain. It appears to resemble *Quercus leucotrichophora* but is capable of establishing on drier locations. Natural seedlings are found plentiful on grassy slopes along with seedlings of *Pinus roxburghii* (Troup, 1921).

Quercus lantana is a large evergreen oak tree that grows at an elevation of 1200-2400m of elevation (Troup, 1921). It is classified as Least concern by International Union of Nature and Natural resources (IUCN) (Carrero et al., 2020). It is distributed in India, Nepal, China, Bhutan, Northern Thailand and Vietnam where it grows at an elevation of 800m to 2600m (Huang et al.,2012). Menitsky (2005), in his book, 'Oaks of Asia', stated that the limit of *Quercus lanata* ranges from Sutlej Valley in the west to Dihang river basin in Burma. However, other literature has mentioned the distribution of *Quercus lanata* to Garhwal of Uttarakhand. Troup (1921) in his book, 'Silviculture of Indian Trees' mentioned Deeba danda, in Pauri Garhwal as one of the westernmost places where *Quercus lanata* occurs. Osmaston, (1927) in his book 'Flora of Kuman' also mentioned the distribution of *Quercus lanata* as not uncommon in Almora but rare in Garhwal where it is often found pure but also in association with *Quercus leucotrichophora*. According to Negi and Naithani, (1995), *Quercus* lanata is distributed from Uttarakhand in Northwestern Himalaya of India followed by Nepal, Bhutan up to far in East Aisa in China (Guangxi, Xizang, Yunnan) and Southeast Asia which includes parts of Myanmar, Thailand, Vietnam and Borneo. In eastern Himalaya it is distributed in dry open forests of *Pinus kesiya* along with *Quercus griffithii*, *Quercus acutissima*, *Quercus glauca*, *Lyonia ovalifolia*. In Burma it is present until 2700m of elevation. In Thailand, it is a component of monsoon dry oak forest at an elevation of 400 to 2000m. In Vietnam, it is a component of

Pinus insularis and *Quercus helferiana*, sometimes it forms pure wood stands on granite and most degraded soils. In India *Quercus lanata* occurs mainly in the Kumaon Himalaya, extending towards Bhutan (Troup, 1921). throughout the Himalaya between 1800m to 2400m of elevation. It is found pure, but also frequently associated with *Quercus leucotrichophora* (Osmaston, 1927). The distribution of woolly-leaved oak is very local. It occurs in patches, small extent in the Garhwal and Kumaun Himalaya, extending towards Bhutan. It is associated with *Quercus leucotrichophora*, *Rhododendron arboreum, Quercus floribunda* and *Pinus roxburghii* respectively (Troup, 1921).

Quercus lanata, generally occupies sunny slopes of southern aspect (Singh et al., 1986). A few studies on different aspects of *Quercus lanata* account as follows, *Quercus lanata* leaf has specific leaf mass of 198.8g/m3 which indicates sclerophyllous properties, leaves are evergreen and its lifespan is approximately 13 months. Its biomass ranges from 285 to 557 Mg/ha. and Net primary productivity (NPP) varies between 15.5 and 17.8 Mg ha^{-1} yr^{-1}. (Singh et al., 1994). In Kumaon, pure forests of *Quercus lanata* are restricted to small pockets not exceeding 15ha where the tree density is 1210 trees/ha. The total basal area recorded is 61.82 m2/ha. (Singh et al., 1986). *Quercus lanata* root system accounts for 17-18% of the total tree biomass (Bhandari et al., 2020). A study from Askot on carbon sequestration of *Quercus lanata* revels that mean carbon sequestration rate is 3.4 Mg C ha^{-1} yr^{-1} where 236 individuals of CBH >30 cm were sampled for biomass estimation. The mean aboveground carbon stock was 475.8±84.9 Mg C ha^{-1} and mean belowground carbon stock was reported 119.8±18.1 Mg C ha^{-1} where highest carbon accumulation was observed in old-growth individuals (Bisht et al 2022).

1.2 Knowledge gap

Previous studies on *Quercus lanata* are mostly from Nepal where its core population is present. Uttarakhand having the westernmost population is still understudied in terms of its local distribution, population structure and habitat preferences. Meagre information is available on *Quercus lanata* as compared to the research impetus given to other forest species of the Himalaya (Bhandari et al. 2020). Therefore, this study is crucial to bridge the ecological research gaps by addressing the habitat preference of *Quercus lanata* in Kumaon region.

1.3 Aim

Considering that the stress zone of *Quercus lanata* is in western region of Kumaon, the study aims to understand the current population and regeneration status, distribution pattern and habitat preference of *Quercus lanata* in the Kumaon region of Uttarakhand. This also includes assessing the environmental factors responsible for shaping the *Quercus lanata* population in its distributional range.

1.4 Research Questions

1.4.1 What is the current population and regeneration status of *Quercus lanata* across Kumaon?

1.4.2 What is the habitat preference of *Quercus lanata* and what are its major associate species in Kumaon?

1.4.3 What are the environmental factors affecting distribution of *Quercus lanata* in Kumaon?

1.5 Objectives

1.5.1 To understand the current population and regeneration status of *Quercus lanata* in selected sites of Kumaon region of Uttarakhand.

1.5.2 To understand the habitat preference of and major associates of *Quercus lanata* in the selected sites of Kumaon region.

1.5.3 To develop the habitat suitability model of *Quercus lanata* in its distributional region.

2. Methods

2.1 Study area

Uttarakhand is a Himalayan state in north India. The state is characterized by its diverse topography ranging from the Terai i.e., flat alluvial Upper Gangetic plains in the south to high alpine and nival zones in the north along an elevation gradient of <200m to 7818m asl. Owing to diverse ecoclimatic and topographic diversity, the state is extremely rich in biodiversity. Being a biodiversity hotspot around 3106 plants are endemic, along with 71 genera (Tiwari et al., 2024). The Himalayan region is home to a significant number of endemic plant species out of the estimated 10,000 species of plants in the Himalaya Hotspot, about 3,160 are endemic, along with 71 genera (Tiwari et al., 2024). The state is divided into two principal regions: Garhwal and Kumaon.

The study area was mostly present in two forest types groups, sub-tropical pine forest (Group-9) and Himalayan moist temperate forest (Group-12) (Champion and Seth, 1962).

Group – 9 Sub-Tropical Pine Forest

Type 9/C_1 Himalayan Sub-tropical Pine Forest

Subtype 9/C_{1a} Lower Siwalik Chir pine Forest

Subtype 9/C_{1b} Upper or Himalayan Chir pine Forest

Sub-tropical pine forests occur between 1000m to 1800m of elevation. The main species is Pinus roxburghii. The mean annual temperature ranges between 15°C to 20°C and mean annual rainfall varies from 1000mm to 3000mm. Himalayan Chir pine forest (9/C_{1b}) may ascend up

to 2300m on southern aspects of Himalaya. Species like *Quercus leucotrichophora, Lyonia ovalifolia, Myrica esculenta* generally occur as middle storey. (L.S. Khanna 1977)

Group – 12 Himalayan Moist Temperate Forest

Type 12/C_1 Lower western Himalayan temperate forest

Subtype 12/C_{1a} Ban oak forest

Subtype 12/C_{1b} Moru oak forest

Subtype 12/C_{1c} Moist deodar forest

Subtype 12/C_{1d} Western mixed coniferous forest

Subtype 12/C_{1e} Moist temperate deciduous forest

Type 12/C_2 Upper western Himalayan temperate forest

Subtype 12/C_{2a} Kharsu oak forest

Himalayan moist temperate forest occurs throughout the Himalaya with altitude ranging from 1500m to 3300m. The mean annual temperature ranges from 13°C to 16°C. The rainfall varies from 1100mm to 2500mm which is mostly received from southwestern monsoon and some part from northwestern disturbances mostly in north western parts of Himalaya. The Lower western Himalayan temperate forest (12/C_1) in turn contains many subtypes. Ban oak forest (12/C_{1a}) ranges from 1800m to 2300m, grows gregariously in pure forms and forms association with *Quercus floribunda, Cedrus deodara*, and *Pinus wallichiana* towards upper limit and with *Pinus roxburghii, Rhododendron arboreum, Quercus glauca* and locally *Quercus lanata* towards the lower limit. Moru oak forest (12/C_{1b}) occurs between 2000m to 2500m and prefers a moisture rich habitat. Its common associates are *Quercus leucotrichophora, Quercus*

semecarpifolia, Cedrus deodar and *Rhododendron arboreum*. Moist deodar forest ($12/C_{1c}$) occurs between 1800m to 2500m but can go up to 3000m. Western mixed coniferous forest ($12/C_{1d}$) occurs between 2400m to 3000m with rainfall varying from 1140mm to 1300mm. Common species includes *Picea smithiana, Abies pindrow, Cedrus deodara, Taxus contorta, Ulmus, Betula alnoides*. Moist temperate deciduous forest ($12/C_{1e}$) occurs between 1800m to 2750m along with *Aesculus indica, Carpinus viminea, Betula alnoides Fraxinus micrantha*. The second type Upper western Himalayan temperate forest ($12/C_2$) has one subtype which forms part of study area, Kharsu oak forest ($12/C_{2a}$), it occurs between 2500m to 3000m of elevation. The forest is dominated by *Quercus semecarpifolia* which shows distribution up to timberline. Its associates with *Picea smithiana, Abies pindrow, Quercus floribunda, Betula alnoides*. (L.S. Khanna 1977)

Based on the available literature and after examining herbarium specimens (Table 2.), the study was conducted in various parts of Uttarakhand where the distribution of *Quercus lanata* was found. This includes five districts of Kumaon Division, namely; Almora, Bageshwar, Champawat Nainital and Pithoragarh and two districts of Garhwal Division namely; Chamoli and Pauri Garhwal. Out of seventeen locations, *Quercus lanata* was only observed at fifteen locations, all present in Kumaon. At two locations, Gwaldam and Deeba danda no occurrence of *Quercus lanata* was observed so at these two locations, no sampling was carried out. Table 1. provides details on the various locations sampled in the study area.

Table 1. Details of locations sampled at the study area.

S. No.	Division	District	Locations	Latitude	Longitude	Altitude
01.	Kumaon	Almora	Binsar WLS	29.675872°	79.774779°	1890m
02.		Bageshwar	Liti	29.993758°	80.042983°	2144m
03		Champawat	Kranteshwar	29.305583°	80.131403°	2148m
04			Manch	29.304573°	80.161373°	1930m
05		Nainital	Bhowali (Pines)	29.392765°	79.485233°	2211m
06.			Kilbury	29.421832°	79.436754°	2260m
07.			Okhalkanda	29.361228°	79.710265°	2308m
08.			Ramgarh	29.426937°	79.577245°	2226m
09.			Sundarkhal	29.41219°	79.66691°	1996m
10.		Pithoragarh	Askot WLS	29.903923°	80.359160°	2584m
11.			Chaukodi	29.863738°	80.008357°	1991m
12.			Gangolihat	29.676772°	80.080751°	1910m
13.			Lamkeshwar	29.711105°	80.02101°	2356m
14.			Sandev	29.793205°	80.204637°	2140m
15.			Thalkedar	29.519537°	80.227453°	2360m
16.	Garhwal	Chamoli	Gwaldam	29.996682°	79.547576°	2345m
17.		Pauri Garhwal	Deeba danda	29.790304°	79.013478°	2514m

2.1.1 Study area map showing *Quercus lanata* sampling locations

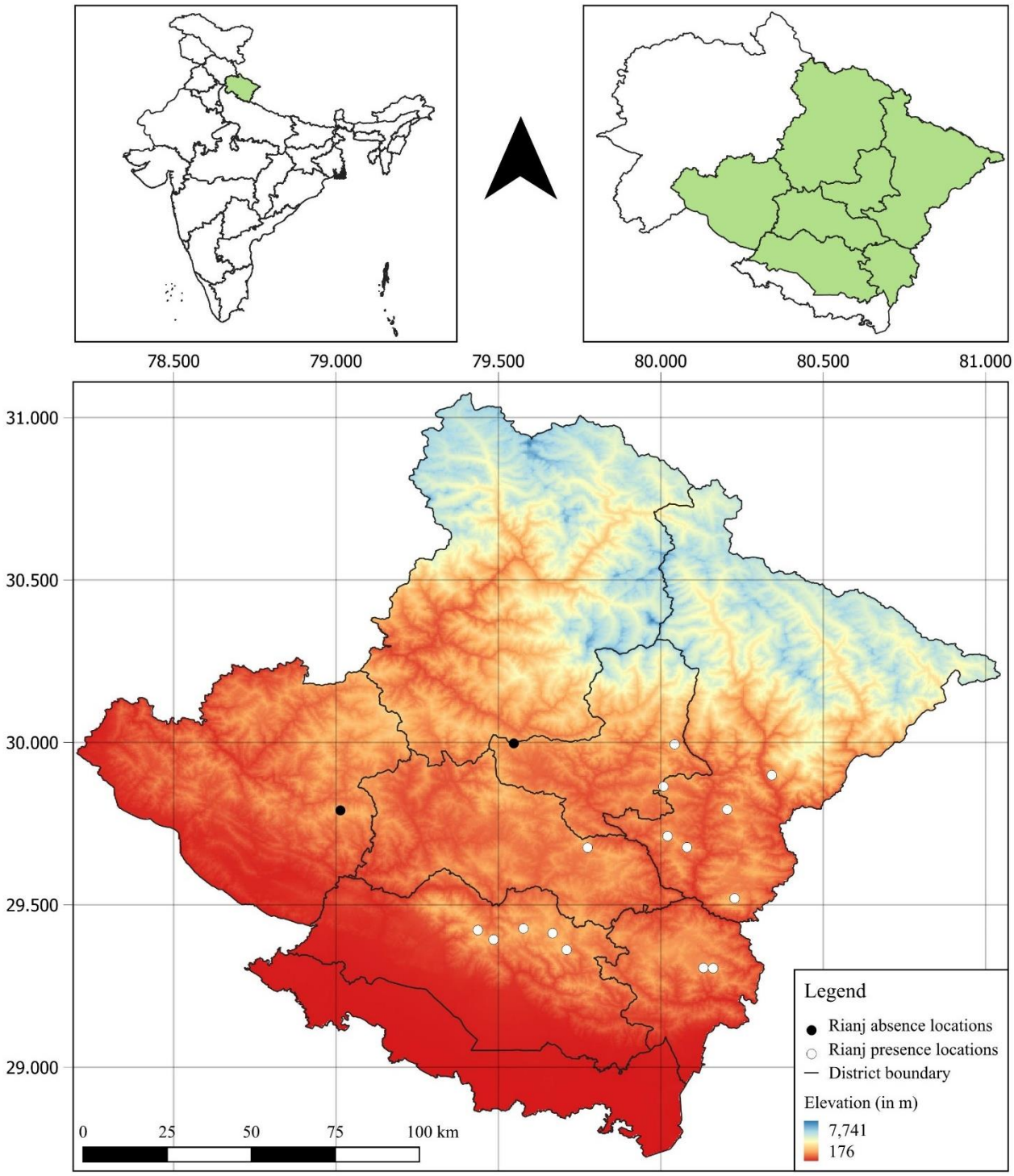

Figure 1. Study area map of *Quercus lanata* showing different sampling locations

Table 2. List of herbarium species examined for fieldwork.

S. No.	Herbaria	Accession No.	Collection No.	Location of collection	Date of collection	Collector name
1	Royal Botanical Garden Kew	K000832212	2772	Kumaon	1821	Robert Brown?
2	New York Botanicak Garden	NY4370736	217	Nainital	17-11-1961	A. Linn Bogle
3	New York Botanicak Garden	NY4370732	186	Chana Kana, Nepal	30-03-1929	Bis Ram
4	FRI Herbarium	6039	11	Almora	1913	J.H. Lyall
5	FRI Herbarium	11985	sn	Kilbury	25-09-1914	R.S. Troup
6	FRI Herbarium	11935	3	China range, Nainital	May-14	Shambhu Dutt Joshi
7	FRI Herbarium	-	s.n.	Nainital	1879	Col. Davidson
8	FRI Herbarium	63038	2285	East Almora	26-05-1933	Bis Ram
9	FRI Herbarium	11984	s.n.	Kilbury, Nainital	20-12-1914	R.S. Troup
10	FRI Herbarium	7386	4	Lariakanta, Nainital	25-04-1913	Urti Dutt
11	FRI Herbarium	50203	186	Chanu kana, Nepal	30-03-1929	Bis Ram
12	FRI Herbarium	51	14181	Almora border, Garhwal	15-02-1916	Sadanand Girola
13	FRI Herbarium	-	4381	Nainital	10-06-1885	J. F. Duthie
14	FRI Herbarium	-	479	Bheemtal	04-10-1849	s.coll.
15	FRI Herbarium	-	5966	Askot, Pithoragarh	04-05-1900	J. F. Duthie

2.2 Field methods

As no robust data was available on the patch size and extent of *Quercus lanata* forest, a reconnaissance survey was conducted in November 2024 at Manch, Champawat. Based on the reconnaissance survey and discussion with ground staff of forest department the aim of the study became clear, to capture variability in data in terms of variation in population structure, environmental variables and associate species. In order to cover a large area and after visualising a rough extent of patches, sampling plots where *Quercus lanata* is present were laid using the snowball sampling design. A minimum of two plots at small populations and a maximum of fourteen plots at largest population were laid. Species accumulation curves created from each location were also used as a supplementary to look at sampling completeness. The sampling was carried out at 15 locations where presence of *Quercus lanata* was observed (Table 3.). Objective-specific sampling methods are described below in detail.

Table 3. Details of sampling a carried out at each location.

S. No.	Locations	Number of sampling sites	Number of sampling plots
01.	Askot WLS	3	12
02.	Bhowali, (Pines)	2	8
03.	Binsar WLS	4	16
04.	Chaukodi	5	20
05.	Gangolihat	2	8
06.	Kilbury	6	24
07.	Kranteshwar	2	8
08.	Lamkeshwar	2	8
09.	Liti	3	12
10.	Manch	14	56
11.	Okhalkanda	6	24
12.	Ramgarh	2	8
13.	Sandev	4	16
14.	Sundarkhal	3	12
15.	Thalkedar	2	8
Total number of sampling sites			60
Total number of sampling plots			240

2.2.1 To understand the current population structure and regeneration status of *Quercus lanata* in the study area.

i. A 100 × 100 m grid (1 hectare) was established as primary sampling site. Within each grid, four circular plots of radius 10m were laid randomly as sampling plots. Each circular plot had two more concentric circular plots of radius 5m and radius 1m respectively.

ii. Circular plot of radius 10m: The abundance of *Quercus lanata* tree individuals and their girth at breast height (1.75m approx..) was recorded (Curtis et al., 1956).

iii. Circular plot of radius 5m: The abundance of *Quercus lanata* saplings was recorded (Curtis et al., 1956).

iv. Circular plot of radius 1m: The abundance of *Quercus lanata* seedlings was recorded (Curtis et al., 1956).

v. Additionally ocular canopy cover and overall lopping of tree individuals from centre of the plot for radius of 10m was recorded. For circular plot of a radius 5m cover of invasive species was recorded. Initially, all this data was recorded as percentages but later it was changed to categorical data as low medium and high based upon equal division from 100%.

2.2.2 To understand the site characteristics (habitat preference) of *Quercus lanata* including its associates in the study area.

i. Within each sampling plot, environmental variables such as slope, aspect (as categorical data), and elevation (in meter from Mean Sea Level) were recorded. To understand elevational preference of *Quercus lanata*, elevation data was categorised into four categories as follows (adapted and modified from Forest types of India by Champion and Seth, 1964):

- Lower elevation (1601m to 1900m)

- Lower middle elevation (1901m to 2150m)
- Middle elevation (2151m to 2300m)
- Upper elevation (2301-2600m)

ii. Circular plot of radius 10m: The abundance of all the co-occurring tree species along with *Quercus lanata* was recorded.

iii. Circular plot of radius 5m: The abundance of all the co-occurring shrub species along with *Quercus lanata* was recorded.

iv. All the specimens collected were first identified by Plant Net Application (Version 3.22.1) followed by various floras if identity was not satisfied.

2.2.3 To develop the habitat suitability model of *Quercus lanata* in its distributional region.

i. GPS coordinates were recorded using Locus map application (Version. 4.29.0) for all the sampling units. In addition to this opportunistic presence points of *Quercus lanata* individuals were also recorded during transit to other locations. GPS coordinates of absence of *Quercus lanata* in surrounding area with at least a distance of 1.5km were also recorded.

ii. Along with this opportunistic conversations and forest department personnel and local villagers were also carried out to understand their perspective on the population and distribution of *Quercus lanata* at respective locations.

2.3 Analytical methods

2.3.1 To understand the current population and regeneration status of *Quercus lanata* in the study area.

i. Bar graphs were used to visualise the population structure of *Quercus lanata* across different locations.

ii. A tree map was used to visualise the mean basal area of *Quercus lanata* across different locations.

iii. A comparison of mean densities of seedlings, saplings and trees, was used to compare between different sites. The following criteria were applied to understand regeneration status (Dhakal et al. 2022)

- Good Regeneration: Seedling density > Sapling density > Mature tree density
- Fair Regeneration: Seedling density ≥ Sapling density ≤ Mature tree density
- Poor Regeneration: Species present only in the sapling stage, absent as seedlings

iv. Bubble density map was used to visualise the mean seedling, sapling and tree density of *Quercus lanata* across Kumaon.

v. Variance mean ratio (VMR) was used to find the pattern of dispersion of *Quercus lanata* at different locations.

2.3.2 To understand the habitat preference of and major associates of *Quercus lanata* in the selected sites of Kumaon region.

i. Various negative binomial generalized linear models were developed for finding the effect of environmental variables on distribution of *Quercus lanata*.

ii. Rarefaction curves for associate tree species and associate shrub species were created to show sampling completeness.

iii. Bar plots and tables of density per hectare were made for associate tree and shrub species.

2.3.3 To develop the habitat suitability model of *Quercus lanata* in its distributional range in Kumaon.

i. All the available bioclimatic layers were downloaded from WorldClim website.

ii. NDVI layer was downloaded from Google Earth engine.

iii. Digital elevation model layer was downloaded from United States Geological Survey website.

iv. Arc GIS and QGIS was used to prepare the raster files.

v. Moran's I test was used to find autocorrelation between points followed by spatial thinning.

vi. Maxent software was used to develop the habitat suitability model. (Ganguly, 2011)

2.4 Effort

Fieldwork was carried out from December 2024 to mid-April 2025, over four and a half months. Within this period seventeen locations across seven different districts of Uttarakhand were covered to conduct the fieldwork. This includes Almora, Bageshwar, Chamoli, Champawat, Nainital, Pauri Garhwal, and Pithoragarh. Approximately 4,000 kilometers were transversed by vehicle to access various locations, and an additional 200 kilometers were covered on foot to sample the various locations. A total of sixty 1-hectare plots (sampling sites) were established across the study area, each containing four subplots (sampling units) for vegetation sampling. Circular plot of radius 10m for trees and circular plot of radius 5m for shrubs. This resulted in a total of 240 subplots for each vegetation type. The total area covered for tree sampling, based on 240 circular plots with a 10 m radius, was approximately 75,398 square meters (7.54 hectares). Across all sampled plots, a total of 2,136 individuals of *Quercus lanata* were recorded for girth at breast height (GBH), and opportunistically while travelling between locations, GPS coordinates of the presence of *Quercus lanata* were also recorded. (Refer to Table 2.4)

Table 4. Details of sampling effort

S. No.	Effort type	Total
01.	Number of districts covered	7
02.	Number of locations covered	17
03.	Distance covered by vehicle (in Km.) (approx.)	4000
04.	Distance covered on foot (in Km.) (approx.)	200
05.	Number of sampling units	240
06.	Total area sampled (in ha.)	7.536
07.	Number of Quercus lanata trees recorded for GBH	2132
08.	Number of GPS coordinated collected (opportunistically)	184
09.	Number of specimens submitted to WII Herbarium	23

3. Results

3.1 Population structure and regeneration status

3.1.1 Population structure

i. Kumaon

A total of 126 seedlings, 271 saplings and 2132 trees were recorded across all sampling sites in Kumaon. Figure 3.1 depicts a bell-shaped trend which shows stable and growing population of *Quercus lanata* across Kumaon. High relative density of sapling than seedlings depicts a good.

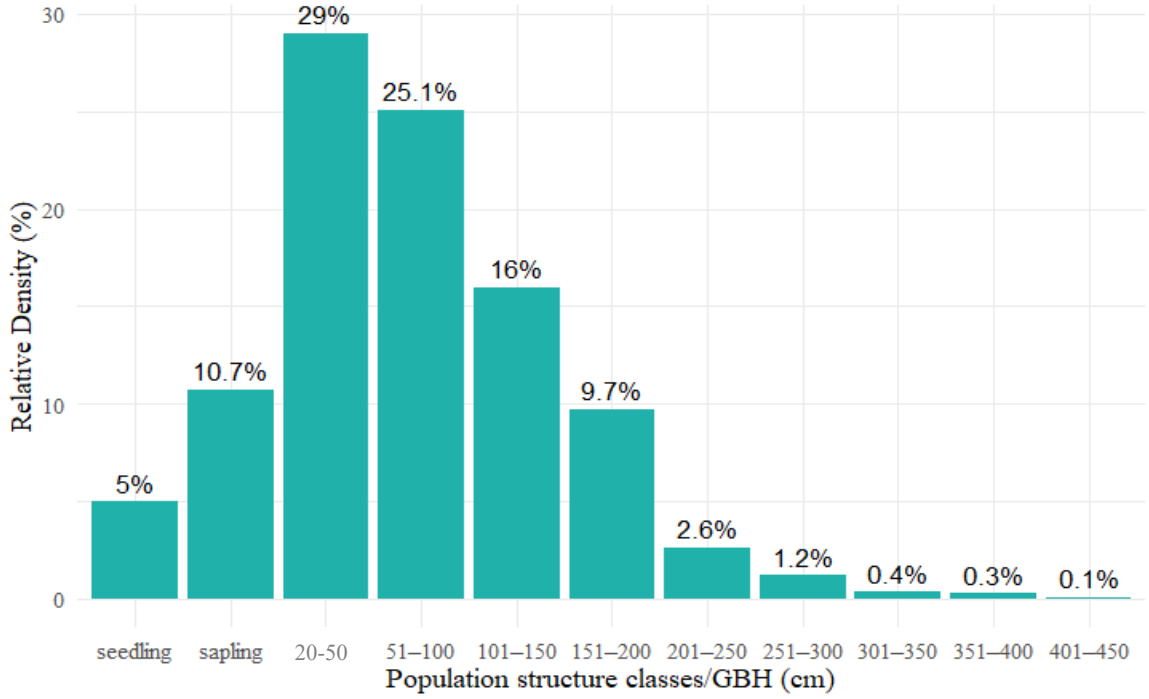

Figure 2. Overall population structure of *Quercus lanata* in Kumaon

ii. Askot Wildlife Sanctuary

A total of 267 individuals were recorded which includes 4 seedlings, 0 sapling and 263 trees. Figure 3. shows the highest proportion of lower girth class with very low seedlings and zero saplings.

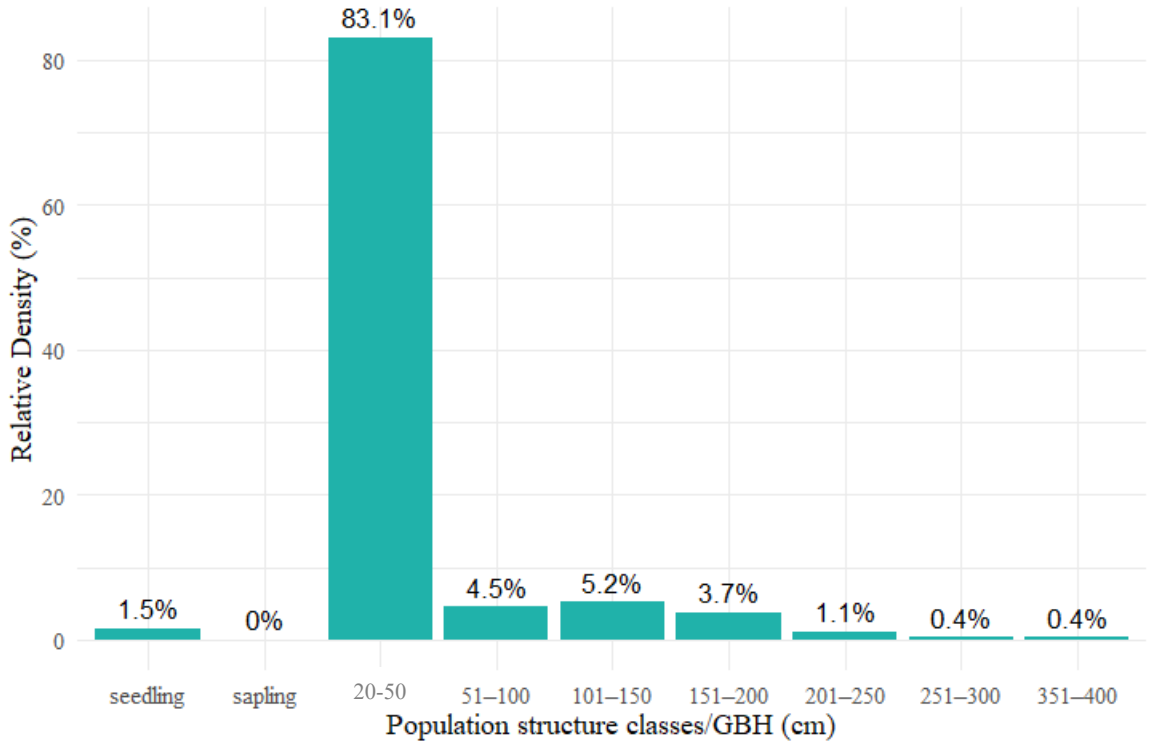

Figure 3. Population structure of *Quercus lanata* at Askot Wildlife Sanctuary, Pithoragarh

iii. Bhowali, (Pines)

A total of 72 individuals were recorded which includes 5 seedlings, 3 saplings and 72 trees. Figure 4. shows the highest proportion in 101-150 girth class. Overall, graph is like bell-shaped which depicts a stable population.

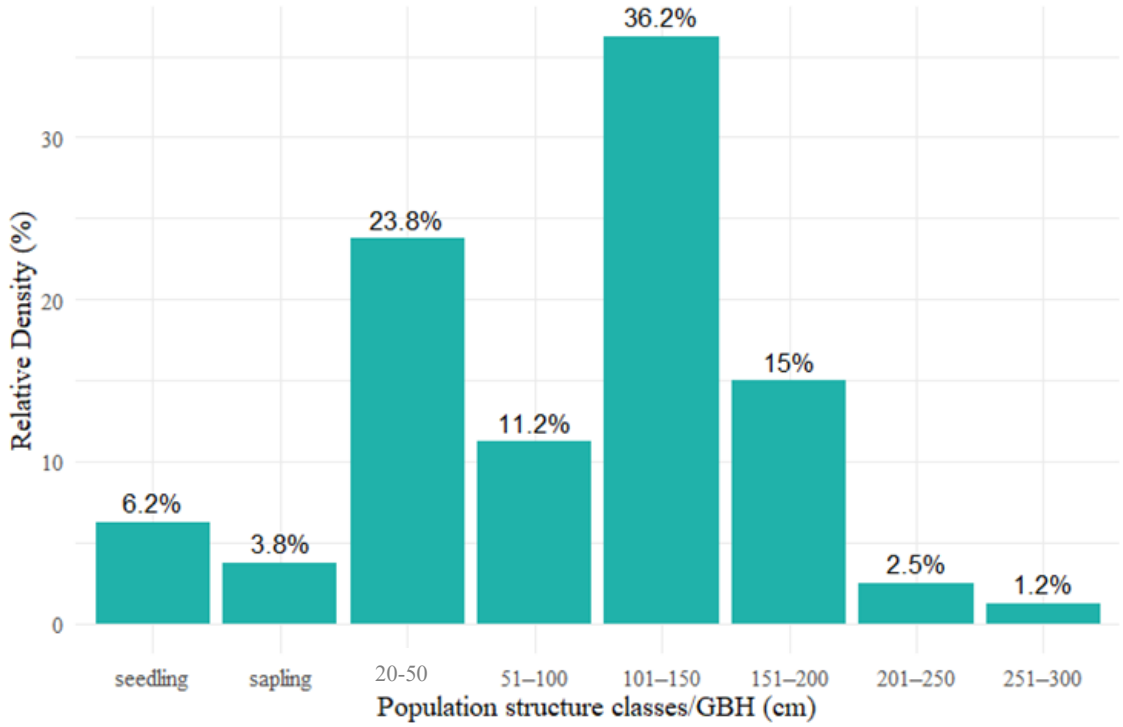

Figure 4. Population structure of *Quercus lanata* at Bhowali, Nainital

iv. Binsar Wildlife Sanctuary

A total of 208 individuals were recorded which includes 11 seedlings, 76 saplings and 121 trees. Figure 5. shows a highest percentage of saplings followed by girth classes where 1-50 has highest percentage. Figure 5. overall depicts a bell-shaped curve with a stable population.

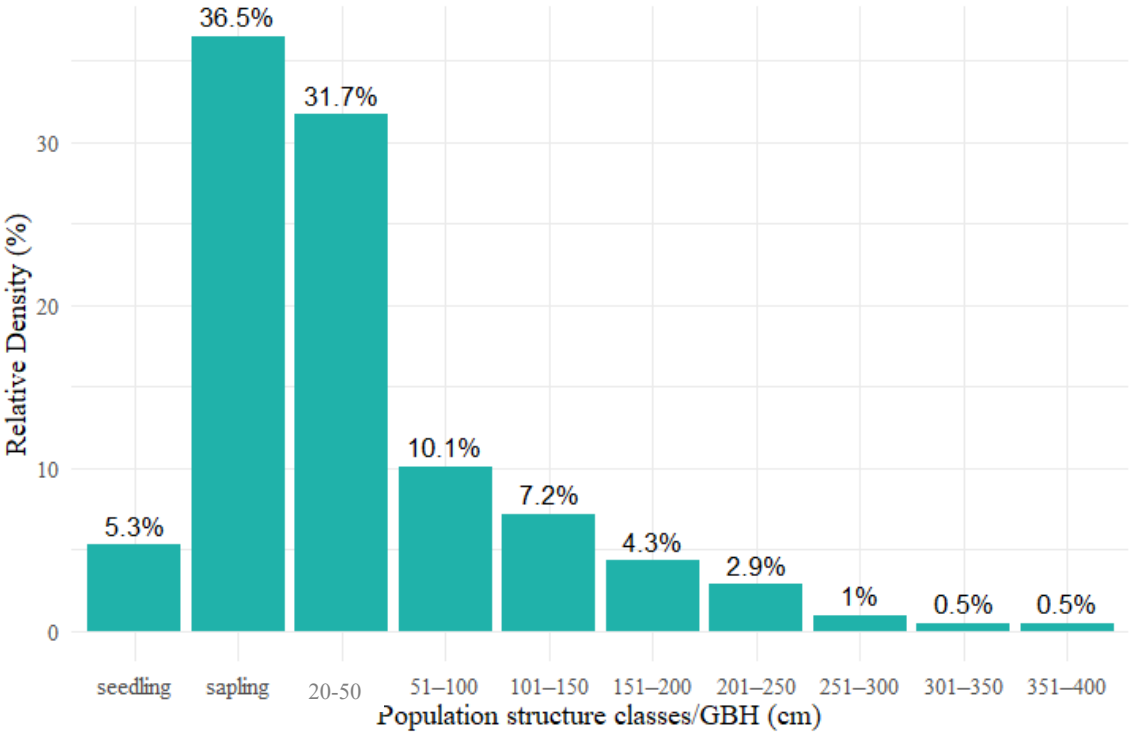

Figure 5. Population structure of *Quercus lanata* at Binsar Wildlife Sanctuary, Almora

v. Chaukodi

A total of 167 individuals were recorded which includes 14 seedlings, 8 saplings and 145 trees. Figure 6. Depicts a stagnant population with only 51-100 girth class have more than 50% of population. Population of rest of the classes is comparatively very low.

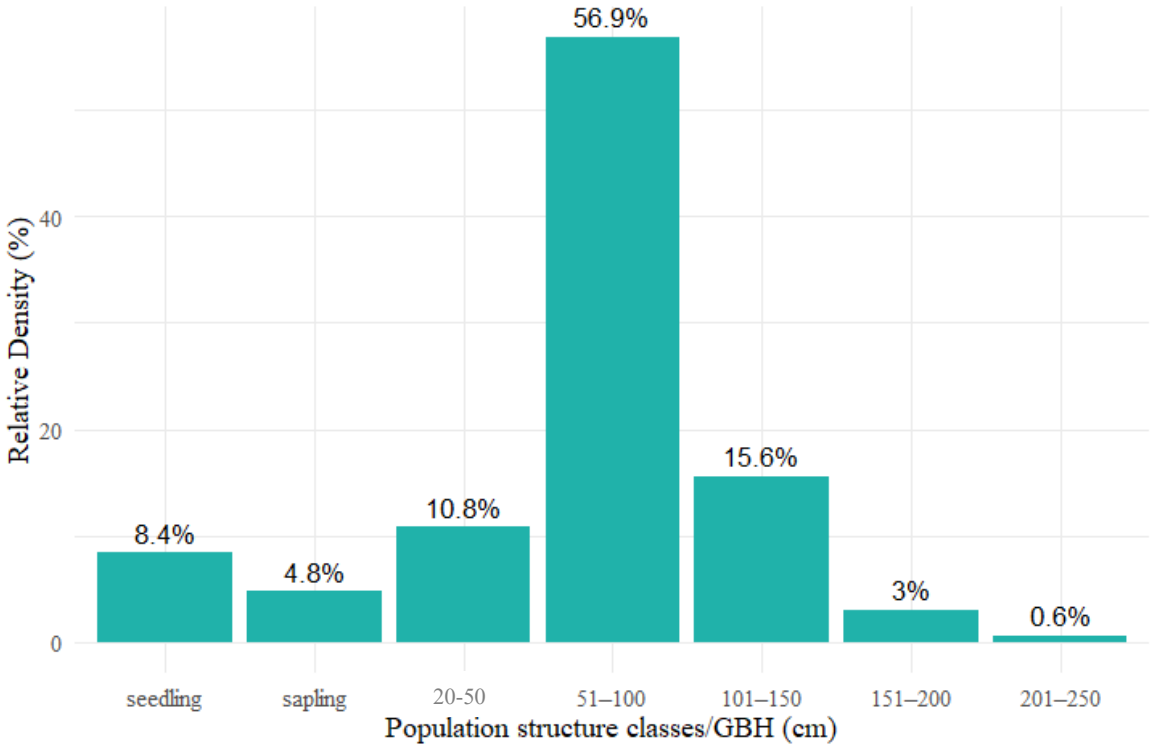

Figure 6. Population structure of *Quercus lanata* at Chaukodi

vi. Gangolihat.

A total of 245 individuals were recorded which includes 2 seedlings, 6 saplings and 237 trees.

Only 1-50 girth class has the highest percentage of individuals which suggests that it is still an establishing young population. (Figure 7.)

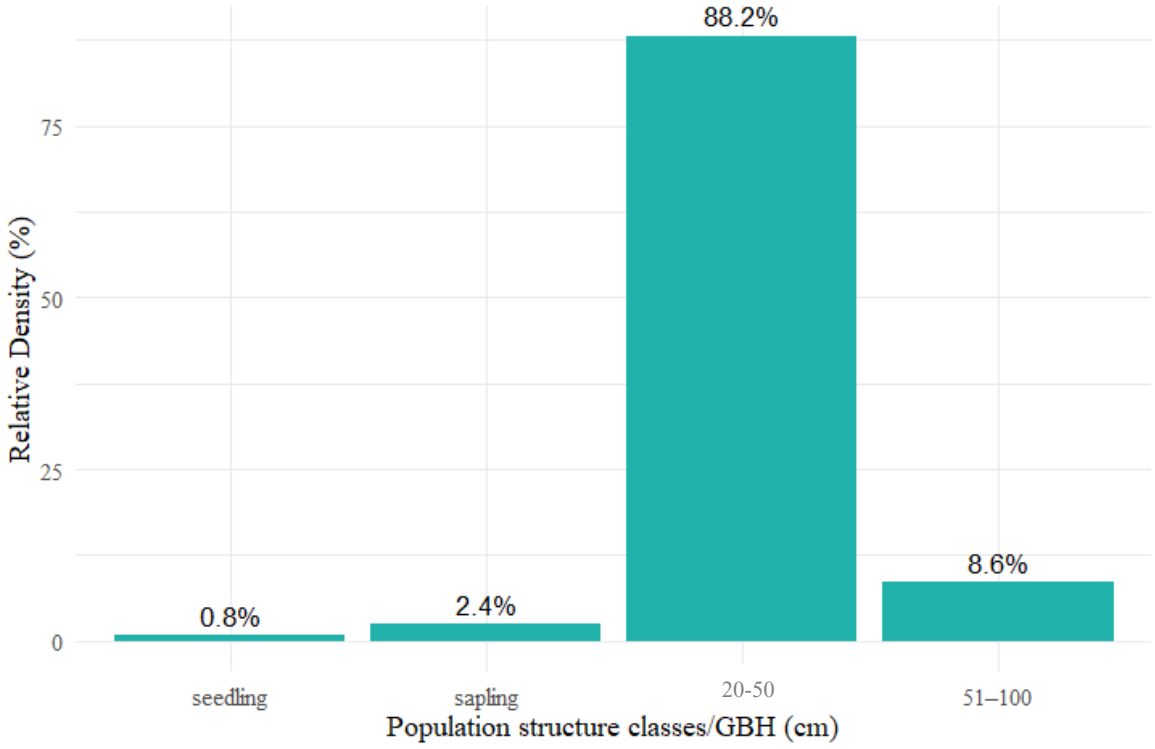

Figure 7. Population structure of *Quercus lanata* at Gangolihat

vii. Kilbury

A total of 487 individuals were recorded which includes 39 seedlings, 9 saplings and 439 trees. Figure 8. depicts a proper bell-shaped curve which shows it's a stable population. Kilbury is a part of Naina Devi Bird Conservation Reserve, therefore it has a very minimal amount of disturbance.

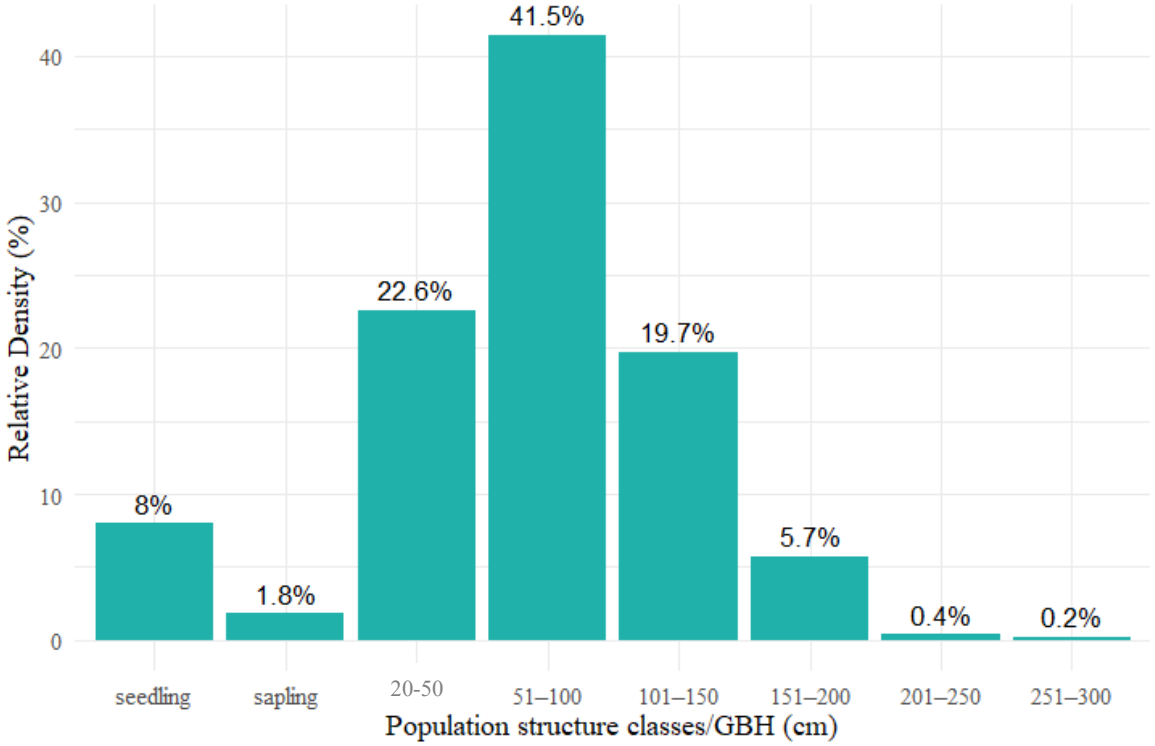

Figure 8. Population structure of *Quercus lanata* at Kilbury

viii. Kranteshwar.

A total of 44 individuals were recorded which includes 5 seedlings, 6 saplings and 33 trees. Figure 9. Depicts a bell-shaped curve which shows and percentage of seedlings and saplings are higher than those larger girth classes which shows that it's stable and growing population.

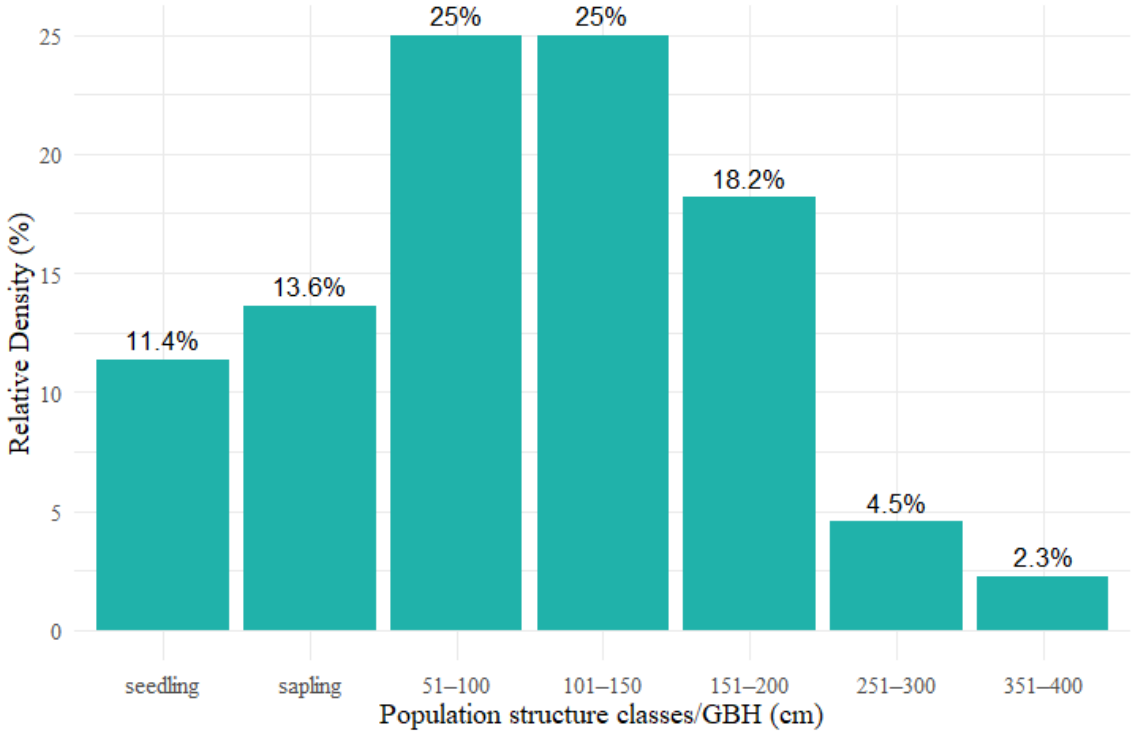

Figure 9. Population structure of *Quercus lanata* at Kranteshwar

ix. Lamkeshwar.

A total of 56 individuals were recorded which includes 0 seedlings, 8 saplings and 48 trees. Seedlings are completely absent while some saplings are present followed by lower girth classes.

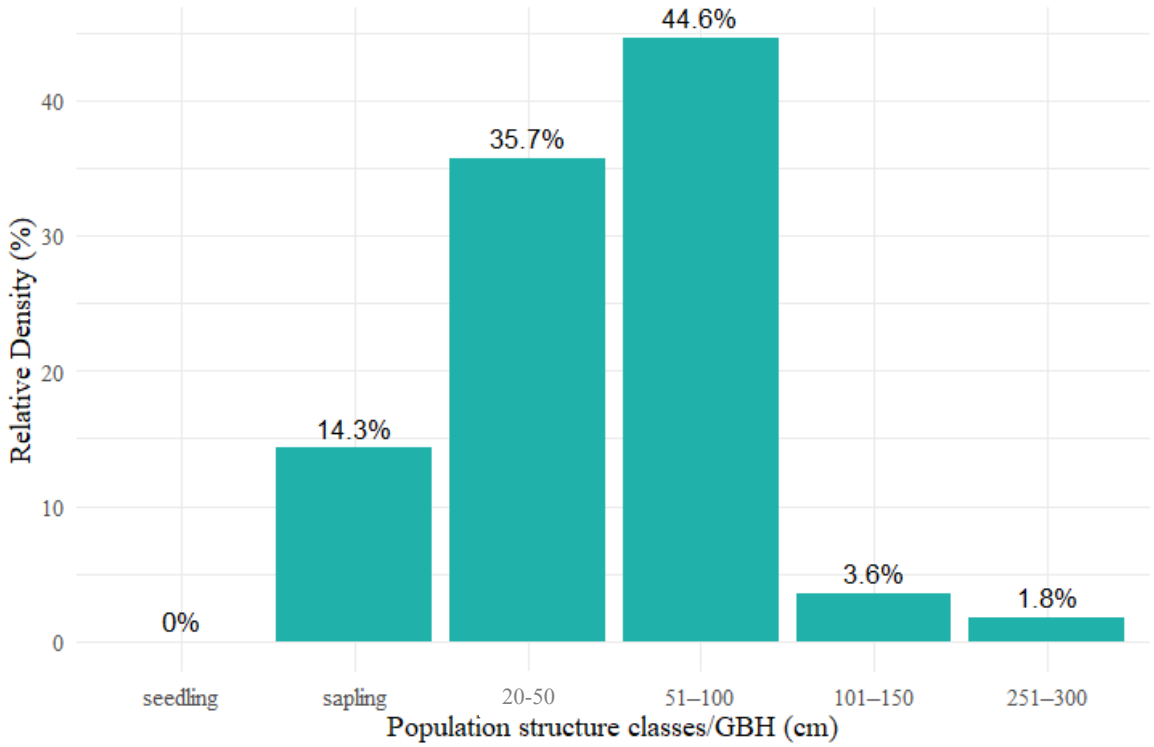

Figure 10. Population structure of *Quercus lanata* at Lamkeshwar

x. Liti

A total of 115 individuals were recorded which includes 4 seedlings, 3 saplings and 108 trees. Highest percent is contributed by 51-100 girth class; this shows a sign of stagnant population with very less young individuals available to replace the older individuals.

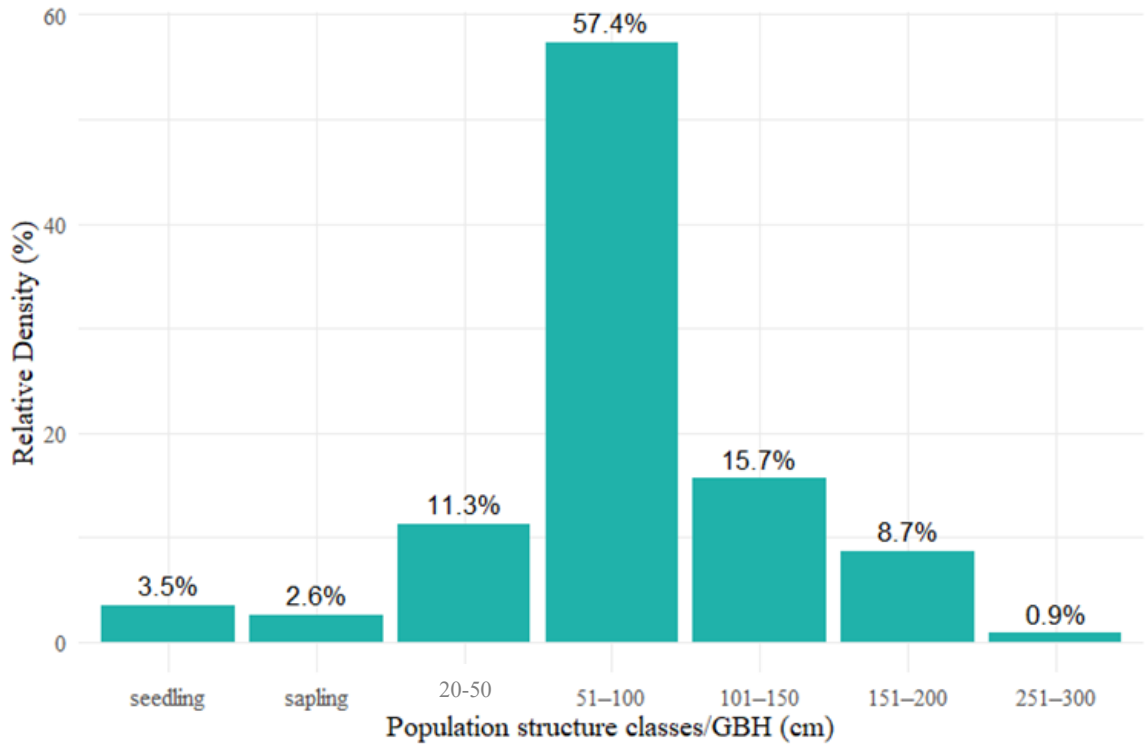

Figure 11. Population structure of *Quercus lanata* at Liti

xi. Manch.

A total of 411 individuals were recorded which includes 13 seedlings, 58 saplings and 340 trees. Manch shows a stable and growing population with high proportion of lower girth class individuals followed by saplings and seedlings.

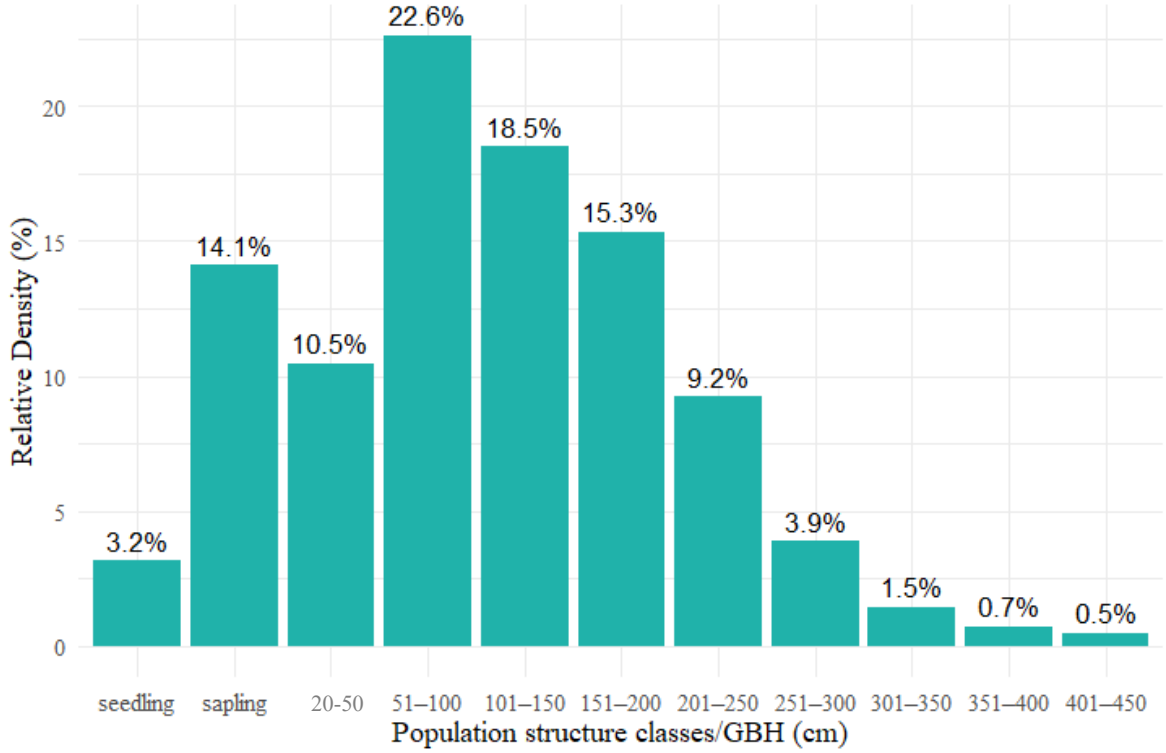

Figure 12. Population structure of *Quercus lanata* at Manch

xii. Okhalkanda

A total of 184 individuals were recorded which includes 14 seedlings, 45 saplings and 125 trees. Okhalkanda shows higher proportion of saplings but very low proportion of lower girth class when compared with higher girth class.

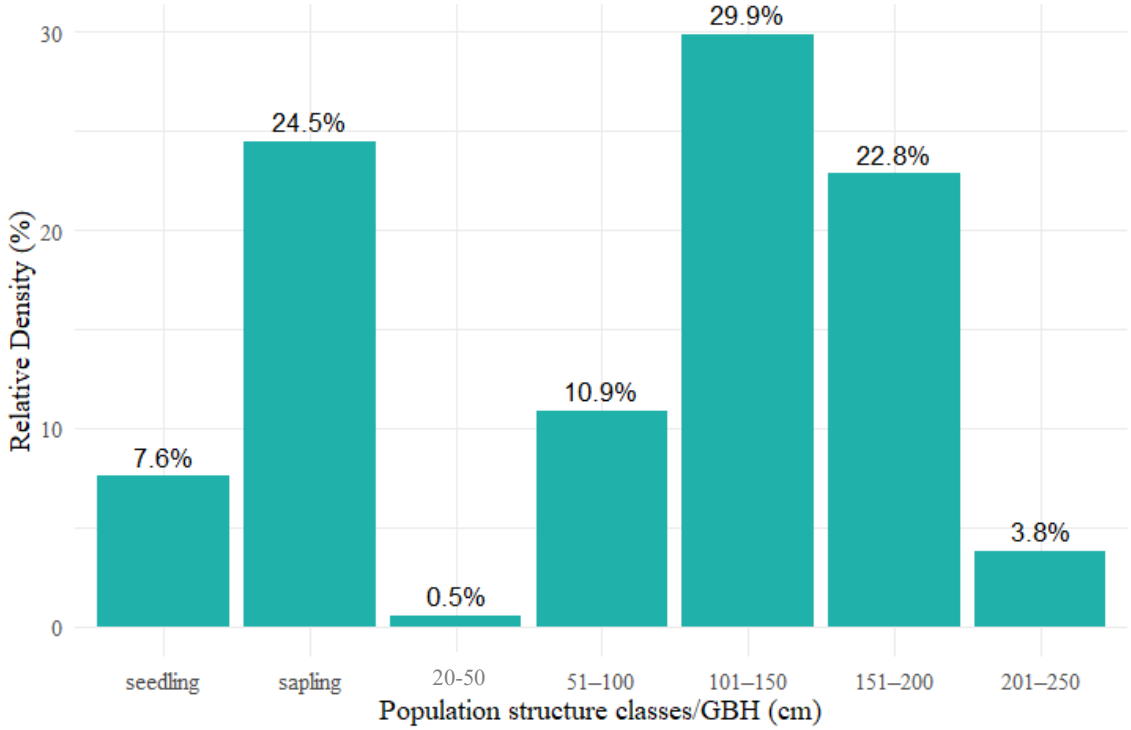

Figure 13. Population structure of *Quercus lanata* at Okhalkanda

xiii. Ramgarh

A total of 57 individuals were recorded which includes 04 seedlings, 15 saplings and 38 trees.

Ramgarh shows high sapling establishment but lower proportion of individuals in lower girth class. The graph appears to be staggered.

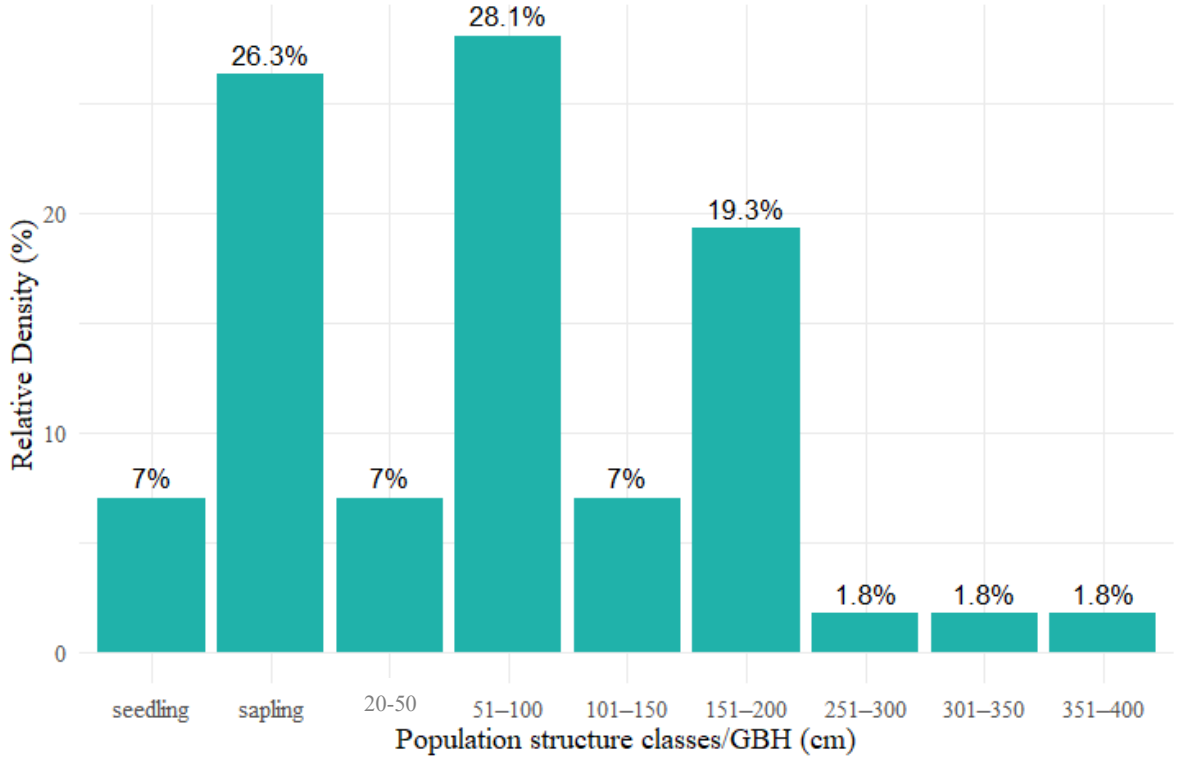

Figure 14. Population structure of *Quercus lanata* at Ramgarh

xiv. Sandev

A total of 47 individuals were recorded which includes 04 seedlings, 14 saplings and 30 trees. Population of Sandev shows a stable pattern with highest proportion of individuals from middle girth class. Young individuals are also present showing a gradually growing population.

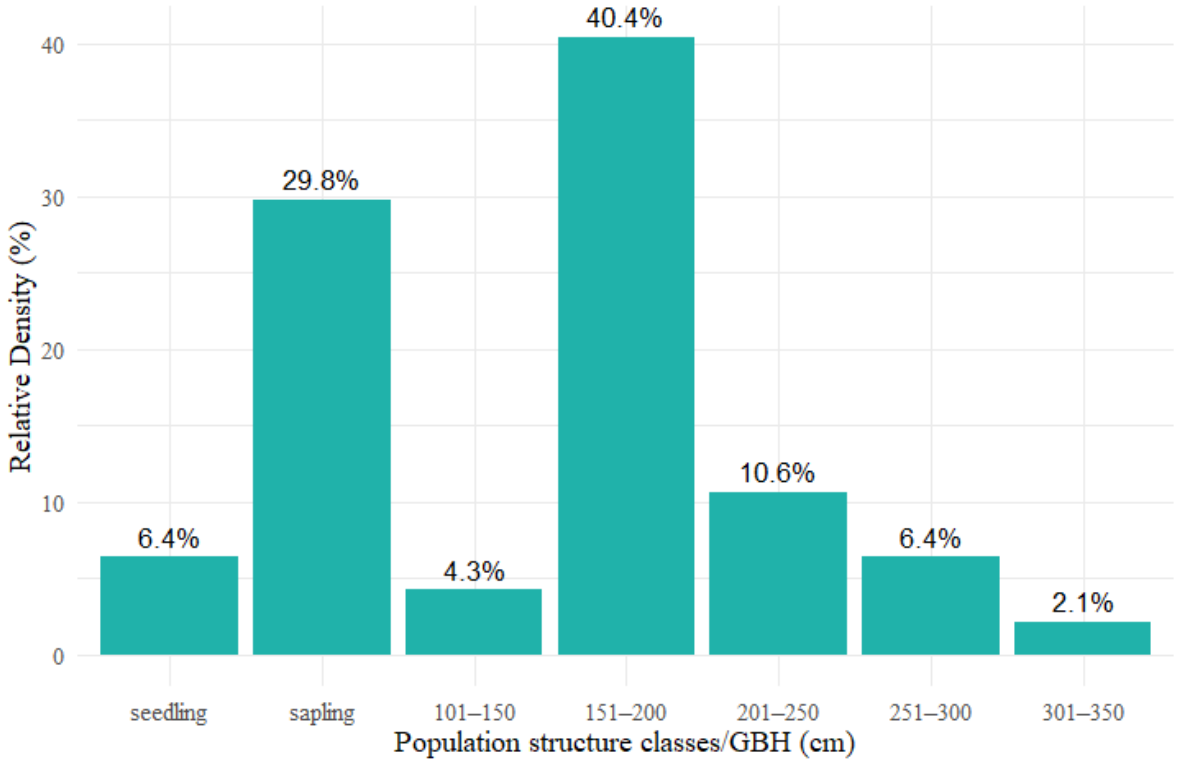

Figure 15. Population structure of *Quercus lanata* at Sandev

xv. Sundarkhal

A total of 75 individuals were recorded which includes 7 seedlings, 19 saplings and 49 trees. Sundarkhal shows higher proportion of saplings when compared with seedlings and higher proportion of individuals in lower girth class.

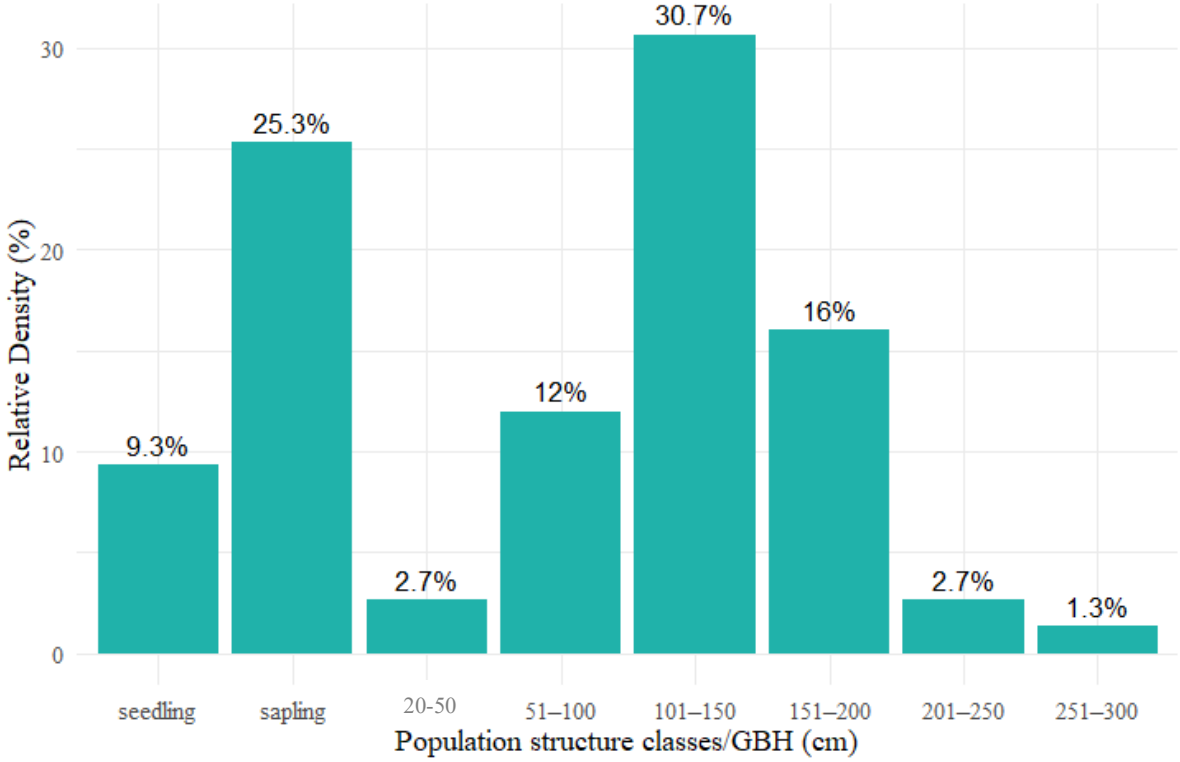

Figure 16. Population structure of *Quercus lanata* at Sundarkhal

xvi. Thalkedar, Pithoragarh

A total of 86 individuals were recorded which includes 1 seedling, 1 sapling and 84 trees. Thalkedar population only has larger girth class individuals with very few seedlings and saplings showing a declining population.

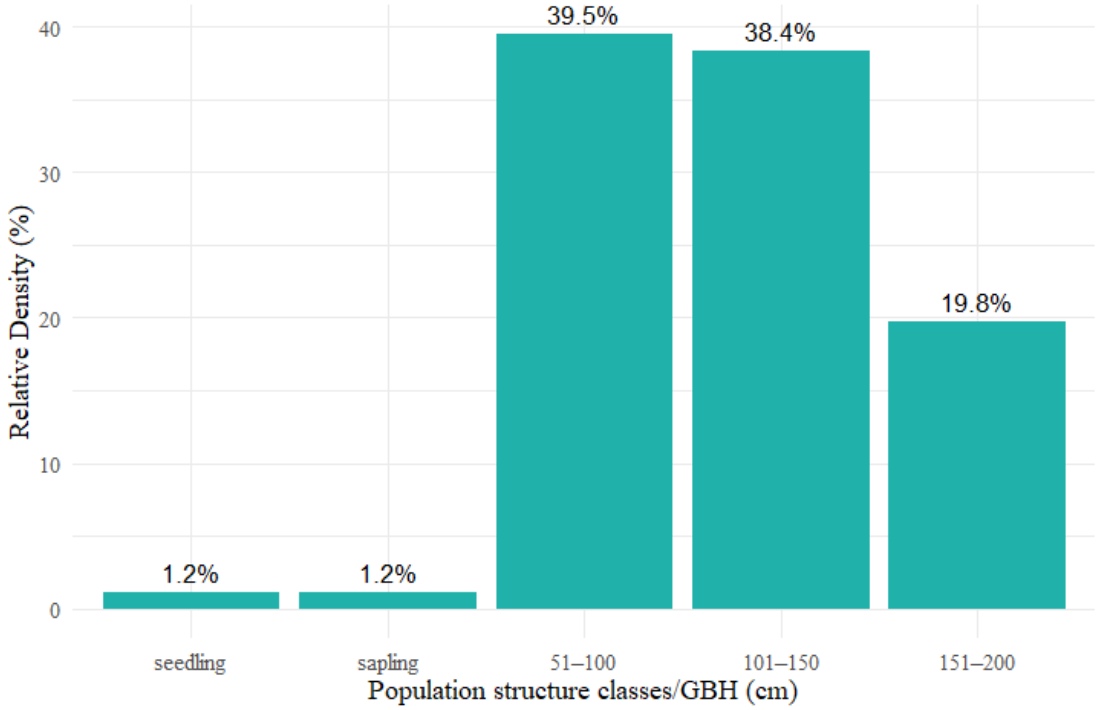

Figure 17. Population structure of *Quercus lanata* at Thalkedar

3.1.2 Mean girth at breast height and mean basal area.

A total of 2132 adult trees varying in girth classes, ranging from 11cm to 433cm were recorded. The mean GBH of whole population was 90.08 ± 63.38cm (SD, n = 2132). Gangolihat has lowest GBH 35.19cm while Sandev has highest GBH 193.70cm. (Refer to Appendix)

The basal area was calculated location-wise. The highest basal area was recorded at Kilbury (39.52 m^2/ha) and the lowest basal area was recorded at Lamkeshwar (7.56 m^2/ha). Refer to Figure 18.

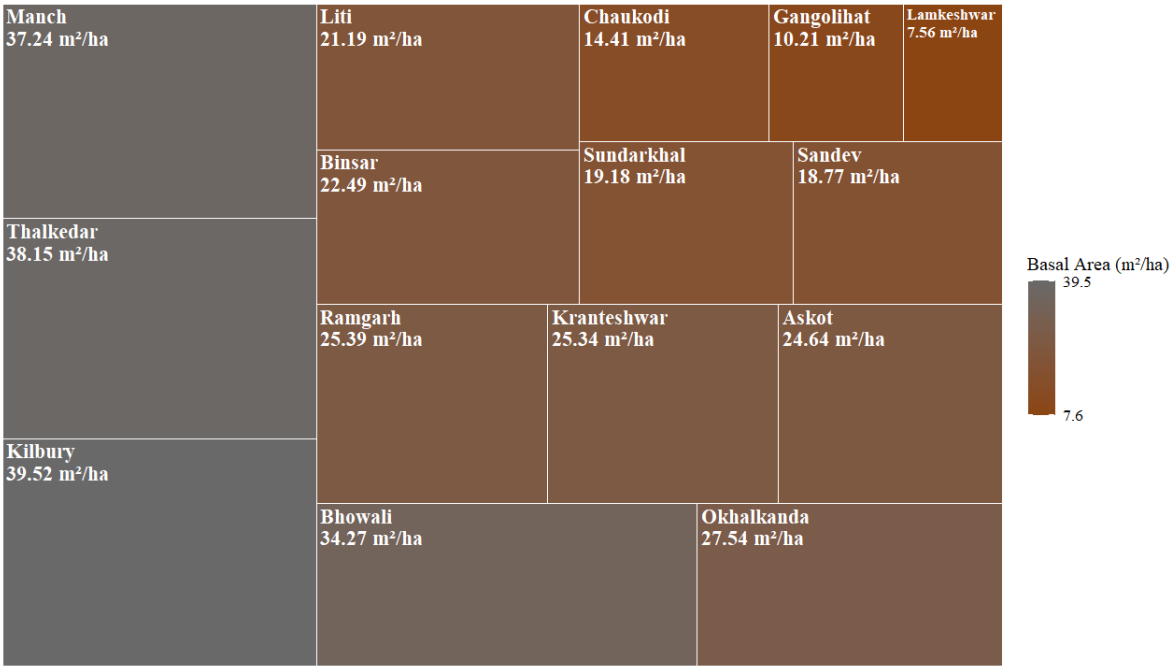

Figure 18. Average basal area(m^2/ha.) of *Quercus lanata* across all locations.

3.1.3 Densities of trees, saplings and seedlings

i. Tree density

The highest density was recorded at Gangolihat 942.99 ± 301.94 individuals/ha. and the lowest density was recorded at 59.68 ± 25.66 individuals/ha. (Refer to Appendix)

Gangolihat is a newly establishing population which is the reason why it has such high density of individuals whereas at Sandev mostly old-growth individuals are present with sporadic distribution. Figure 19. Shows bubble density map of tree density of *Quercus lanata*.

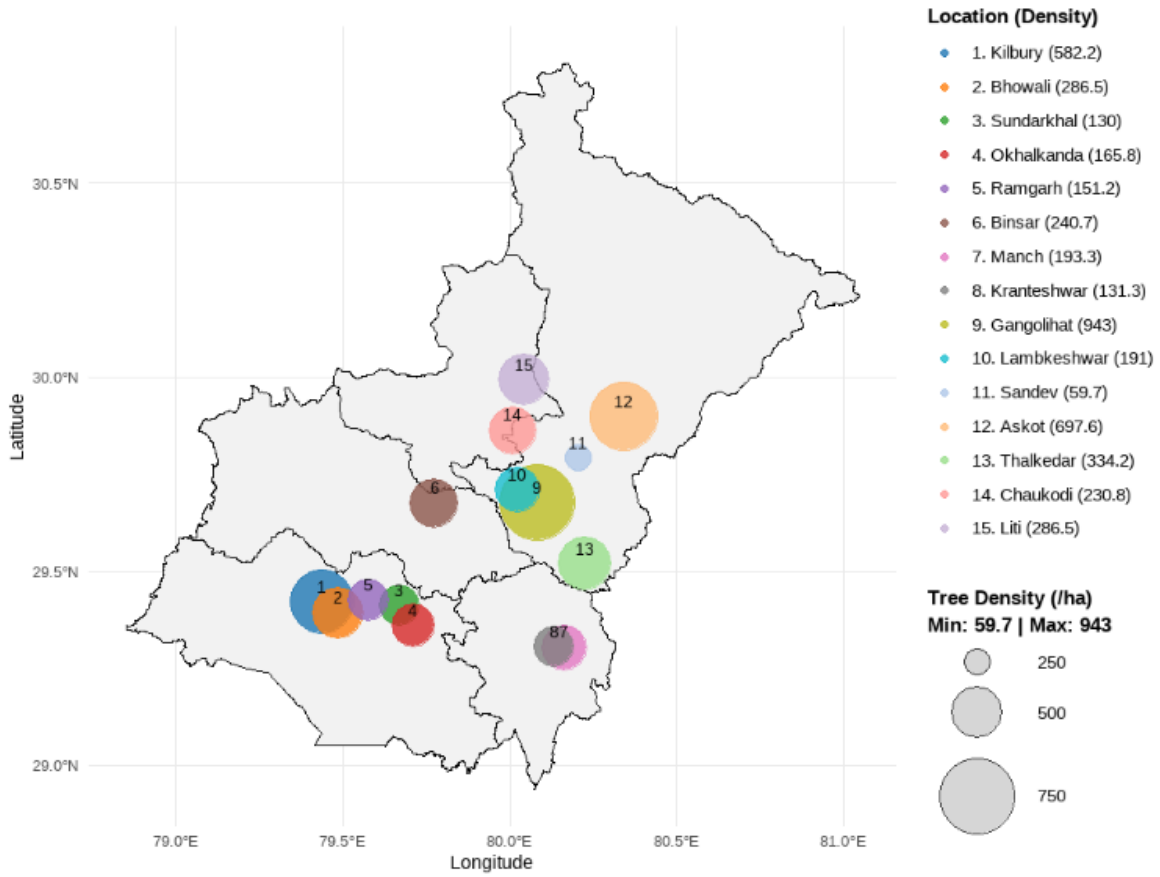

Figure 19. Mean tree density of *Quercus lanata* across Kumaon

ii. Sapling density

The highest density was recorded at Binsar 604.79 ± 601.71 individuals/ha. and the lowest density was recorded at Askot with no presence in the sample plots. (Refer to Appendix) The absence of sapling at Askot should only be accounted as absence within the sampled area.

Figure 20. Shows a bubble density map of sapling density of *Quercus lanata*.

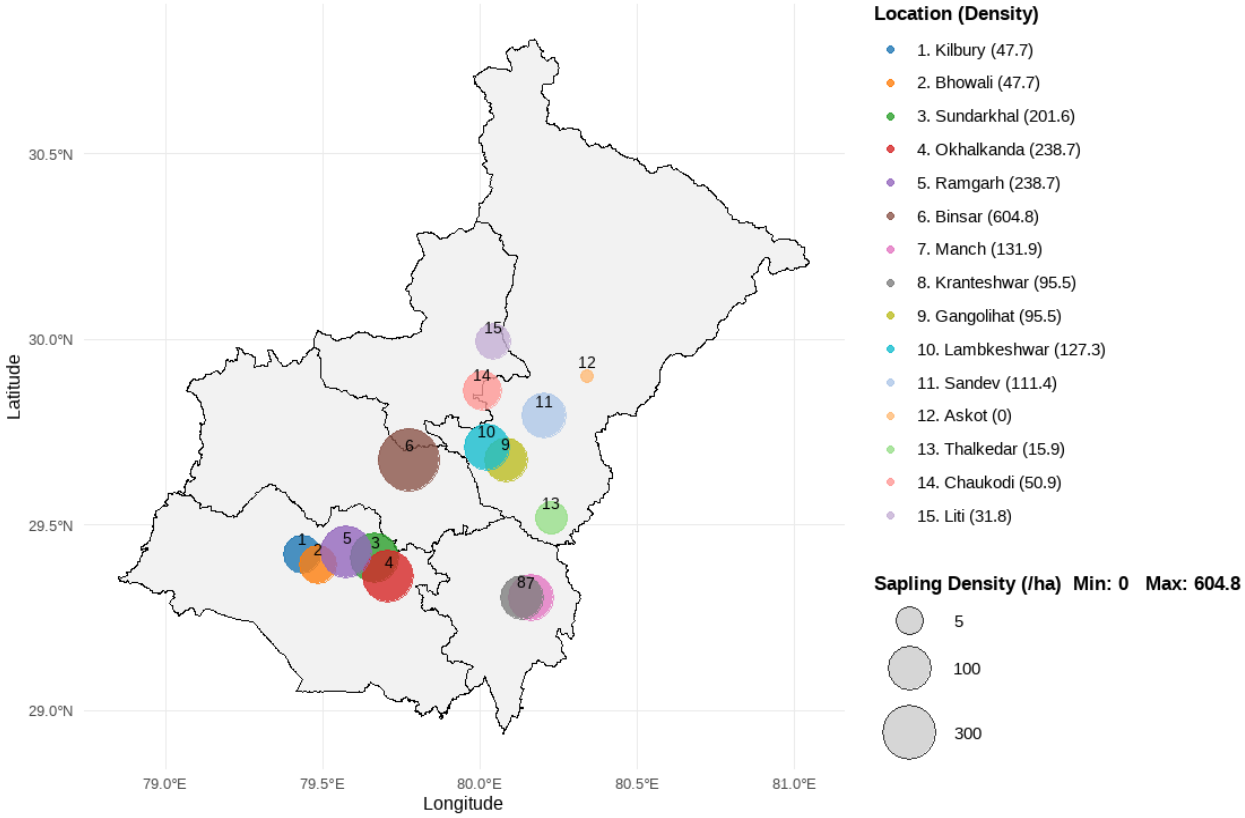

Figure 20. Mean sapling density of *Quercus lanata* across Kumaon

iii. Seedling density

The highest density was recorded at Kilbury 5172.52 ± 4383.82 individuals/ha. and the lowest density was recorded at Lamkeshwar with no presence in the sample plots. (Refer to Appendix) The absence of seedling at Lamkeshwar should only be accounted as absence within the sampled area.

Figure 21. Shows a bubble density map of seedling density of *Quercus lanata*.

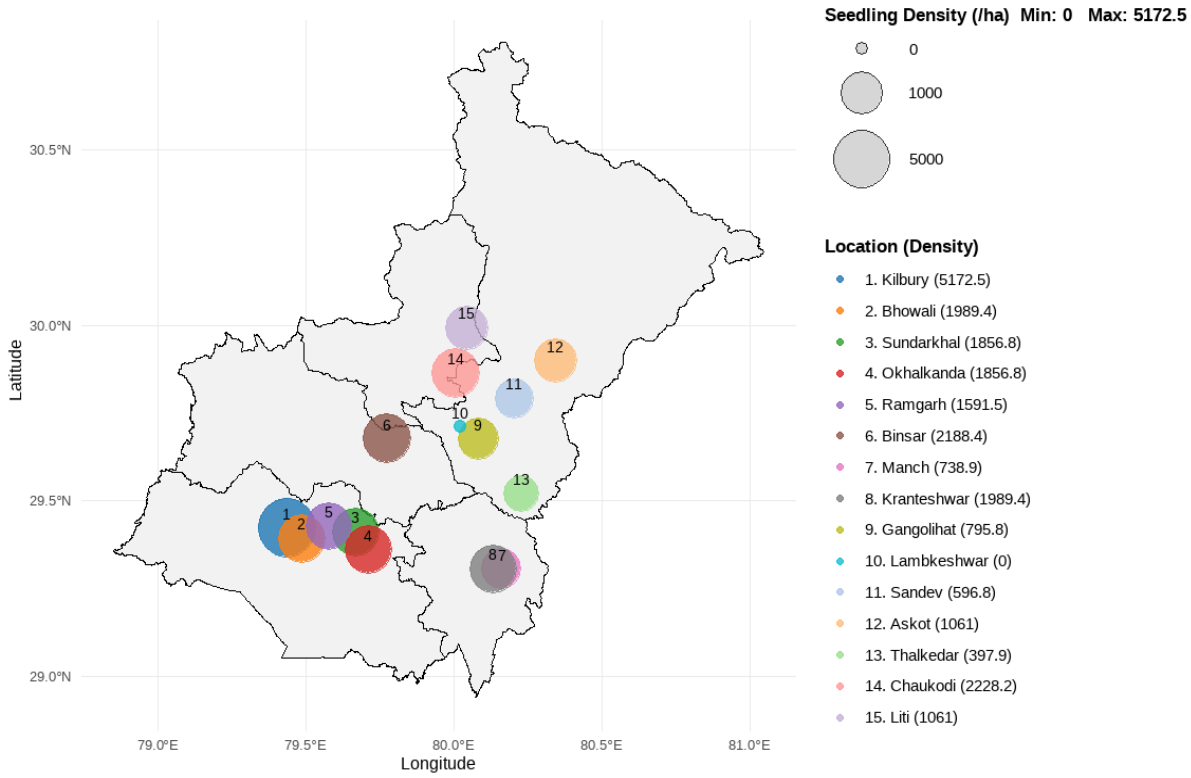

Figure 21. Mean seedling density of *Quercus lanata* across Kumaon

iv. Densities across different forest types

Based upon the elevation gradient densities were calculated for each forest type. The highest density was recorded in Middle temperate forest followed by lower temperate forest. (Refer to appendix). Figure 22. Depicts the densities across different forest types.

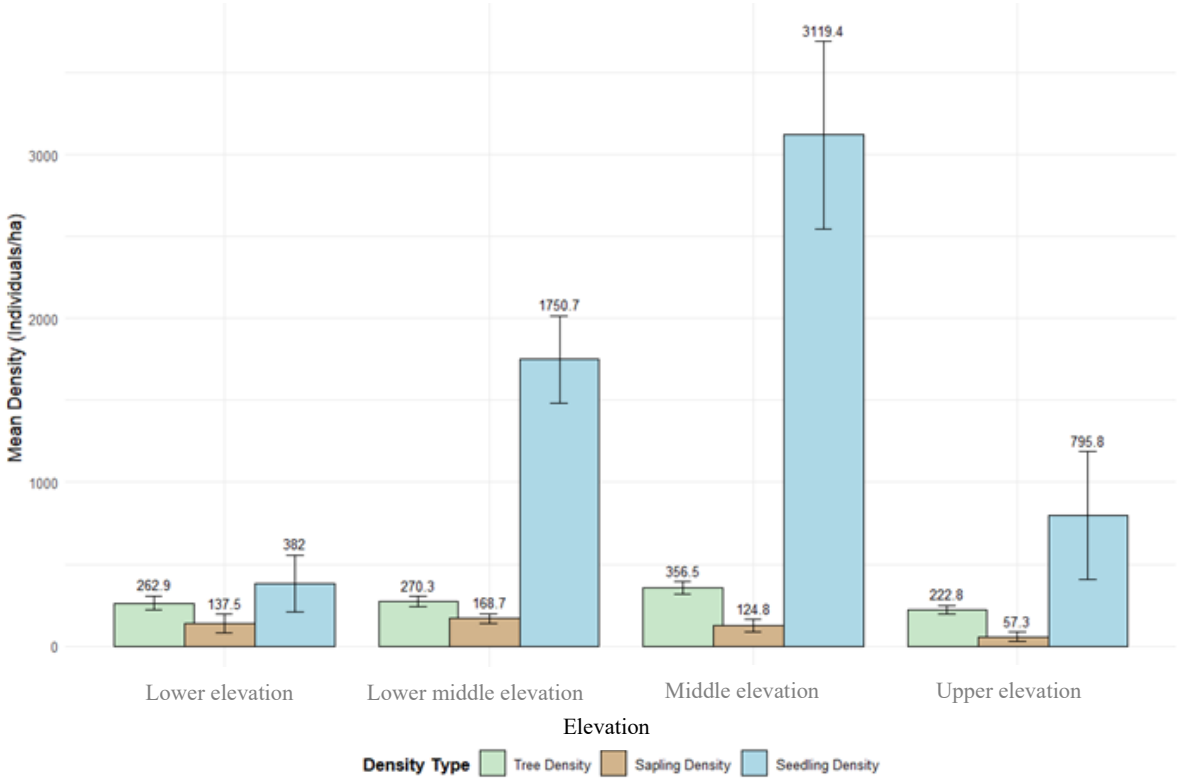

Figure 22. Mean densities of *Quercus lanata* across different forest types

v. Densities across different aspects

The densities do not show much difference across the different aspects. Though the values are slightly higher for southern aspect but don't differ much from other aspect values. (Refer to Appendix). Figure 23. Depicts the densities across different aspects.

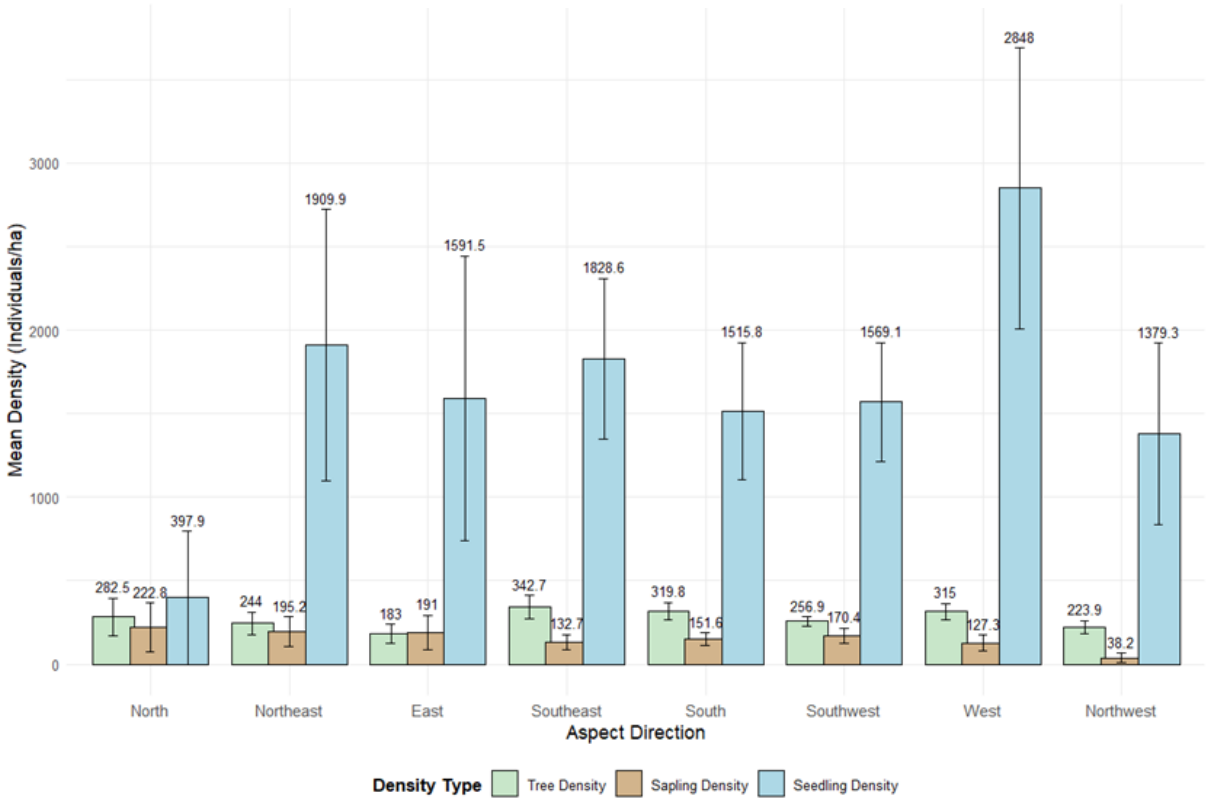

Figure 23. Mean densities of *Quercus lanata* across different aspects

3.1.4 Regeneration status

i. The following criteria were used to estimate the regeneration status of *Quercus lanata*.

- Good Regeneration: Seedling density > Sapling density > Mature tree density
- Fair Regeneration: Seedling density ≥ Sapling density ≤ Mature tree density
- Poor Regeneration: Species present only in the sapling stage, absent as seedlings

Five locations showed good regeneration, nine locations showed fair regeneration and only one location showed poor regeneration.

ii. Seedling to sapling establishment rate: Percentage of seedlings that successfully established and grew into saplings.

Lamkeshwar showed poor regeneration as no seedlings were recorded. (Table 5.)

Table 5. Regeneration status and establishment rate of *Quercus lanata* across Kumaon

S. No.	Location	Seedling density/ha.	Sapling density/ha.	Tree density/ha.	Regeneration status	Est. rate %
01.	Askot WLS	1061	-	697.6	fair	-
02.	Bhowali, (Pines)	1989.4	47.7	286.5	fair	2.4
03.	Binsar WLS	2188.4	604.8	240.7	good	27.67
04.	Chaukodi	2228.2	50.9	230.8	fair	2.28
05.	Gangolihat	795.8	95.5	943	fair	12
06.	Kilbury	5172.5	47.7	582.2	fair	0.92
07.	Kranteshwar	1989.4	95.5	131.3	fair	4.8
08.	Lamkeshwar	-	127.3	191	poor	-
09.	Liti	1061	31.8	285.5	fair	3
10.	Manch	738.9	131.9	193.3	fair	17.85
11.	Okhalkanda	1856.8	238.7	165.8	good	12.86
12.	Ramgarh	1591.5	238.7	151.2	good	15
13.	Sandev	596.8	111.4	59.7	good	18.67
14.	Sundarkhal	1856.8	201.6	130	good	10.86
15.	Thalkedar	397.9	15.9	334.2	fair	4

3.2 Habitat characterisation of and major associates of *Quercus lanata* in the selected sites of Kumaon region

3.2.1 Habitat characterization

To understand the habitat of *Quercus lanata*, aspect, slope and elevation data was collected from field along with data of common associates that co-occur with *Quercus lanata*.

i. Test for multicollinearity

To find multicollinearity, the Variance Inflation Factor (VIF) was calculated for all the predictor variables. From Table 6. it is clear that Generalized VIF values are below the threshold of 5. Therefore, multicollinearity was not an issue while running Generalised linear models (GLMs).

Table 6. Test for multicollinearity

S. No.	Variable Name	Generalized VIF	Degrees of Freedom	Adjusted VIF
01.	Slope	1.15	1	1.07
02.	Aspect	1.58	7	1.03
03.	Canopy Cover	1.87	2	1.17
04.	Lopping	1.96	2	1.18
05.	Invasive species	2.06	2	1.2

ii. Models AIC comparison to understand effect of environmental variables on distribution of *Quercus lanata* in Kumaon.

In order to understand how environmental variables affect the distribution of *Quercus lanata* eleven negative binomial models were developed. The negative binomial models were chosen because the data shows overdispersion (321.46) as the variance is quite higher than mean. The Akaike Information Criterion (AIC) of all the models with the lowest AIC was short-listed.

Table 7. AIC values of all Generalised Linear Models developed

S. No.	Models	AIC value
01.	Interaction: Aspect × Elevation	1532.6
02.	Single: Elevation	1538.02
03.	Single: Slope	1538.2
04.	Additive: Slope + Elevation	1540.02
05.	Interaction: Slope × Elevation	1541.1
06.	Single: Aspect	1541.17
07.	Additive: Aspect + Elevation	1542.84
08.	Additive: Slope + Aspect	1543.13
09.	Additive: All	1544.78
10.	Interaction: Slope × Aspect × Elevation	1545.1
11.	Interaction: Slope × Aspect	1548.7

iii. Effect of aspect and elevation on distribution of *Quercus lanata*

From the table 8. It is clear that south aspect, Southeast aspect, Southwest aspect, Elevation and interactive models show a significant p-value of <0.05. This explains that south aspects and elevation do play a role in characterizing the habitat for *Quercus lanata*.

Table 8. Interactive model of aspects and elevation for habitat characterisation of *Quercus lanata*

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-10.9417	4.731209	-2.313	0.020741
Aspect S	**17.05238**	**5.059796**	**3.37**	**0.000751**
Aspect E	12.43822	7.563071	1.645	0.100052
Aspect W	9.901487	5.369437	1.844	0.065176
Aspect NE	8.251553	5.464699	1.51	0.13105
Aspect NW	9.566656	4.994049	1.916	0.055415
Aspect SE	**15.33701**	**4.97715**	**3.081**	**0.00206**
Aspect SW	**12.88025**	**4.834556**	**2.664**	**0.007717**
Elevation	**0.00637**	**0.002327**	**2.737**	**0.006193**
Aspect S × Elevation	-0.00823	0.002483	-3.315	0.000917
Aspect E × Elevation	-0.00625	0.003681	-1.697	0.089669
Aspect W × Elevation	-0.00474	0.002639	-1.797	0.072294
Aspect NE × Elevation	-0.00394	0.002722	-1.446	0.148145
Aspect NW × Elevation	-0.0047	0.002463	-1.909	0.05621
Aspect SE × Elevation	-0.00736	0.002447	-3.009	0.00262
Aspect SW × Elevation	-0.0063	0.002374	-2.653	0.007979
AIC:	1532.6			
Null deviance	278.91	239	Degree of freedom	
Residual deviance	243.14	224	Degree of freedom	
Theta:	1.878			
Std. Error	0.196			

iv. Comparison of seedling abundance to lopping intensity

Kruskal-Wallis test was conducted to compare seedling abundance among three lopping intensity groups. The test shows significant difference in seedling abundance among the groups, $\chi^2(2) = 24.26$, $p < 0.001$. From figure 24. It is clear that lopping practices significantly affects the seedling abundance of *Quercus lanata*.

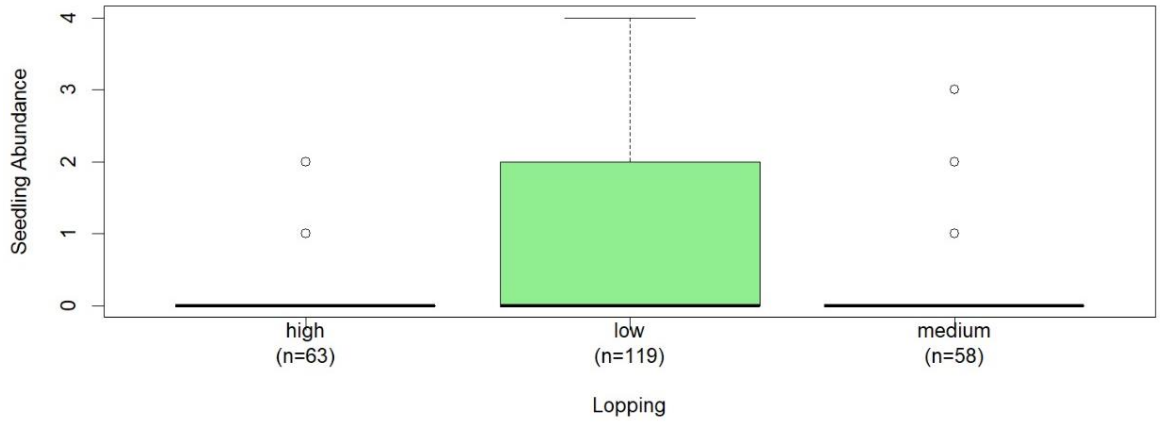

Figure 24. Comparison of seedling abundance among three lopping intensity groups

v. Comparison of seedling abundance to invasive species

Kruskal-Wallis test was conducted to compare seedling abundance among three levels of invasive species. The test showed a significant difference in seedling abundance across these groups, $\chi^2(2) = 14.11$, $p < 0.001$. From figure 25. it becomes clear that only places with low invasive species have high seedling abundance.

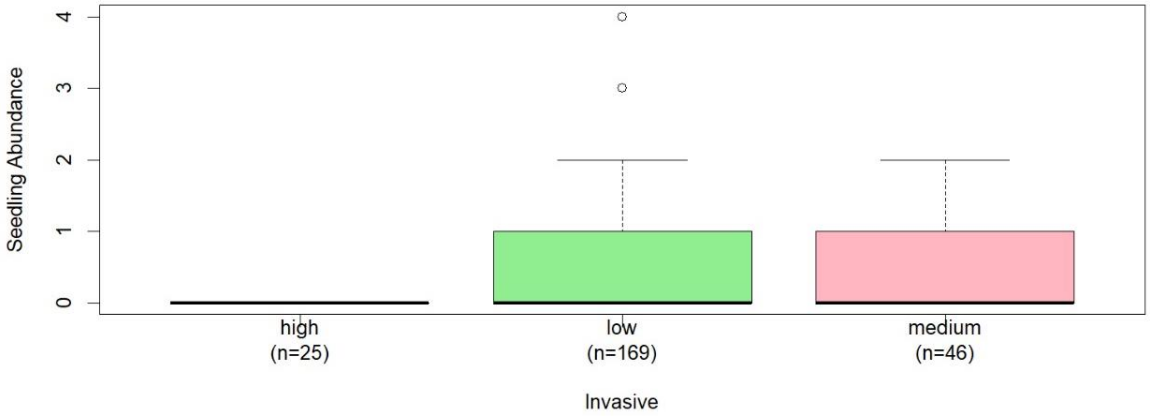

Figure 25. Comparison of seedling abundance among three invasive species intensity groups

3.2.2 Common associate species of *Quercus lanata*

i. Common tree associates

A total of 30 tree species were recorded across the 15 sites where they co-occurred with *Quercus lanata*. The details can be found in Table 09.

Table 09. Density of common associates and co-occurring tree species of *Quercus lanata*

S. No.	Species	Mean density	SD	SE
01.	*Rhododendron arboreum*	70.46	74.31	9.59
02.	*Myrica esculanta*	51.22	46.76	6.04
03.	*Lyonia ovalifolia*	32.91	30.90	3.99
04.	*Quercus leucotrichophora*	31.32	40.99	5.29
05.	*Pinus roxburghii*	23.22	51.69	6.67
06.	*Quercus floribunda*	14.73	32.38	4.18
07.	*Eurya acuminata*	13.27	26.25	3.39
08.	*Cupressus torulosa*	9.16	31.64	4.08
09.	*Viburnum cotinifolium*	7.43	26.62	3.44
10.	*Cedrus deodara*	7.30	25.61	3.31
11.	*Viburnum coriaceum*	4.91	8.56	1.10
12.	*Castronopsis tribuloides*	4.64	14.68	1.90
13.	*Machilus odoratissima*	3.72	7.40	0.96
14.	*Glochidion velutinum*	3.58	8.09	1.04
15.	*Carpinus viminea*	3.32	19.07	2.46
16.	*Alnus nepalensis*	3.05	7.77	1.00
17.	*Pyrus pashia*	2.12	8.14	1.05
18.	*Bridelia verruiosa*	1.59	4.59	0.59
19.	*Quercus glauca*	1.59	3.53	0.46
20.	*Symplocos ramosissima*	1.59	6.84	0.88
21.	*Machilus duthiei*	1.46	5.95	0.77
22.	*Quercus semecarpifolia*	1.46	11.31	1.46
23.	*Euonymus tingens*	1.33	4.67	0.60
24.	*Fraxinus micrantha*	1.19	5.45	0.70
25.	*Boehmeria rugulosa*	1.06	5.95	0.77
26.	*Symplocos theifolia*	0.80	2.41	0.31
27.	*Engelhardia spicata*	0.40	2.28	0.29
28.	*Symplocos paniculata*	0.40	1.75	0.23
29.	*Toona ciliata*	0.40	3.08	0.40
30.	*Betula alnoides*	0.27	1.44	0.19

ii. Most abundant tree associates of Kumaon

Rhododendron arboreum and *Myrica esculenta* were the most co-occurred species.

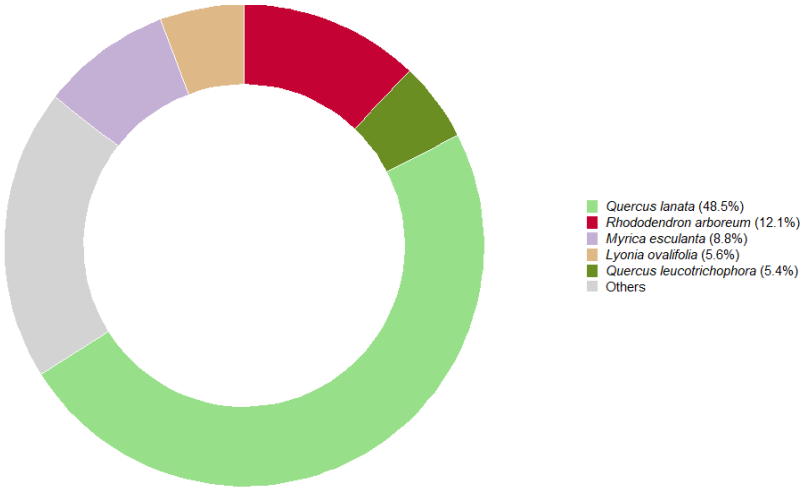

Figure 26. Most co-occurred species of Kumaon

ii. Most abundant tree associates of Askot WLS

Rhododendron arboreum was the most co-occurred species.

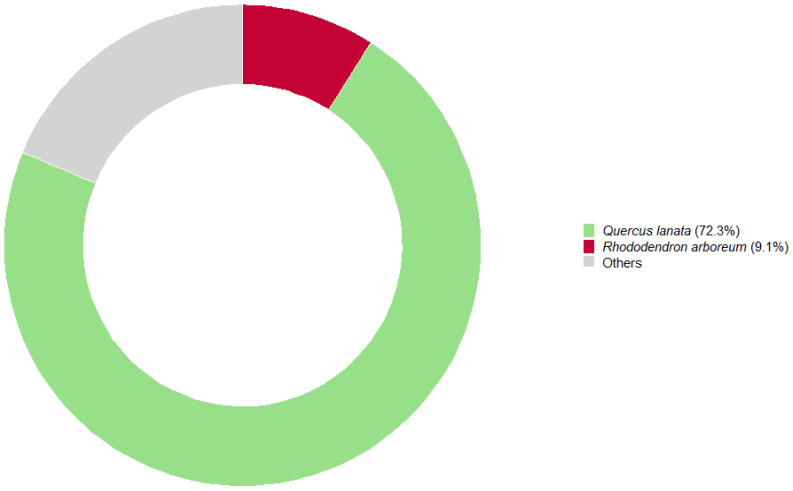

Figure 27. Most co-occurred species of Askot WLS

iii. Most abundant tree associates of Bhowali, (Pines)

Rhododendron arboreum was the most co-occurred species.

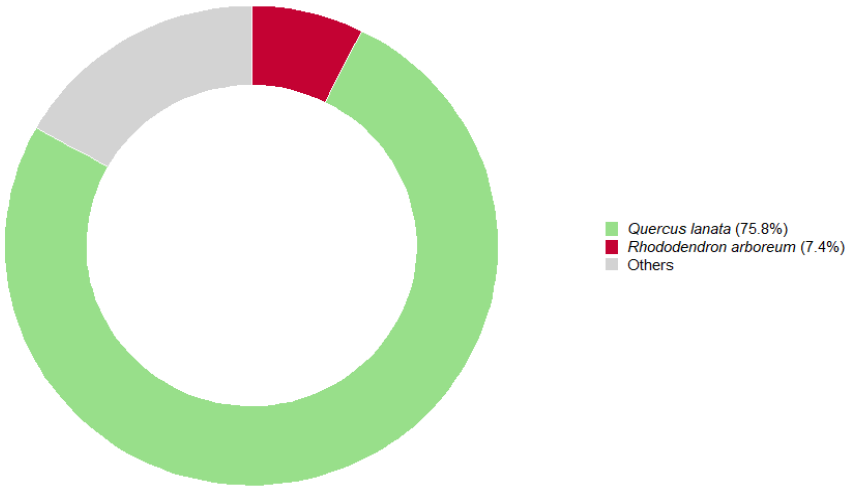

Figure 28. Most co-occurred species of Bhowali

iv. Most abundant tree associates of Binsar WLS

Pinus roxburghii and *Lyonia ovalifolia* were the most co-occurred species.

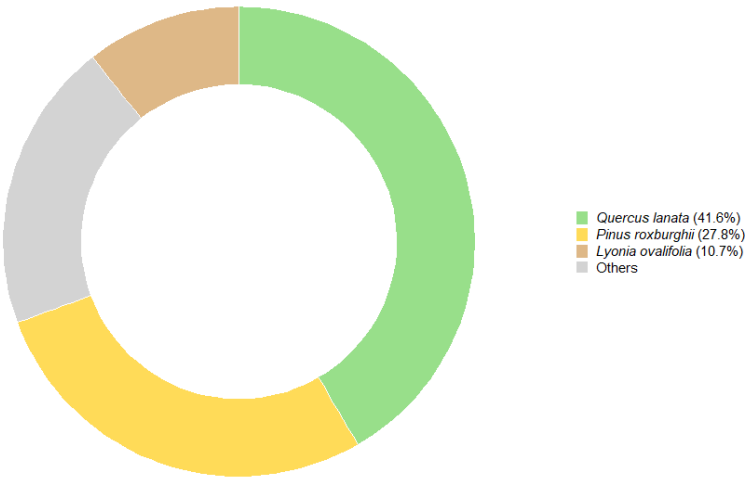

Figure 29. Most co-occurred species of Binsar WLS

v. Most abundant tree associates of Chaukodi

Rhododendron arboreum and *Myrica esculenta* were the most co-occurred species.

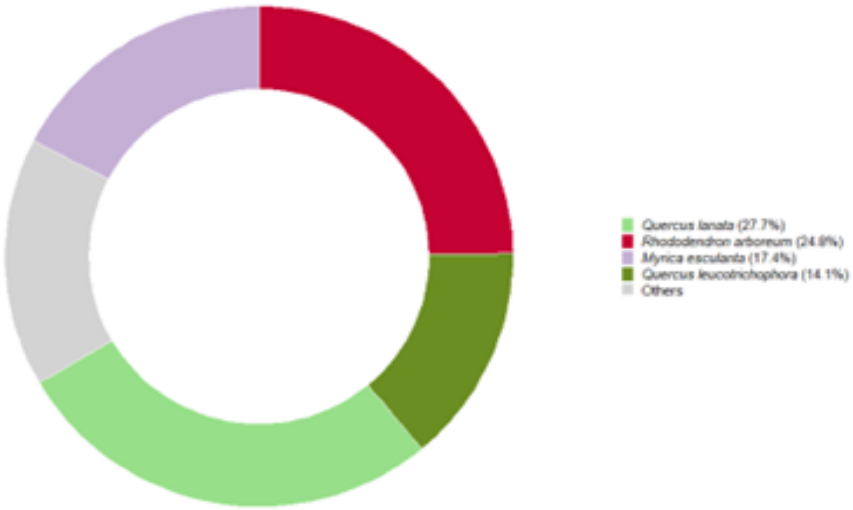

Figure 30. Most co-occurred species of Chaukodi

vi. Most abundant tree associates of Gangolihat

Quercus lanata itself is the most abundant species as it is a new established population.

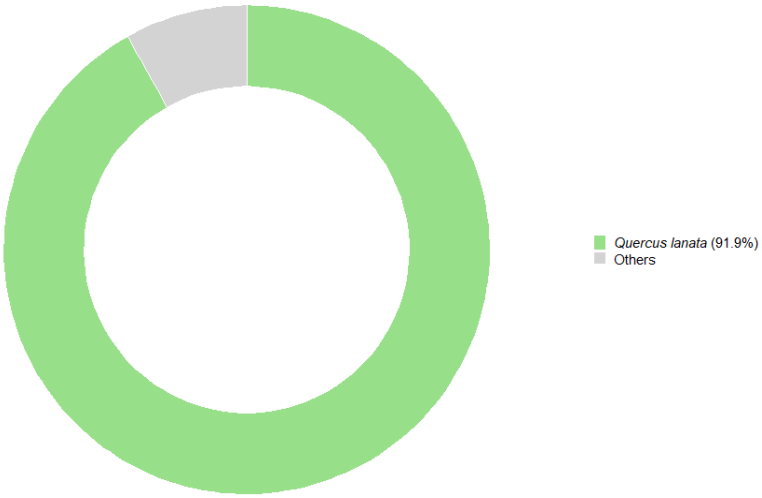

Figure 31. Most co-occurred species of Gangolihat

vii. Most abundant tree associates of Kilbury

Rhododendron arboreum and *Viburnum cotinifolium* were the most co-occurred species.

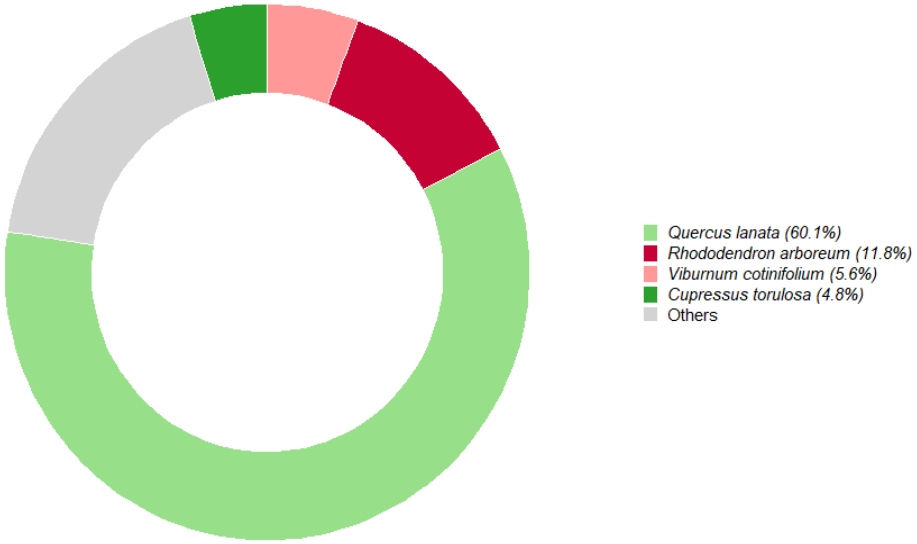

Figure 32. Most co-occurred species of Kilbury

viii. Most abundant tree associates of Kranteshwar

Rhododendron arboreum and *Myrica esculenta* were the most co-occurred species.

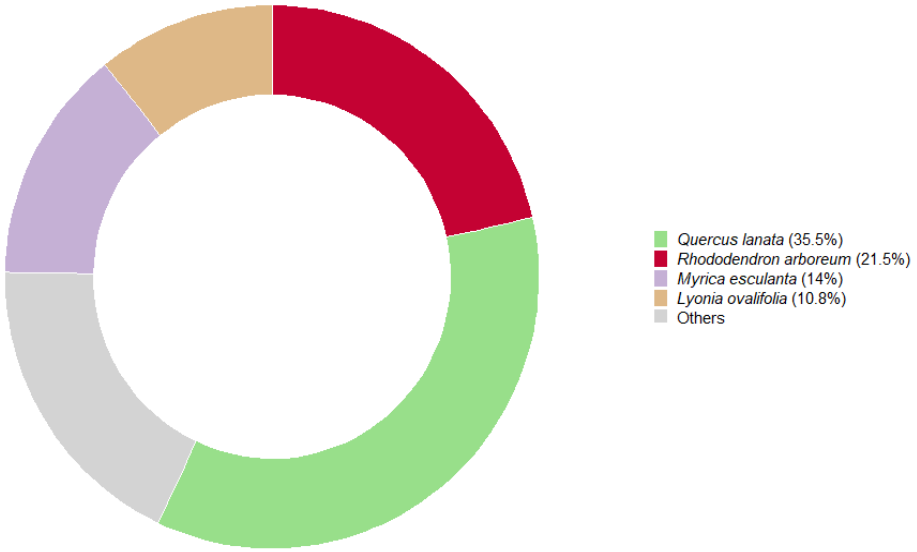

Figure 33. Most co-occurred species of Kranteshwar

ix. Most abundant tree associates of Lamkeshwar

Quercus floribunda and *Pinus roxburghii* were the most co-occurred species.

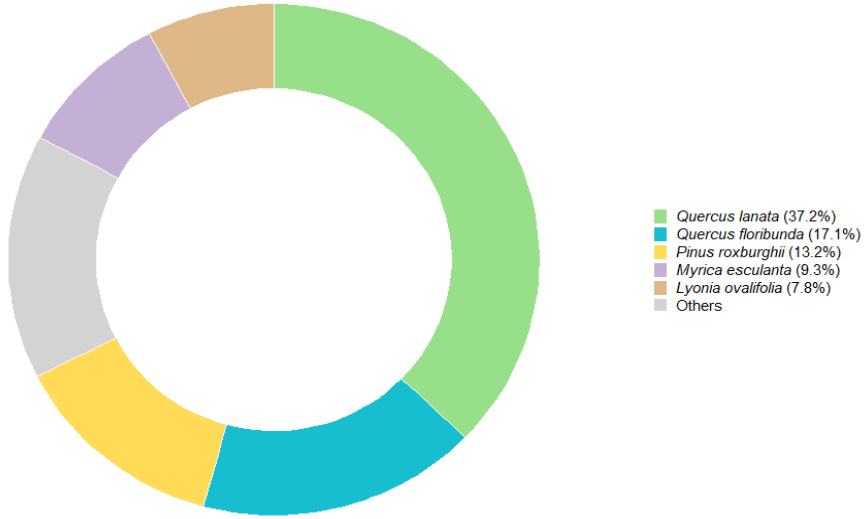

Figure 34. Most co-occurred species of Lamkeshwar

x. Most abundant tree associates of Liti

Quercus leucotrichophora and *Rhododendron arboreum* were the most co-occurred species.

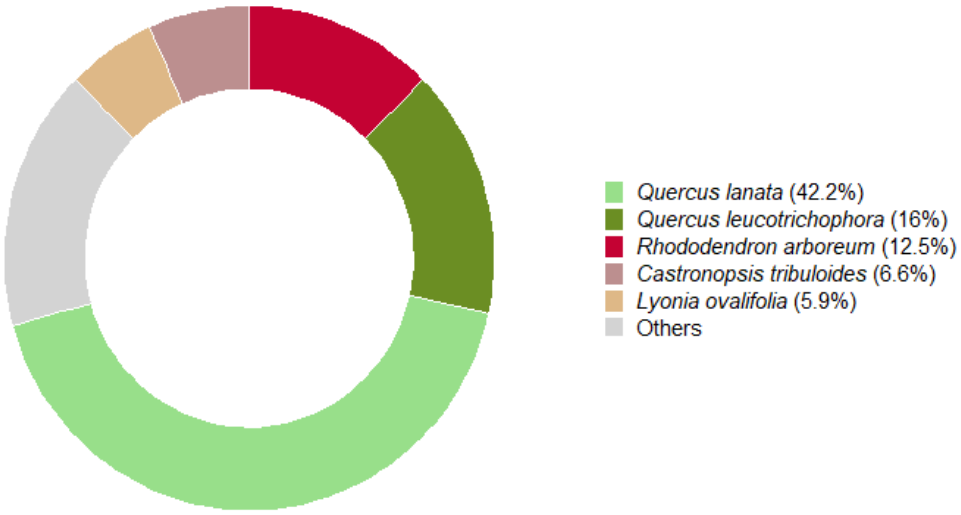

Figure 35. Most co-occurred species of Liti

xi. Most abundant tree associates of Manch

Myrica esculenta and *Rhododendron arboreum* were the most co-occurred species.

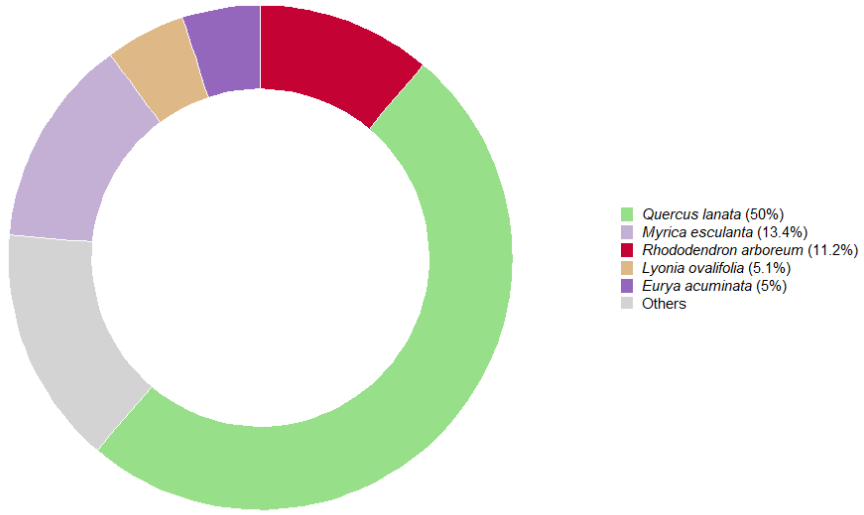

Figure 36. Most co-occurred species of Manch

xii. Most abundant tree associates of Okhalkanda

Myrica esculenta and *Rhododendron arboreum* were the most co-occurred species.

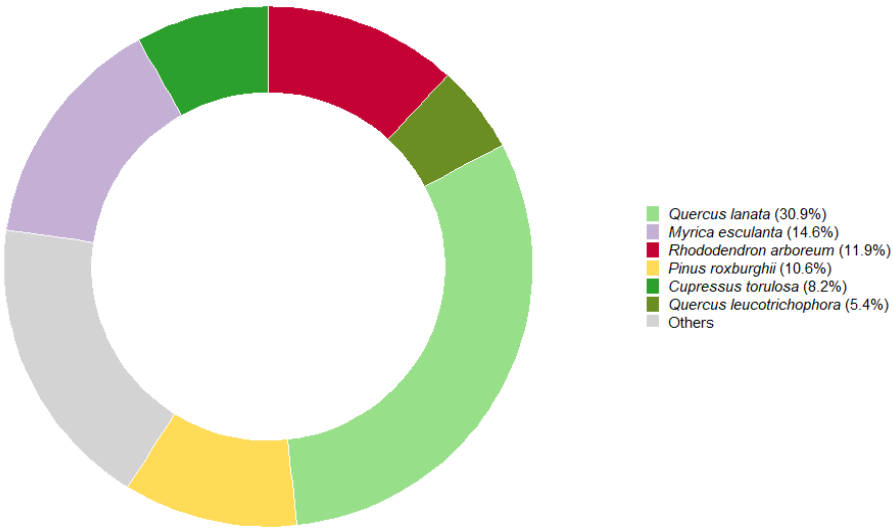

Figure 37. Most co-occurred species of Okhalkanda

xiii. Most abundant tree associates of Ramgarh

Rhododendron arboreum and *Quercus leucotrichophora* were the most co-occurred species.

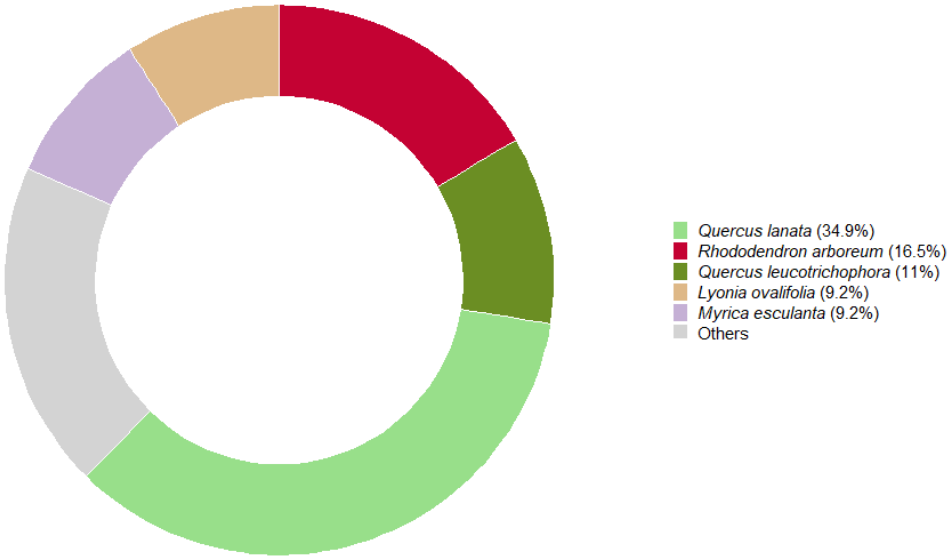

Figure 38. Most co-occurred species of Ramgarh

xiv. Most abundant tree associates of Sandev

Eurya acuminata and *Carpinus viminea* were the most co-occurred species.

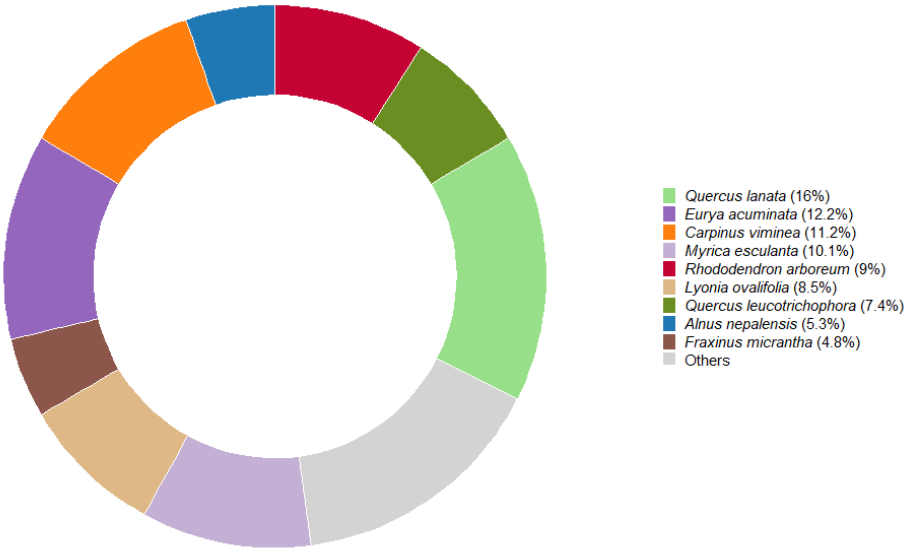

Figure 39. Most co-occurred species of Sandev

xv. Most abundant tree associates of Sundarkhal

Myrica esculenta and *Rhododendron arboreum* were the most co-occurred species.

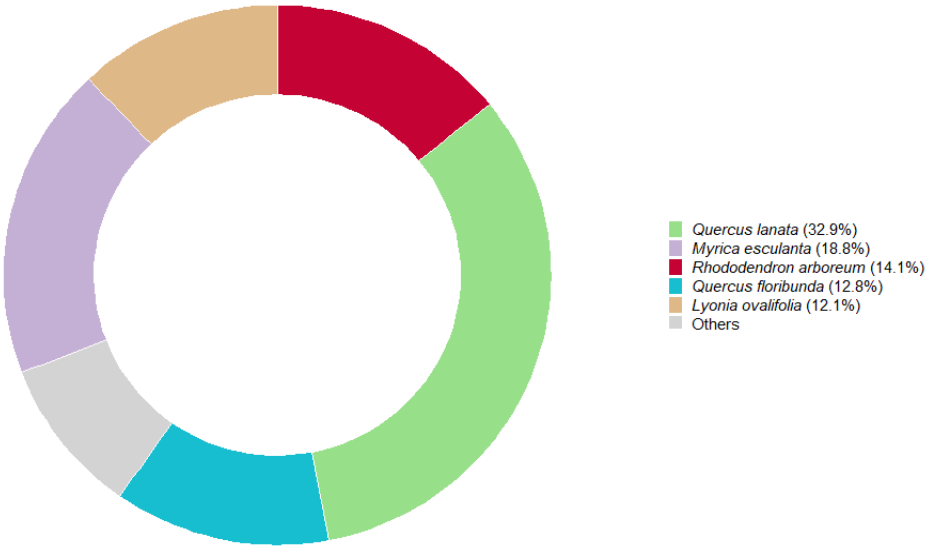

Figure 40. Most co-occurred species of Sundarkhal

xvi. Most abundant tree associates of Thalkedar

Myrica esculenta was the most co-occurred species.

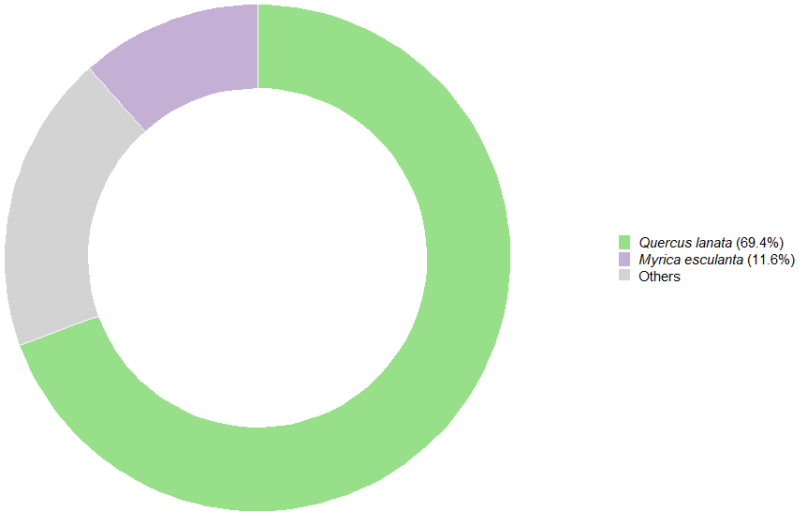

Figure 41. Most co-occurred species of Thalkedar

xvii. Common shrub associates

A total of 45 shrub species were recorded across the 15 sites where they co-occurred with *Quercus lanata*. The details can be found in Table 11.

Table 11. Density of common associates and co-occurring tree species of Quercus lanata

S. No.	Species	Mean density	SD	SE
1	*Berberis asiatica*	175.69	196.36	25.35
2	*Daphne papyracea*	160.30	268.63	34.68
3	*Myrsine africana*	102.44	128.48	16.59
4	*Elsholtzia fruticosa*	80.68	183.51	23.69
5	*Rubus elipticus*	71.13	364.83	47.10
6	*Myrica esculanta*	58.39	87.40	11.28
7	*Berberis aristata*	57.32	92.30	11.92
8	*Neolitsea pallens*	54.14	137.05	17.69
9	*Rhododendron arboreum*	51.49	84.38	10.89
10	*Inula cappa*	48.30	103.98	13.42
11	*Lyonia ovalifolia*	37.15	60.13	7.76
12	*Myrsine semiserrata*	37.15	45.86	5.92
13	*Pyrus pashia*	27.07	90.61	11.70
14	*Pinus roxburghii*	24.95	62.90	8.12
15	*Sarcococca saligna*	22.29	39.03	5.04
16	*Cotoneaser spp*	20.70	51.73	6.68
17	*Pyracantha crenulata*	20.70	55.57	7.17
18	*Quercus leucotrichophora*	19.11	49.48	6.39
19	*Flemingia sp*	17.52	76.55	9.88
20	*Himalrandia tetrasperma*	15.92	54.53	7.04
21	*Rhus parviflora*	13.80	40.78	5.26
22	*Eurya acuminata*	10.62	35.51	4.58
23	*Leucomeris spectabilis*	10.62	29.71	3.84
24	*Neolitsea umbrosa*	9.55	39.46	5.09
25	*Ilex dipyrina*	9.02	38.93	5.03
26	*Agave spp*	7.96	31.91	4.12
27	*Alnus nepalensis*	7.96	30.82	3.98
28	*Quercus semecarpifolia*	7.43	57.56	7.43
29	*Desmodium sp*	6.37	17.39	2.25
30	*Viburnum coriaceum*	6.37	22.56	2.91
31	*Elaeagnus umbellata*	5.84	25.21	3.26
32	*Aspanagus curillus*	4.78	21.00	2.71
33	*Pseudocaryopteris foetida*	4.25	32.89	4.25
34	*Viburnum cotinifollum*	4.25	18.97	2.45
35	*Mahonia nepalensis*	3.72	14.47	1.87
36	*Viburnum mullaha*	3.72	22.01	2.84
37	*Coriaria nepalensis*	2.65	20.56	2.65
38	*Lindera pulcherrima*	2.65	20.56	2.65
39	*Stranvaesia nussia*	2.12	9.93	1.28
40	*Urtica dioica*	2.12	12.94	1.67
41	*Quercus glauca*	1.59	12.33	1.59
42	*Machilus odoratissima*	1.06	8.22	1.06
43	*Quercus floribunda*	1.06	5.76	0.74
44	*Saurauia nepalensis*	1.06	8.22	1.06
45	*Daphniphyllum himalense*	0.53	4.11	0.53

3.3 Habitat Suitability Model of *Quercus lanata* for Uttarakhand

i. Maxent model

A total of 424 GPS coordinates were recorded from five different districts of Kumaon as mentioned earlier in the study. For analysis Moran's I test for conducted for all these points to remove autocorrelation among the clustered points. After running a threshold distance from 500m to 40,000m Moran's I test showed no autocorrelation at 30km (where Moran's I = 0 i.e., not correlated). Followed by this spatial thinning was conducted at 30km. After spatial thinning, 38 points were left which were at least at the distance of 30km from one another.

Of 38 points, 28 points were used to train the model (75%) and rest 10 points (25%) were used for testing the model. The maxent model was developed with 10 replicates at 500 iterations. Based on this the following distribution pattern was predicted by the model for *Quercus lanata* (Figure 42.)

It should be noted that for modelling purposes area of extent up to the Districts of Pauri Garhwal and Chamoli was considered so that the maximum area with the least possibility of presence of species could also be predicted.

The probability of occurrence of the species ranges from 0 to 1. The AUC is 0.979, and the standard deviation is 0.007. which is very close to 1 suggesting a good fit. (Figure 43.)

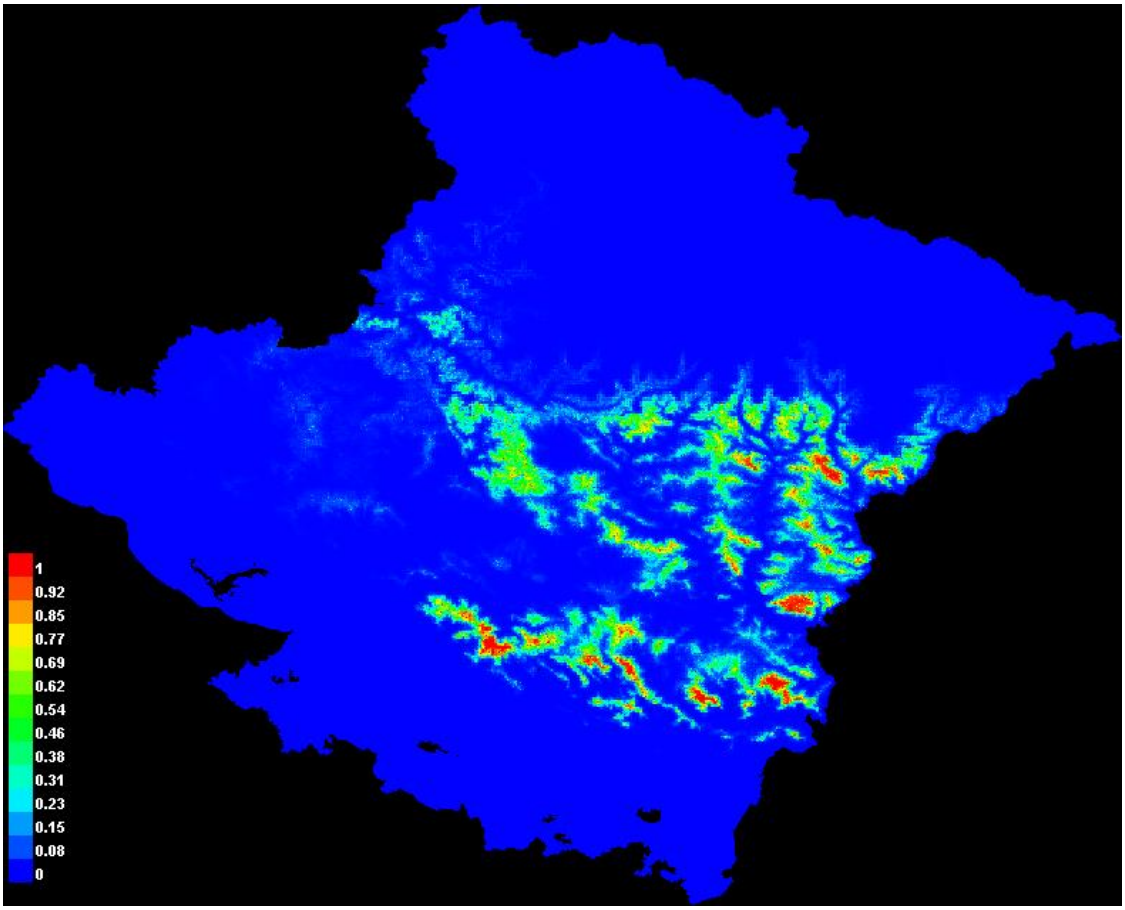

Figure 42. Habitat suitability model predicted by Maxent software

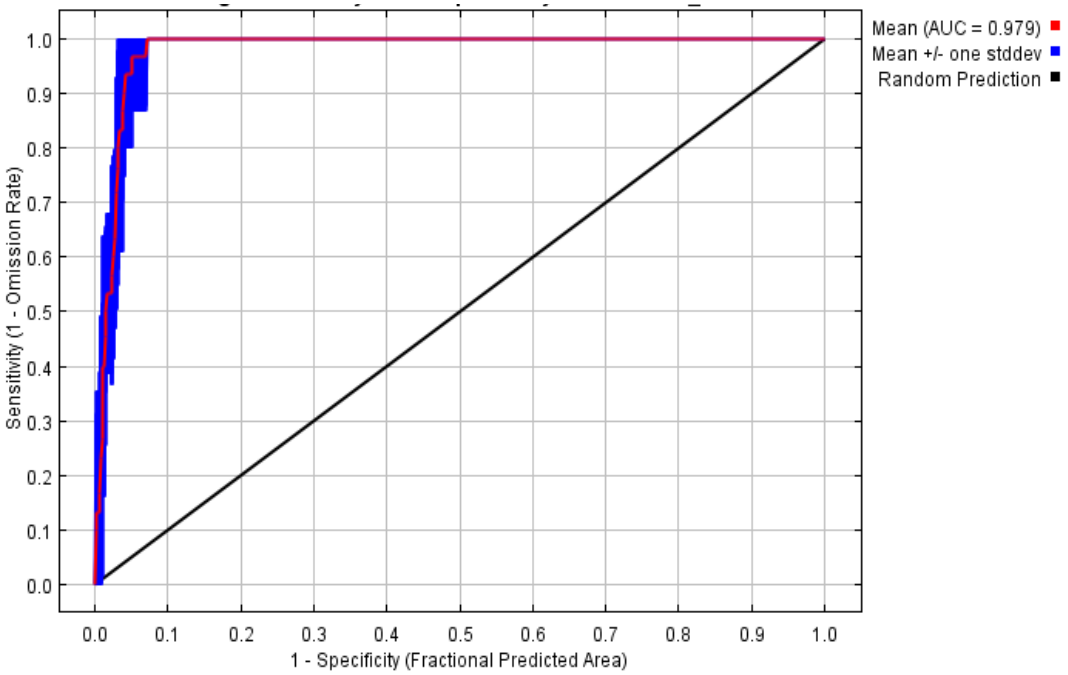

Figure 43. Average sensitivity and specificity of *Quercus lanata*

ii. Predictor variables

The Table 12. gives relative contributions of the environmental variables which were used to develop the final maxent model after segregating the raster layers from raw model using percent contribution.

Table 12. List of Predictor variables with percent contribution

S. No.	Variable	Percent contribution
01.	Temperature Annual Range (BIO7)	38.4
02.	Temperature Seasonality (BIO4)	21.7
03.	Precipitation of Coldest Quarter (BIO19)	17.7
04.	Minimum Temperature of Coldest Month (BIO6)	6.8
05.	Mean Diurnal Range (BIO2)	5.7
06.	Elevation	5.2
07.	Precipitation of Wettest Month (BIO13)	2.7
08.	Aspect	2

iii. Response curves

Response curves (Refer to Appendix) show how the predicted suitability (on the y-axis, ranging from 0 to 1) changes with respect to individual environmental variables (on the x-axis).

- Temperature Annual Range (BIO7): Suitability is high for lower values and then it decreases from around 21.3 to 33.8.
- Temperature Seasonality (BIO4): Suitability is high for lower values and then drops as the variable increases from approximately 408 to 811.
- Precipitation of Coldest Quarter (BIO19): Suitability remains high for lower values and then drops around 84 to 400.
- Minimum Temperature of Coldest Month (BIO6): Suitability is low for lower values and then increases from -30.7 to 8.8.
- Mean Diurnal Range (BIO2): Suitability is high at lower values and then slowly decreases as the variable increases from around 8.342 to 12.042.

- Elevation: Suitability is low at very low elevations, then increases suddenly, it suggests a strong preference for higher elevations.
- Precipitation of Wettest Month (BIO13): Suitability decreases significantly as values increase from approximately 170 to 600.
- Aspect: Suitability is high across most aspects except north-facing aspects.

iv. Reliability of developed maxent model

In order to find the reliability of developed model. The graph of elevation vs. maxent suitability (≥ 0.7) was developed (Figure 44.). From the graph it became clear that most of the suitable points lies between the elevation of 1500 to 2500m which coincides with the data collected from field.

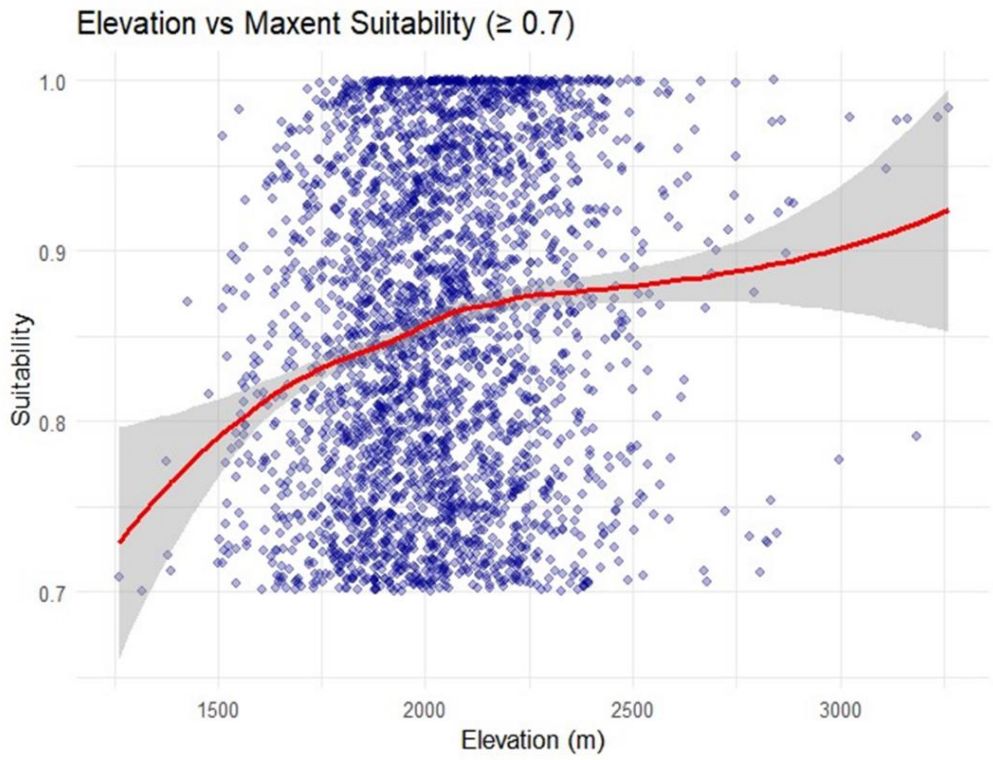

Figure 44. Graph between maxent suitability (≥ 0.7) vs. elevation (m)

v. Possible dispersal routes

Based upon the Figure 44. A map was developed to find probable high suitability sites using elevation profile, maxent suitability (≥ 0.7) and GPS points collected from fieldwork. From figure 45. it is clear that places with maxent suitability (≥ 0.7), elevation of 1500m and above up to 3000m and occurrence points collected from fieldwork, all are coinciding. Therefore, it can be said that *Quercus lanata* may be dispersing along contiguous ridge lines above 1500 m. Deeper valleys with elevation below 1500m are unsuitable for the species and that could be one of the reasons, for *Quercus lanata* to shows a patchy distribution.

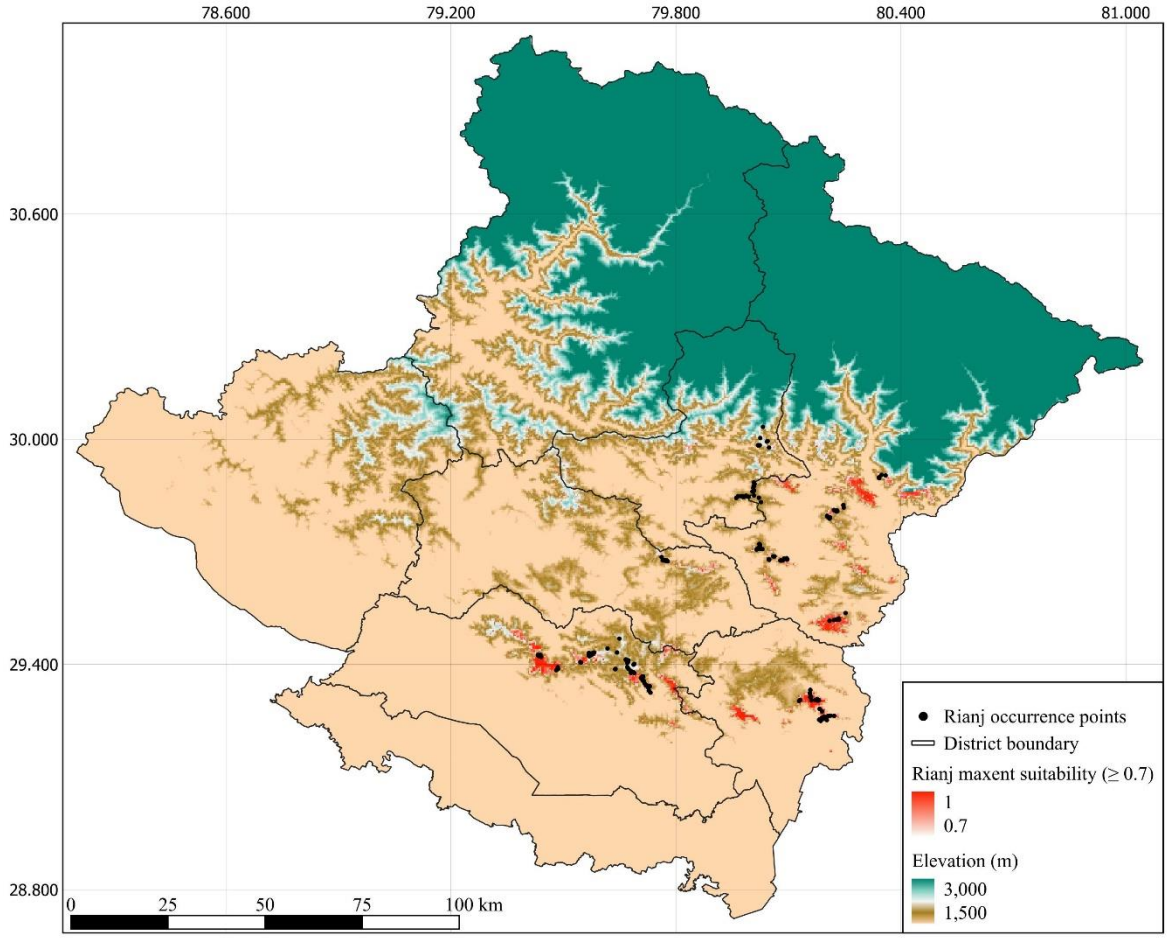

Figure 45. Map showing highly suitable areas, preferred elevation and occurrence points of *Quercus lanata*

4. Discussion

4.1 What is the population structure, regeneration status and habitat characterisation of *Quercus lanata* in Kumaon Himalaya?

In Uttarakhand, *Quercus lanata* is present in the westernmost extent of its native distribution and therefore shows a disjunct population. At some locations it shows gregarious distribution, like in Champawat, also mentioned by Osmaston 1927 in 'Flora of Kumaon'. While at other places it occurs sporadically. The mean tree density of *Quercus lanata* across Kumaon was found to be 282.76 individuals/ha., followed by a mean sapling density of 143.77 individuals/ha. and mean seedling density of 1671.12 individuals/ha. Figure 2. shows a bell-shaped population structure for *Quercus lanata* in Kumaon depicting that it has a stable and growing population which is contributed by young classes. In terms of aspect, the highest population was present at southern aspect (4865.4 individuals/ha.) followed by west (3290.3 individuals/ha.), northeast (2349.1 individuals/ha.), Southeast (2304 individuals/ha.), Southwest (1996.4 individuals/ha.), Northwest (1985.2 individuals/ha.), East (1965.5 individuals/ha.), and North (903.2 individuals/ha.). Therefore, the population of *Quercus lanata* shows a preference towards southern aspects of Himalaya when compared with populations with other aspects. Similar results have been mentioned in previous studies (Singh et al., 1986). This could be because of the factor that *Quercus lanata* prefers more of the drier and sunny slopes which are present in southern aspect as compared to *Quercus leucotrichophora* which prefers high more moisture-rich slopes which are generally present in Northern aspect. The word *lanata* is derived from a latin word 'lanatus' or 'lanatum' meaning "woolly" or "covered with wool-like hairs". So, the presence of wool-like hairs on lower part of the leaf could be possibly to reduce the transpiration rate. The presence of dense trichomes

on the leaf surface, on the abaxial side, is a xeromorphic feature that reduces transpiration (Fahn, 1990). In terms of elevation, *Quercus lanata* population was compared across different vegetation types based on elevation gradient. Middle temperate forest (2151-2300m of elevation) accounts for the highest population of 3600.7 individuals/ha. Lower temperate forest (1901-2150m of elevation) holds a population of 2189.7 individuals/ha. Upper temperate forest (2301-2600m) holds population of 1075.9 individuals/ha. The least population of 781.9 individuals/ha. was accounted by subtropical forest. In a similar study at Askot Wildlife Sanctuary (Bisht, S., et al. 2022). the tree density of *Quercus lanata* varies across sites with highest density at 1000 individuals/ha and lowest at 450 individuals/ha.

In order to find the significance of same various generalized linear models were analysed which could explain the effect of environmental variables like aspect, elevation and slope on the distribution of *Quercus lanata*. In the results, the interactive effect of aspect and elevation gave the lowest AIC value within which the interactive effect of elevation and southern aspect gave the significant p-value at 95% confidence interval which signifies that aspect and elevation both affects the distribution of *Quercus lanata.* The closest associates of *Quercus lanata* in order of abundance across Kumaon are *Rhododendron arboreum, Myrica esculanta, Lyonia ovalifolia, Quercus leucotrichophora, Pinus roxburghii*. Whereas the other closely associated co-dominant species include *Quercus floribunda, Eurya acuminata, Cupressus torulosa, Viburnum cotinifolium* and *Cedrus deodara*. The similar diversity of species was observed in Nepal where close associate of *Quercus lanata* are *Rhododendron arboreum*, *Ilex dipyrena*, *Symplocos paniculata* (Miehe et al., 2015). However, it needs to be noted that *Cupressus torulosa* and *Cedrus deodara* are naturalised in the study area, with a history of plantations dating back to British era (Osmaston, 1927). As observed on field and found in results, at some places *Quercus lanata* occurs in pure patches like in Askot and Gangolihat, while at other places it occurs on moisture-rich site with *Quercus leucotrichophora* and on moisture poor site

with *Pinus roxburghii*. Therefore, the overall habitat preferences of *Quercus lanata* depends on a variety of factors some of which include elevation ranges from 1600m to 2500m, aspect from drier southern slopes co-dominated by *Pinus roxburghii* to wetter slopes of north where in occurs with *Quercus leucotrichophora*.

From table 10. And followed by donut graphs, it is clear that *Quercus lanata* does occur with its most closely related other *Quercus* species which includes all the four oaks, i.e., *Quercus floribunda, Quercus glauca, Quercus leucotrichophora* and *Quercus semecarpifolia.* The occurrence with *Quercus leucotrichophora* is most common among all. *Quercus semecarpifolia* being a typical high-altitude element does show some overlap and that could be the highest reach for *Quercus lanata. Quercus floribunda* is a species that favours high moisture areas at middle and upper temperate forests and also exhibit some overlap with *Quercus lanata. Quercus glauca*, itself is a very patchy distributed oak and does not occur gregariously in nature. Its occurrence with *Quercus lanata* could be a mere coincidence as *Quercus glauca* does occur sporadically with major oaks i.e., Leucotrichophora and Floribunda.

4.2 What are the potential threats to *Quercus lanata* and their management?

Apart from the ecological approach, if we look from a management point of view, out of the fifteen locations sampled only three are part of the Protected area network within which two are Wildlife sanctuaries namely, Askot Wildlife Sanctuary and Binsar Wildlife Sanctuary and the third one is Kilbury, which is the part of Naina Devi Bird Conservation Reserve. If we look at the mode of lopping across locations, high lopping is at Binsar, Manch, Okhalkanda and Thalkedar. This includes Binsar Wildlife Sanctuary which legally enjoys a higher level of protection but still has very high lopping when compared with Kilbury which has a

comparatively lower level of legal protection than a Wildlife Sanctuary, According to Sec-18 and Sec 36A of The Wildlife (Protection) Act, 1972. When observed on field it relates to the socio-economic conditions of locals residing in these locations. Around Kilbury, Nainital there is good amount of eco-tourism which provides locals with opportunities to indulge in different livelihood activities apart from cattle farming, whereas at Dhaulchinna, Binsar WLS, no such socio-economic niche is available for locals and therefore they are more indulged into cattle and dairy farming for which they depend on *Quercus lanata* for fodder and fuelwood. The same condition is at Manch, Champawat, which holds one of the largest continuous populations of *Quercus lanata* in Uttarakhand, but being an underdeveloped area, allied agriculture practices are the sole source of income for local, which promotes lopping and this in turn promotes the spreads of invasive species like *Ageratina adenophora* which has covered large area of *Quercus lanata* forest floors. Populations like Gangolihat and Askot show a very skewed bar graph for GBH classes. This is due to the fact that certain patches at these locations are entirely of *Quercus lanata* with minimum girth <50 cm as it is a new establishing population, therefore these could be planted patches. Since the factors like natural thinning have not shaped the population, the mean basal area of these locations is very low indicating the present of no mother trees. While at other places like Manch, Binsar, Sandev, Kilbury and Okhalkanda trees of girth >200cm are present. The tree of largest girth (433cm) was recorded at Manch, near Manch FRH, Champawat but the tree was highly lopped with no new seedlings or saplings around, indicating a serious threat for the establishment of younger generations.

Champion and Seth have described three subtypes of Oak Forest from western Himalaya. While the distribution of *Quercus lanata* remains disjunct in Kumaon, its conservation and management is important in various aspects. From forest management perspective, *Quercus lanata* forests are mostly presented as either Banj oak forest or Mour oak forests. In the working plans of all divisions, *Quercus lanata* is classified under Banj oak forest This is in exception to

Pithoragarh Forest Division, where *Quercus lanata* forests are mentioned separately (Chandran & Sinha, 2012). This small caveat resonates with the large problem that is the identity of *Quercus lanata* itself. In order to effectively manage the few disjunct patches of *Quercus lanata* in Uttarakhand, a new forest subtype, Rianj Oak forest ($12/C_{1g}$) shall be proposed under lower western Himalayan temperate forest. This revision in Forest types classification shall act as the foundation for effective management and conservation of *Quercus lanata* in Uttarakhand and will allow close monitoring of the ecological dynamics and economic benefits of this species.

4.3 What are the suitable areas for *Quercus lanata* in Kumaon?

From the above results, it is clear that *Quercus lanata* is not an oak species that forms continuous patches but rather has a kind of disjunct and patchy distribution across the Kumaon Himalaya. There are multiple variables that account for this pattern out of which only some could have been quantified in this study. One of the major variables is elevation and aspect. If we look at Figure 45. the distribution of *Quercus lanata* is patchy and more concentrated towards the eastern part of Kumaon. When this pattern was simultaneously observed with elevation, some dots were connected. High altitude area and areas lower than 1600m of elevation and predicted least probability of its occurrence. As mentioned by Osmaston, 1921 certain species like Deodar, Himalayan Spruce don't enter Kumaon whereas in Kumaon species like *Quercus lanata* don't make it to Garhwal which means there are some ecological barriers that are acting on the dispersion of these species. Most of the suitable habitats as predicted in the model overlaps with the sampled sites but don't make the model robust, there could be many underlying factors that determine fate of Lanata's distribution.

5. Conclusion

Rianj/Woolly-leaved oak (*Quercus lanata*) is a evergreen oak species with patchy distribution in Kumaon, Uttarakhand. It usually prefers dry, sunny, Southern slopes, of Himalaya at elevation between 1600 to 2500m. The current population of Rinaj is Kumaon is stable with some poor performing patches. Its common associates include *Rhododendron arboreum* and *Myrica esculenta.* Leaves of this species is highly palatable and wood has high calorific values therefore, it is extensively used for fodder and fuelwood purposes. Due to its local distribution this species remains off the sight it terms of Oaks forests management and conservation. Therefore, this study amid to generate baseline data by characterising the habitat and predicting the potential distribution of this species.

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7. Appendices

Appendix I. Mean girth class of *Quercus lanata* across Kumaon

S. No.	Location	Mean GBH (cm)	Standard Deviation	Standard Error
01.	Askot WLS	45.39	48.85	3.01
02.	Bhowali, (Pines)	106.62	60.96	7.18
03.	Binsar WLS	77.08	76.47	6.95
04.	Chaukodi	82.87	31.37	2.60
05.	Gangolihat	35.19	11.08	0.72
06.	Kilbury	83.08	40.39	1.93
07.	Kranteshwar	140.61	67.97	11.83
08.	Lamkeshwar	59.67	38.02	5.49
09.	Liti	87.77	40.06	3.85
10.	Manch	133.96	79.27	4.30
11.	Okhalkanda	139.22	38.73	3.46
12.	Ramgarh	124.16	76.42	12.40
13.	Sandev	193.70	45.50	8.31
14.	Sundarkhal	128.27	46.20	6.60
15.	Thalkedar	113.42	38.73	4.23

Appendix II. Mean tree density of *Quercus lanata* across Kumaon

S. No.	Location	Mean tree density/ha.	Standard deviation	Standard error
01.	Askot WLS	697.63	843.09	243.38
02.	Bhowali, (Pines)	286.48	176	62.22
03.	Binsar WLS	240.72	289.87	72.47
04.	Chaukodi	230.77	231.36	51.73
05.	Gangolihat	942.99	301.94	106.75
06.	Kilbury	582.24	208.94	42.65
07.	Kranteshwar	131.3	43.17	15.26
08.	Lambkeshwar	190.99	97.74	34.56
09.	Liti	286.48	65.09	18.79
10.	Manch	193.26	127.01	16.97
11.	Okhalkanda	165.79	54.72	11.17
12.	Ramgarh	151.2	37.08	13.11
13.	Sandev	59.68	25.66	6.42
14.	Sundarkhal	129.98	53.36	15.4
15.	Thalkedar	334.22	61.35	21.69

Appendix III. Mean sapling density of *Quercus lanata* across Kumaon

S. No.	Location	Mean sapling density/ha.	Standard deviation	Standard error
01.	Askot WLS	-	-	-
02.	Bhowali, (Pines)	47.75	135.05	47.75
03.	Binsar WLS	604.79	601.71	150.43
04.	Chaukodi	50.93	126.65	28.32
05.	Gangolihat	95.49	148.33	52.44
06.	Kilbury	47.75	134.39	27.43
07.	Kranteshwar	95.49	270.09	95.49
08.	Lambkeshwar	127.32	192.5	68.06
09.	Liti	31.83	57.58	16.62
10.	Manch	131.87	342.48	45.77
11.	Okhalkanda	238.73	338.56	69.11
12.	Ramgarh	238.73	329.48	116.49
13.	Sandev	111.41	222.36	55.59
14.	Sundarkhal	201.6	257.29	74.27
15.	Thalkedar	15.92	45.02	15.92

Appendix IV. Mean seedling density of *Quercus lanata* across Kumaon

S. No.	Location	Mean seedling density/ha.	Standard deviation	Standard error
01.	Askot WLS	1061.03	2073.27	598.5
02.	Bhowali, (Pines)	1989.43	3376.18	1193.66
03.	Binsar WLS	2188.38	3805.31	951.33
04.	Chaukodi	2228.16	3115.36	696.62
05.	Gangolihat	795.77	1473.49	520.96
06.	Kilbury	5172.52	4383.82	894.84
07.	Kranteshwar	1989.43	3780.67	1336.67
08.	Lambkeshwar	-	-	-
09.	Liti	1061.03	1567.25	452.42
10.	Manch	738.93	2270.43	303.4
11.	Okhalkanda	1856.8	2802.86	572.13
12.	Ramgarh	1591.55	2406.19	850.72
13.	Sandev	596.83	1283.15	320.79
14.	Sundarkhal	1856.8	2524.07	728.64
15.	Thalkedar	397.89	1125.39	397.89

Appendix V. Mean densities of *Quercus lanata* across different forest types

S. No.	Forest type	Mean tree density	SD	SE	Mean sapling density	SD	SE	Mean seedling density	SD	SE
01.	Sub-tropical forest	263	314	44.4	138	405	57.3	382	1227	174
02.	Lower temperate forest	270	348	31.8	169	308	28.1	1751	2914	266
03.	Middle temperate forest	357	258	36.5	125	265	37.5	3119	4041	572
04.	Upper temperate forest	223	112	25.1	57.3	134	29.9	796	1751	392

Appendix VI. Mean densities of *Quercus lanata* across different aspects

S. No.	Aspect	Mean tree density	SD	SE	Mean sapling density	SD	SE	Mean seedling density	SD	SE
01.	North	282	318	112	223	413	146	398	1125	398
02.	Northeast	244	261	67.5	195	340	87.7	1910	3137	810
03.	East	183	161	57	191	289	102	1592	2406	851
04.	Southeast	343	486	70.9	133	306	44.7	1829	3302	482
05.	South	320	335	51.6	152	237	36.6	1516	2653	409
06.	Southwest	257	218	25.9	170	400	47.5	1569	2990	355
07.	West	315	208	47.8	127	216	49.6	2848	3659	840
08.	Northwest	224	208	38	38.2	164	30	1379	2977	544

Appendix VII. Mean densities of *Quercus lanata* across different aspects

S. No.	Location	Canopy cover	Lopping	Invasive Species cover
01.	Askot WLS	Medium	Low	Low
02.	Bhowali, (Pines)	Medium	Medium	Low
03.	Binsar WLS	Medium	High	Low
04.	Chaukodi	High	Low	Low
05.	Gangolihat	High	Medium	Low
06.	Kilbury	Medium	Low	Low
07.	Kranteshwar	High	Low	Low
08.	Lambkeshwar	Low	Medium	Low
09.	Liti	High	Low	Low
10.	Manch	Low	High	High
11.	Okhalkanda	Medium	High	Medium
12.	Ramgarh	Medium	Low	Low
13.	Sandev	High	Low	Low
14.	Sundarkhal	Medium	Low	Low
15.	Thalkedar	Medium	High	Medium

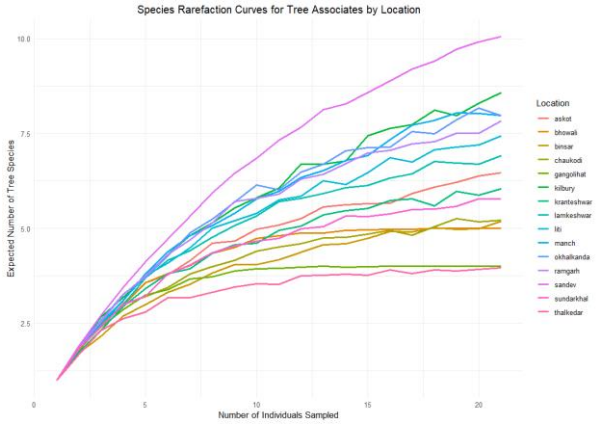
Appendix VII. List of species submitted to WII Herbarium

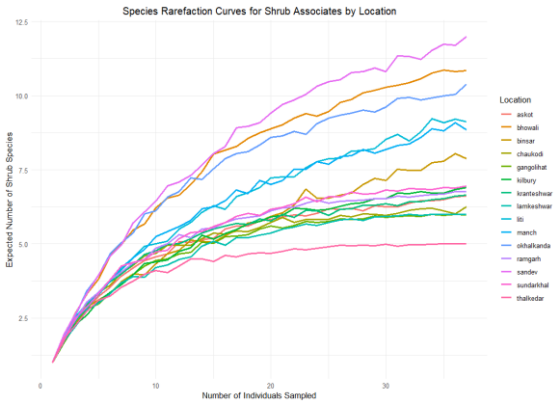
S.No.	Species	Location	Collection No.	Accession No.
01.	*Quercus lanata*	Dehradun	33044	WII006385
02.	*Quercus lanata*	Kilbury	33045	WII006386
03.	*Quercus lanata*	Bhowali, (Pines)	33046	WII006387
04.	*Quercus lanata*	Mukteshwar	33047	WII006388
05.	*Quercus lanata*	Ramgarh	33048	WII006389
06.	*Quercus lanata*	Okhalkanda	33049	WII006390
07.	*Quercus lanata*	Sundarkhal	33050	WII006391
08.	*Quercus lanata*	Binsar	33051	WII006392
09.	*Quercus lanata*	Liti	33052	WII006393
10.	*Quercus lanata*	Manch	33053	WII006394
11.	*Quercus lanata*	Kranteshwar	33054	WII006395
12.	*Quercus lanata*	Gangolihat	33055	WII006396
13.	*Quercus lanata*	Lamkeshwar	33056	WII006397
14.	*Quercus lanata*	Sandev	33057	WII006398
15.	*Quercus lanata*	Askot	33058	WII006399
16.	*Quercus lanata*	Thalkedar	33059	WII006400
17.	*Quercus lanata*	Chaukodi	33060	WII006401
18.	*Taxus contorta*	Liti	33062	WII006402
19.	*Quercus glauca*	Liti	33063	WII006403
20.	*Ulmus × brandisiana*	Manch	33065	WII006404
21.	*Symplocos ramosissima*	Kilbury	33080	WII006405
22.	*Symplocos theifolia*	Kilbury	33081	WII006406
23.	*Machilus duthiei*	Manch	33083	WII006407
24.	*Arundinella nepalensis*	Binsar WLS	33087	WII006408
25.	*Chrysopogon gryllus*	Lamkeshwar	33088	WII006409
26.	*Themeda anathera*	Lamkeshwar	33089	WII006410

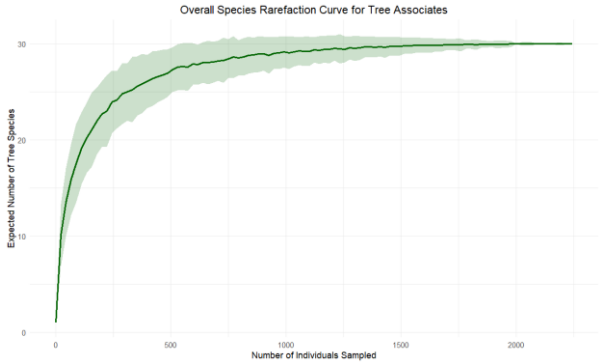
Appendix IX. Checklist of grasses observed in Rianj-Pine forest

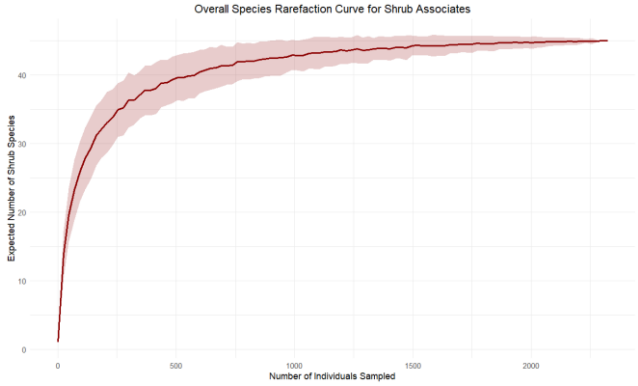
S. No.	Scientific name	Family
01.	*Arundinella nepalensis*	Poaceae
02.	*Capillipedium assimile*	Poaceae
03.	*Chrysopogon gryllus*	Poaceae
04.	*Sorghum halepense*	Poaceae
05.	*Themeda anathera*	Poaceae

Appendix X. Rarefaction curves

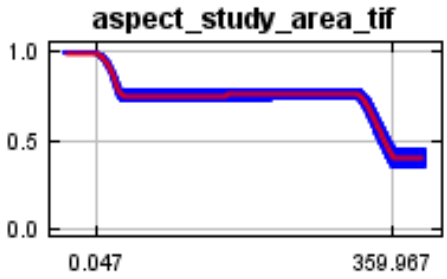


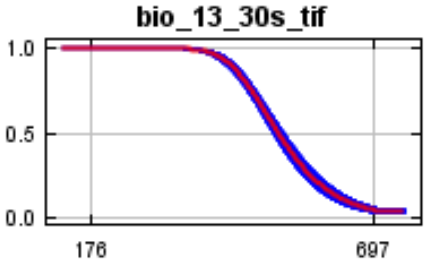


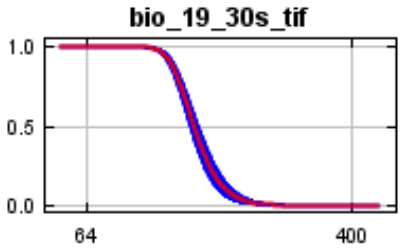


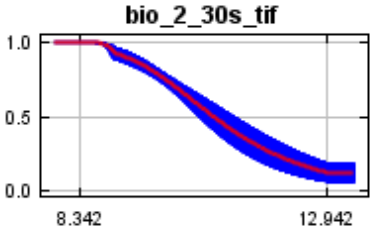


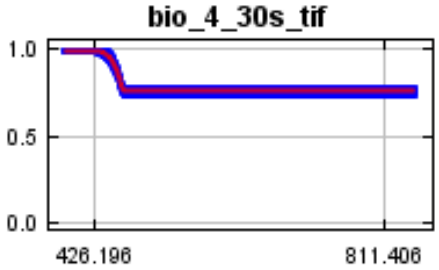
Appendix XI. Response curves of Habitat suitability model

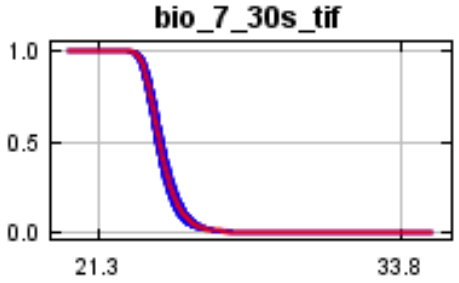


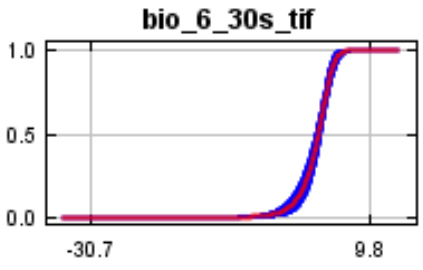


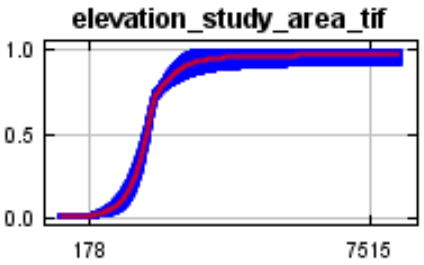












Appendix XII. Datasheet

Habitat characterization and spatial distribution of *Quercus lanata* Sm. in the Kumaon Himalaya

Place:	Date: __/__/____	Time: __:__hrs.	GPS ID:	Aspect:	Total QL adults:
Observer:	Canopy cover:		Lat:	Slope:	Total QL saplings:
Plot ID:	Soil bag ID:		Long:		Total QL seedlings:
Photo ID:	Specimen ID:		Altitude:		Plot type: Presence/Absence

10m radius plot					**5m radius plot**					**1m radius plot**		
S. No.	*QL* GBH	Associated tree species	Abundance	Lopping	S. No.	*QL* sap ht	Associated Shrubs	Abundance	Browsing	S. No.	Associated Herbs	% cover
1					1					1		
2					2					2		
3					3					3		
4					4					4		
5					5					5		
6					6					6		
7					7					7		
8					8					8		
9					9					9		
10					10					10		
11					11					11		
12					12					12		
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24					24					24		
25					25					25		

Remarks:
Remarks:
Remarks:
Remarks:
Remarks:

Plate 01. Different shapes and sizes of young leaves of *Quercus lanata*

Plate 02. Different shapes and sizes of mature leaves of *Quercus lanata*

Plate 03. Different shapes and sizes of mature leaves of *Quercus lanata*

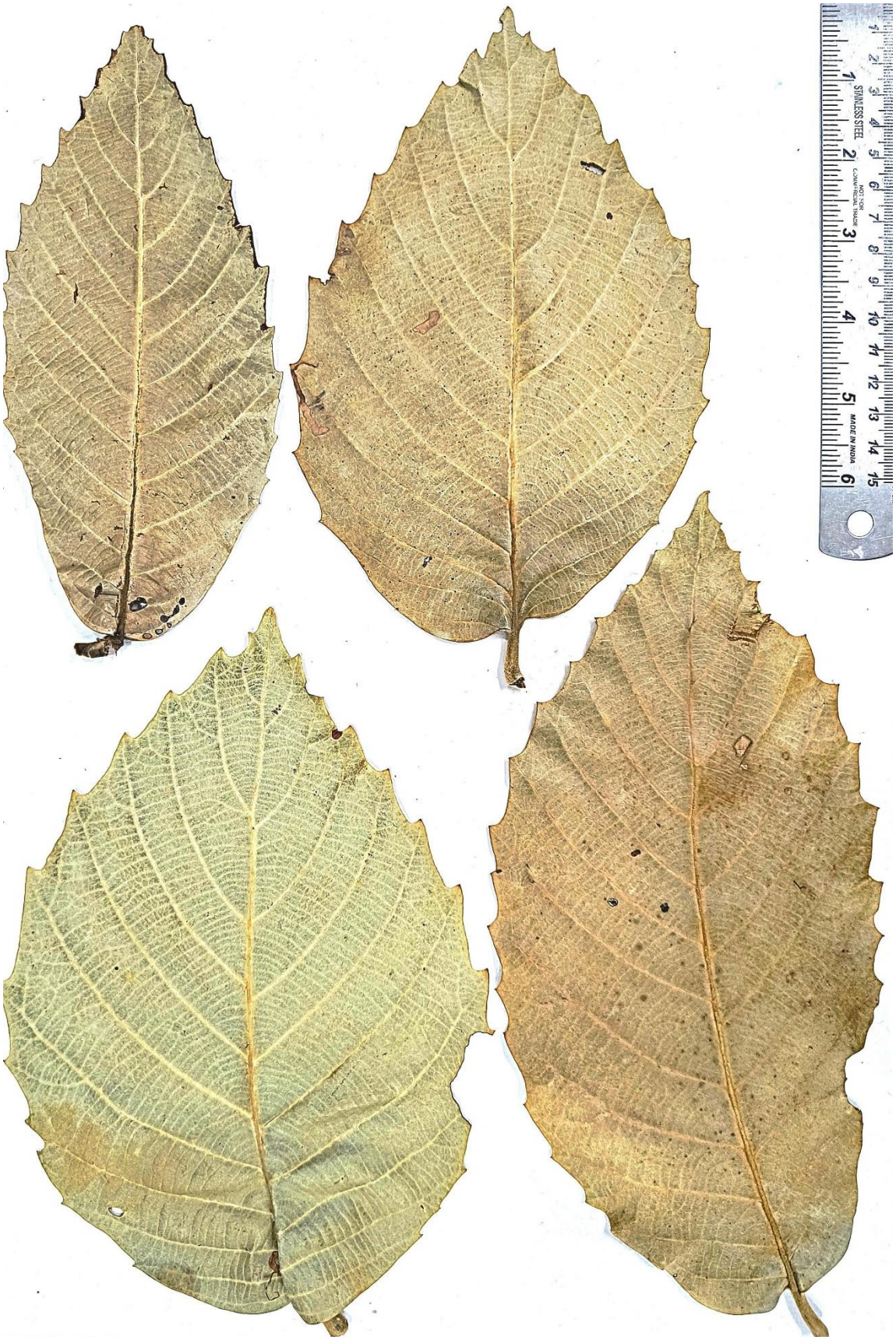

Plate 04. Mature tree, leaf, acorns and pure patch of *Quercus lanata*

Plate 05. Some images from the field

Plate 06. Lopping for fodder and fuelwood and lopped patch of *Quercus lanata*

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