Effect of Elevation and Canopy on Population Structure and Bark Characteristics of *Daphne bholua* and *Edgeworthia gardneri* in Dolakha, Nepal

A Dissertation Submitted for Partial Fulfillment of Master's Degree in Botany, Central Department of Botany, Tribhuvan University

Submitted by:

ROJINA BASI

Plant Systematics and Biodiversity Conservation Unit

Exam Roll no.: Bot 423/073

TU. Regd. No.: 5-2-20-20-2012

Batch: 2073/074

Central Department of Botany

Institute of Science and Technology

Tribhuvan University

Kirtipur, Nepal

2022

RECOMMENDATION

It is hereby recommended that Rojina Basi, M.Sc. Botany final semester student of 'Plant Systematics and Biodiversity Conservation Unit' at Tribhuvan University, Institute of Science and Technology, Kirtipur, Kathmandu has carried out the research work 'Effect of Elevation and Canopy on Population Structure and Bark Characteristics of *Daphne bholua* and *Edgeworthia gardneri* in Dolakha, Nepal' under my supervision. The entire work is based on the field work performed by her and brings out some useful findings in the field of plant science.

As per my knowledge, this work has not been submitted for any other academic degree. I, therefore recommend this dissertation to be accepted for the partial fulfillment of the requirement of Master's Degree in Botany at the Institute of Science and Technology, Tribhuvan University.

…………………………………

(Supervisor)

Dr. Suresh Kumar Ghimire,

Professor

Central Department of Botany, TU,

Kirtipur, Kathmandu, Nepal

Date: ....

TRIBHUVAN UNIVERSITY
INSTITUTE OF SCIENCE AND TECHNOLOGY
CENTRAL DEPARTMENT OF BOTANY

Ref No:

Kirtipur, Kathmandu
NEPAL

LETTER OF APPROVAL

The M.Sc. dissertation entitled "Effect of Elevation and Canopy on Population Structure and Bark Characteristics of *Daphne bholua* and *Edgeworthia gardneri* in Dolakha, Nepal" submitted by Rojina Basi has been accepted for the partial fulfillment of Master's Degree in Botany (Plant Systematics and Biodiversity Conservation Unit)

Expert Committee:

....	....
(Supervisor)	(Head of the Department)
Suresh Kumar Ghimire, Ph.D.	Ram Kailash Prasad Yadav, Ph.D.
Professor	Professor
Central Department of Botany	Central Department of Botany
Tribhuvan University, Nepal	Tribhuvan University, Nepal
....	....
(Internal Examiner)	(External Examiner)
Chitra Bahadur Baniya, Ph.D.	Bishnu Prasad Bhattarai, Ph.D.
Central Department of Botany	Central Department of Zoology
T.U., Kritipur, Kathmandu	T.U., Kritipur, Kathmandu

Date: ....

Tel. #: 977-1-4331322, Email: info@cdb.tu.edu.np, Website www.cdbtu.edu.np

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor Prof. Suresh Kumar Ghimire, for his continuous support, guidance, motivation immense knowledge throughout the research and preparation of this dissertation. Besides my supervisor, I am grateful to Prof. Dr. Ram Kailash Prasad Yadav, Head of Central Department of Botany for his administrative support during my study. My warmest thanks are due to Prof. Dr. Sangeet Rajbhandary, Dr. Bharat Babu Shrestha, Deepak Raj Pant, Giri Prasad Joshi and Dr. Chitra Bahadur Baniya, for their valuable suggestions encouraging words, and necessary help during my study. I am thankful to Dr. Lal Bahadur Thapa for providing his workspace and equipment for the lab works. Similarly, I would like to thank all the respected teachers and staff members of Central Department of Botany.

I would like to express sincere thanks to Federation of Community Forestry Users Nepal (FECOFUN), Duwakot, Bhaktapur for providing permission for this study in community forest. I would also like to thank the Sushpa Community Forest User Committee, Dolakha for providing permission to conduct my research work. I am grateful to Mr. Chitra Bahadur Chhetri and Mr. Shangee Dorje for their precious knowledge about the community forest, study plants and paper making. Without their help in field study, this research would be impossible. Many thanks to Mr. Kul Bahadur Thami, Mr. Birkha Bahadur Thami and all the local people of Sushpa Community Forest for their hospitality, necessary help, suggestions and information about the study site and plants. I am indebted to Mr. James Siddhartha Lucas, for his valuable information regarding the study topic, study materials, field visits, laboratory procedures and financial support.

I also extend my special thanks to all the friends and colleagues for their direct and indirect support from beginning to the completion of this research work. In particular, Lastly, I would like to take this opportunity to appreciate my friends Mr. Lesar Unat Basukala, Mr. Ashish Dhami, Mrs. Kajol Basukala, Mr. Rabindra Thapa, Mr. Vijay Chaudhary, Mr. Suman Poudel, and Mrs. Sabita Chhengutala for their never-ending support, invaluably constructive criticism and friendly advice during the entire work.

Rojina Basi

Date

ACRONYMS AND ABREVIATIONS

ANOVA	Analysis of Variance
GoN	Government of Nepal
Asl	Above Sea Level
cm	centimeter
mm	millimeter
g	gram
wt.	weight
NR	Near Threatened
IUCN	International Union for Nature Conservation
HMG	His Majesty's Government
KATH	National Herbarium and Plant Laboratories
TUCH	Tribhuvan University Central Herbarium, Kathmandu
S.E.	Standard Error
NTFP	Non–Timber Forest Product
SPSS	Statistical Program for Social Science
US$	United State Dollar
ITC	International Trade Center
FSRO	Forestry Services

ABSTRACT

Traditionally, hand-made papers are made from the inner bark of species belonging to the family Thymelaeaceae. Thymelaeaceae species, particularly *Daphne bholua* and *Edgeworthia gardneri,* are commonly used in Nepal to create paper and are referred to as ‘Nepali Kagaj’. These traditional hand-made papers are in high demand among the international buyers due to its superior quality. The bark produced by plants is a key factor in determining the quality of paper, and this is influenced by the conditions in which they grow. This study attempts to assess population characteristics and bark-related traits of *Daphne bholua* and *Edgeworthia gardneri* along a gradient of elevation and canopy. For each species, altogether, 30 plots (10 × 10 m$^{2)}$ were established, 10 each in three elevation sites (high mid and low). In each plot, all individuals of the target species were recorded with their girth size (measured at 20 cm above ground) and height. For measuring bark-related traits, individuals were sampled from three canopy types (close, semi-close and open) in each elevation site. Further, individuals of target species in each canopy type were grouped into different girth size classes (< 10 cm and > 10 cm for D. bholua; < 15 cm, ≥ 15 ≤ 20 cm and > 20 cm). Altogether, 15 bark samples (one sample per individual) per species per girth size were collected for the measurement of fibre length, bark thickness and dry weight. In total, 1070 individual ramets of *D. bholua* per plot (100 m$^{2)}$ were recorded as highest density at the high elevation site, while density of *E. gardneri* was highest at the mid elevation site with 257 ramets per plot (100 m^2). The lower density of ramets at the lower elevation site was found to be associated with anthropogenic disturbances. In *D. bholua,* density of new ramet recruits was higher than that of adults and juvenile ramets while *E. gardneri* exhibited lower density of new ramet recruits than that of adults and juveniles. The longest average fiber lengths were observed measuring 7.78 mm and 5.83 mm in *D. bholua* and *E. gardneri* respectively. In conclusion, the study suggest higher elevation was important site for *D. bholua* while 2200 m was suitable site for *E. gardneri* in the study area. Similarly, *D. bholua* population are more successful in regeneration than *E. gardneri* in the particular area. The research also highlights elevation as important factor that determine bark-related traits in *D. bholua*, whereas both elevation and canopy were equally important in *E. gardneri*. However, combined forces of elevation, canopy and girth were more influential than independent factors upon bark-related traits. But the effects are not strong enough to explain exact cause. Therefore, future researches should explore other environmental factors, particularly those related to soil to make better inferences related to the factors governing bark traits. Overall, the study underscores the need for continued conservation programs to support the growth new ramet recruits and preserve the current population of these valuable species.

Keywords: D. bholua, E. gardneri, Fibre, Elevation and Canopy

CONTENTS

RECOMMENDATION i

ACKNOWLEDGEMENTS iii

ACRONYMS AND ABBREVIATIONS iv

ABSTRACT v

CHAPTER ONE: INTRODUCTION 1

1.1. General Background 1

1.2. Variation of plant traits along elevation and canopy 2

1.3. Rationale 3

1.4. Objectives 4

CHAPTER TWO: MATERIALS AND METHODS 5

2.1. Study area, Sushpa community forest 5

2.1.1. Physiography 5

2.1.2. Flora 6

2.1.3. Socio-culture and economy 6

2.2. Study species 7

2.2.1. Daphne bholua bholua Buchanan-Hamilton ex.P D. Don 7

2.2.2. Edgeworthia gardneri (Wall.) Meisn 9

2.3. Methods 10

2.3.1.Reconnaissance 10

2.3.2. Population sampling 11

2.3.2.1. Individual sampling for bark collection 12

2.3.2.2. Laboratory protocol 13

2.3.2.3. Herbarium collection 14

2.3.2.4. Data analysis 14

CHAPTER THREE: RESULTS 16

3.1. Population characteristics 16

3.1.1 Population size along elevation gradient 16

3.1.2. Population structure along elevation gradient 17

3.2 Comparison of plant traits along elevation and canopy gradient 21

3.2.1 Variation of plant traits along elevation 22

3.2.2 Variation of plant traits with change in canopy cover 23

3.2.3 Relation of plant traits with elevation and canopy gradient 24
3.2.4 Effect of nested factors of elevation and canopy on plant traits 26
CHAPTER FOUR: DISCUSSION 29
4.1. Population size along elevation gradient 29
4.2. Population structure along elevation gradient 31
4.3. Variation of plant traits along elevation and canopy 32
CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS 36
5.1. Conclusion 36
5.2. Recommendation 37
REFERENCES 38
Appendix I: *Daphne bholua* traits in three elevation and canopy types. Value shown are mean ± S.E. 49
Appendix II: *Edgeworthia gardneri* traits in three elevation and canopy types. Value shown are mean ± S.E. 50
Appendix III: Letter of research permission 51
Photoplates

CHAPTER ONE: INTRODUCTION

1.1 Background

The unique geographical position and rich landscape, which encompass a wide altitudes and climates has shaped remarkable floral diversity of Nepal (Pyakurel 2010), which includes over 2000 species of non-timber forests products (NTFPs) (Press *et al.* 2000, DPR 2001 and DPR 2002). The NTFPs may include, but are not limited to, herbs used for medicine, fruits for food, and resins for incense (Ticktin 2002). Among different plant parts extracted as NTFPs, bark has significant role in livelihood of forest dependent people till today (Sharma *et al*. 2017). The human quality of life has been strongly influenced by such bark-derived NTFPs like quinine and cinnamon. However, no bark-derived NTFP has shaped the human existence over space and time as much as paper.

Paper, a laminar material made from pulped bark and stems, was discovered in China about two millennia ago and used as a lightweight yet durable means to record and share information. Seven plant genera in the Thymelaeaceae family have historically been used to make paper: *Daphne* Tourn. Ex L., *Edgeworthia* Meisn., *Wikstroemia* Endl., *Stellera* L., *Aquilaria* Lam., *Rhamnoneuron* Gilg, and *Gnidia* L. (Rantoandro 1983; Helman-Wazny 2014). Among the listed genera, the first four are naturally found in Nepal, with two genera *Daphne* and *Edgeworthia* serving as the predominant sources of handmade paper across the country.

Nepali hand-made paper, also popularly known as 'Nepali Kagaj' is made up of the inner bark of *Daphne bholua* Buch.-Ham. ex D.Don, *Daphne papyracea* Wall. ex G. Don or *Edgeworthia gardneri* (Wall.) Meisn. This study focuses on only two species, *D. bholua* and *E. gardneri* that are extensively harvested for making handmade papers. *D. bholua* is locally known as 'lokta', 'kagate', 'seto-baruwa' (Trier 1972), and is distributed all over Nepal within an elevational range of 1700 m to 3200 m. Similarly, *E. gardneri* is known as 'argeli', 'lokti', pahenle, in Nepali (Pyakurel 2010) and is found within elevational range of 1500 m to 3500 m in central and eastern Nepal.

D. bholua and *E. gardneri* are shade tolerant and grow as understory in moist forests. The key environmental factors for the growth of both species are shade, humus and moisture

(Ghimire *et al.* 2008b); but dense canopy above 80% is not tolerable to plant. They mostly prefer 30% of canopy (Ghimire *et al.* 2008b).

1.2 Variation of plant traits along elevation and canopy

Environmental factors, such as temperature, moisture, soil quality, associated vegetation, topography, light intensity and climate are known to affect the distribution and growth of plants (Becker *et al.* 2007). Change in these variables are the complex phenomenon of elevation gradients (Klimes 2003). The components of local environment vary along the elevation gradients and ultimately may create the variation in overall plant performance (Lomolino 2001). Similarly, the tissue system in plants differs according to the habit of plants and their surrounding environment. These change in plant play a vital role in the development and adaptation of plants to the stress they are subjected to (Norman *et al.* 1989). Similar to the population distribution and morphological features, anatomical features also varies with a distinct pattern along the elevation gradients (Oberhuber 2004; Zhang *et al*. 2012).

Functional traits including physiological, life history and ecological characters are directly related to variation in elevation (Yang *et. al* 2020) Elevation strongly influences the length of the growing season and the availability of soil moisture and nutrients (Namgail *et al*. 2010; Singh *et al.* 2014), plantlife history (Kim and Donhohue 2011) and population performance (Bhattrai and Vetaas 2003).

Like elevation, forest canopy is a proxy component of environment that affects other biotic and abiotic factors, such as air temperature, leaf temperature, atmospheric moisture, soil evaporation below the canopy, soil heat storage and soil microbes. Forest canopy thus makes micro-climate in a community (Nadkarni et al 2001). Shrubs that are frequently found as understory and also in canopy gaps (Denslow *et al.* 1990) vary along the distribution of canopy cover. Despite shade tolerance, studies show that light can have considerable influence on growth and regeneration of *Daphne* and *Edgeworthia*. Stem diameters of open growing *Daphne* individuals increased 30 - 50% more than those growing in the dense canopy (Dutt 1994). Quantity of bast fibres present in a plant can be measured through thickness of bark in a stem and dry weight of bark content in a sample. Through experimentation, papermakers discovered that plants with long and, strong fibers with insecticidal properties were best-suited as a source of paper (Hubbe and Bowden 2009) like that found in Thymelaeaceae. Nepali hand-made papers are therefore durable, insect repellent, resistant to tearing and strong even in wet. Measurement of fiber length is often correlated to paper sheet strength like tear index, and tensile strength (Hubbe and Bowden, 2009). Therefore, fiber length of bark is indirect medium to measure quality of paper (Horn 1974) from a plant.

This study aims to assess the variation in population size and structure of *Daphne bholua* and *Edgeworthia gardneri* and evaluate their bark properties, length, width and dry weight of fibre in relation to a gradient of elevation and tree canopy closure.

1.3 Rationale

Daphne bholua and *Edgeworthia gardneri* are extensively used from wild for paper-making. Since *D. bholua* has now been suffering from over-exploitation through excessive harvesting for production of hand-made paper; there is no doubt that the *E. gardneri* that replaced *D. bholua* may suffer such consequences in near future. In addition, both species also help to check soil erosion and have several ethno-medicinal uses (Shrestha 2002). Investigations on such valuable plants should be of major concern in a developing country like Nepal.

In Nepal, the handmade paper enterprises are making substantial contribution in cultural identity, poverty reduction and employment opportunities especially to rural women and marginalized groups (Poudyal 2004). Nepali handmade paper and paper products / crafts worth about NRs 300 million are consumed in local markets annually (ITC and GoN 2017). Most recent data from Federation of Handicraft Association of Nepal (FHAN 2078) shows the increase in export of handmade papers and its products from 8% in the fiscal year 2073/74 to 39% 2077/78. Similarly, hand-made paper products of a total worth of NRs 135,076,142 were exported in Germany, USA, China, Denmark, Singapore, Netherlands, Australia, UK, Japan, India, Canada and others countries in the fiscal year 2077/78 (FHAN 2078). This indicates that handmade paper enterprises are a potential areas of income generation in Nepal.

Previous studies on *Daphne bholua* and *Edgeworthia gardneri* in Nepal are only limited to ethno-botanical survey providing information on history of paper making manufacture and uses as medicine (Jeanrenaud 1984 and 1986; Trier 1972; Ghimire *et al.* 2008a and 2008b; Pyakurel 2010). The raw materials obtained from pants are directly influenced by environment conditions. But, the knowledge on suitable environmental conditions for sustainable harvesting while maintaining high quality and quantity of fiber, is still unknown.

It is therefore important to study population structure and plant characteristics in area like Suspa Community Forest, Dolakha which harbors two essential fiber yielding Thymelaeaceae species. This study aims to study population structure and bark properties of two paper making plants: *Daphne bholua* var. *bholua* and *Edgeworthia gardneri* in relation to elevation change and canopy types in the study area.

1.4 Objectives

This study aimed to identify elevational impact on population and bark-related properties of two Thymelaeaceae species *D. bholua* and *E. gardneri* in the Sushpa community forest in Dolakha district of Central Nepal.

The specific objectives were

- To assess the distribution pattern and population density of *Daphne bholua* and *Edgeworthia gardneri* along elevation.
- To study elevational and canopy influence on three bark-related properties: bark width, bark dry mass and fibre length of *D. bholua* and *E. gardneri* stems.
- To assess which combination of environment better explain the distribution and bark character of both species.

CHAPTER TWO: MATERIALS AND METHODS

2.1 Study area, Sushpa Community Forest

2.1.1 Physiography

Sushpa Community Forest is located in Dolakha District, of Bagmati Province in Central Nepal. The districtlies in between 27.473768º N latitude and 86.110348º E longitude, and covers an area of 2,191 km^2. It is home to two widely known religious temples Bhimeshor and Kalinchowk Bhagawati.

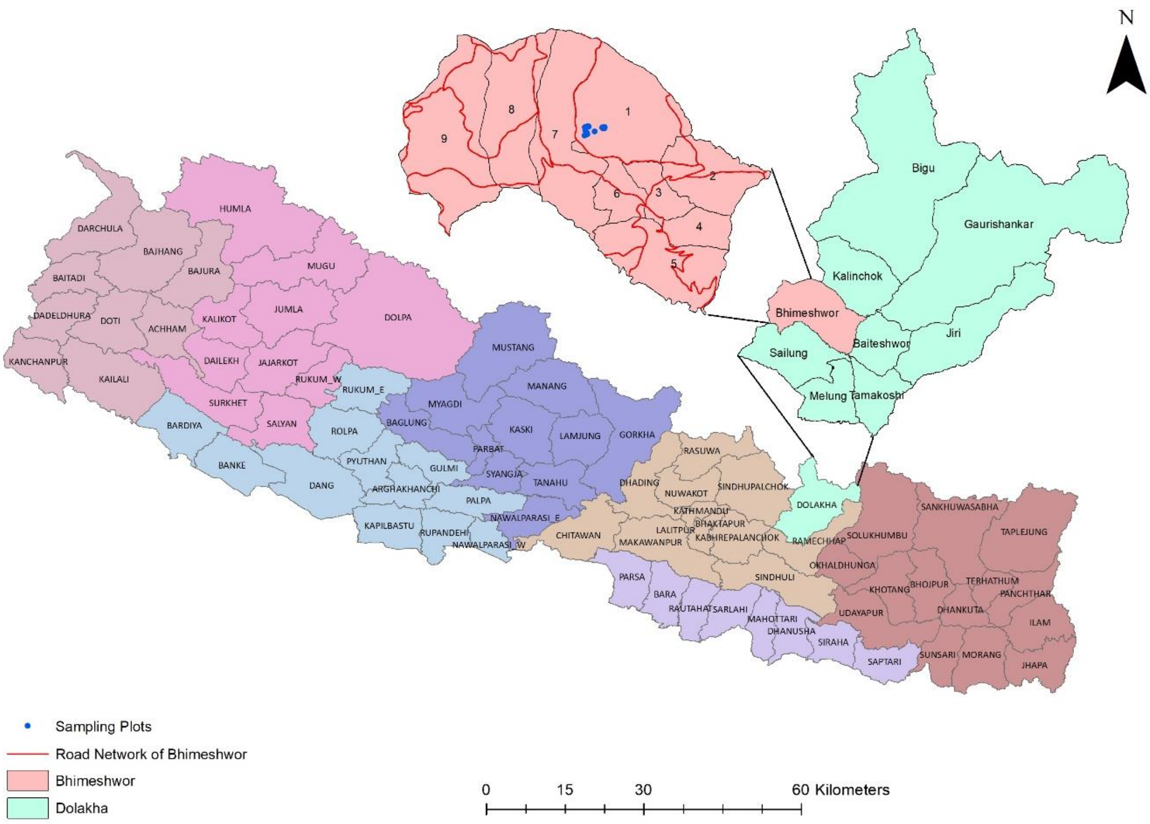


Figure 1: Map of Nepal showing study area with sampling points.

Sushpa Community Forest lies 10 km north-east from the district headquarters, Charikot. It is situated in Chhemawati Rural Municipality of the district and covers three wards 6, 8 and 9. It covers an area of 635.36 ha. The altitude ranges from 1890 m to 3300 m asl. The community forest includes about 24 major water sources and small streams covering 3.12 ha that supply water to more than 30,000 households residing in the community forest and

Bhimeshwor Municipality. In 2050 B.S., the responsibility of forest management was transferred to the local community, according to Kandel (2007).

For the better use, conservation and management of forest and its resources, the community forest has been divided into 5 blocks each with different area, elevation range, slope and vegetation.

2.1.2 Flora

The major forest types available in the study area are natural Thinge salla (*Tsuga dumosa*) and Gobre salla (*Pinus wallichiana*) forest; mixed forest of Khasru (*Quercus semecarpifolia*) and Kholme (*Symplocos pyrifolia*) along Rani salla (*Pinus roxburghii*) and pate salla (*Pinus pitula*); and bushy mixed forest. Similarly Chilaune (*Schima wallichii),* Phalant (*Quercus glauca*), Banjh (*Quercus lantana*), Ghoge salla (*Abies* sp.), Uttis (*Alnus nepalensis*), Silange (*Taxus wallichiana*), Lampate (*Duabanga grandiflora*), Chandan (*Pterocarpus santalinus*), Kafal (*Myrica esculanta*), Phalat (*Quercus lanata*), Gurans (*Rhodendron arboreum*, *Rhododendron campanulatum*), Pahenle (*Litsea lancifolia*), Angeri (*Lyonia ovalifolia*), Jhingani (*Eurya* sp.), Kholme (*Symplocos* sp.) and Bhalayo (*Rhus* sp.) are the main tree species (ANSAB 2004) in the study site.

Most important NTFPs produced by forest are Satuwa (*Paris poryphylla*), Chiraito (*Swertia chiryaita*, *Swertia angustifolia*), *Gaultheria fragrantissima*, Pakhanved (*Berginia ciliata*), Lokta (*Daphne* sp.), Argeli (*Edgeworthia gardneri)*,Majitho (*Rubia manjith*), Sugandhawal (*Valeriana jatamasi*) and some wild edible mushrooms (rato chyau, guchi chyau, thyangre chyau, etc) (Subedi 2004).

2.1.3 Socio-culture and economy

About 408 households reside near the community forest. Ethnic groups include Thami, Magar, Sherpa, Tamang, Chhetri and Brahmin. Main occupations of people are agriculture, animal husbandry, office workers and some are foreign employed.

The community forest provides timber for building and furniture. *Tsuga dumosa* and *Pinus* sp. Are the main timber source (Subedi 2004). The local people are allowed harvesting of timber and NTFPs under a regulated system. The community forest allows harvest of about 847 - 9747 kg dry lokta bark, 628 - 764 kg Argeli bark, 150 g Chiraito, 1133 kg Allo fibre and 173414 kg machino (Winter green) leaves and collection of some amounts of Jhyau (*Parmelia* sp.), *Rubia manjith*, *Berginia* sp at a time. Timber of about 4679 cubic feet is allowed to collect from the community forest (Subedi 2004).

2.2 Study species

2.2.1 *Daphne. bholua* Buchanan–Hamilton ex D. Don

Daphne bholua are shrubs or small trees (1 - 3 m tall) with sparse branches (Halda 2003). The species consists of two varieties *Daphne bholua* var *bholua* and *Daphne. bholua* var glacialis (Press *et al*. 2000). This study was based on *D. bholua* var *bholua*. *D. bholua* propagates both sexually and asexually. Seed viability is very short and often limited to less than a week. Therefore, they are difficult to propagate by seeds (Ghimire and Nepal 2007). It regenerates asexually through root suckers. These suckers can arise within the periphery of 5 m from the taproot and more than eight suckers can arise from one adventitious root. 75 % of plants regenerate by root suckers while only 25% are known to reproduce by seeds (Jeanrenaud 1984). Coppices arise from the cut stem and are less vigorous than plants that have originated from seeds or suckers (Jeanrenaud and Thompson 1986). The life span of *D. bholua* has been reported to be more than 60 years (NSCFP 2001). Wind and insects (mainly bees, flies, and lepidopteran) are the major means of pollination. In view of the bitterness and other chemical properties of the plant, it is not useful as cattle fodder nor can it be used as fuel, as burning of the plant produces a bad smell and lots of smoke (Mark 2007).

Taxonomy and morphology: The species found in the study area has been identified as *Daphne bholua* var. *bholua* Buch. –Ham. ex D. Don. It is an evergreen shrub of 1–4 m tall, sometimes reaches up to 6 m. Branches are almost brownish that become dark brown ssturated with purple tint, rarely hirsute but soon glabrescent. Leaves are clustered at terminal of stem, alternate arrangement; leaf blade dark green, oblong–lanceolate or narrowly elliptic, leathery, surfaces glabrous, base broadly cuneate, margin sometimes slightly revolute or undulate and apex acute, rarely obtuse or acuminate. Inflorescences are of 5–20 flowered, terminal or axillary; peduncle almost absent; bracts paired, caducous, broadly oblong-ovate or lanceolate, apex caudate. Flowers are borne in terminal rounded stalkless clusters and have very sweet-scented. Calyx purplish red or red at least dorsally; tube cylindrical, Stamens 8, filaments about 0.5 mm; anthers about 2 mm. Ovary cylindric–pyriform, about 4 mm, glabrous, shortly stipitate; style about 0.5 mm; stigma capitate.

Drupe black, ovoid, Flowering January to March, fruiting April to May (Yinzheng *et al*. 2007).

Distribution and habitat: In Nepal, *D. bholua* var. bholua is found in temperate region from east to west between 2000 and 2900 m asl. It is distributed in the Himalayas of Nepal to Arunachal Pardesh, North East India and West China (Press *et al*. 2000).

D. bholua being a shade tolerant species, often grows gregariously in the moist conifer and broadleaf forests of the temperate Himalaya. It generally favors sites with medium to light crown–cover dominated by *Quercus semecarpifolia*, *Rhododendron arboreum*, *Tsuga dumosa* and *Abies* sp. (Jeanrenaud 1984). It is scattered or absent in open forest, pasture or in forest dominated by *Pinus wallichiana*, *Cedrus deodara* and *Picea smithiana* (Forestry services 1984). It needs moist acidic sites rich in organic humus layer with well-drained sandy loam soil (Ghimire *et al.* 2008a).

Medicinal and other uses: The bark is used to make fiber or cordage (Kunwar 2014). Root and bark juice is used as anti-helminthic and to treat intestinal worms, fever, and intestinal disorder as a result of disturbances due to spiritual power (Ghimire and Nepal 2007; Kunwar *et al.* 2010). Extracts from plant are known to possess biologically active secondary metabolites, such as coumarins, biflavanoids and daphnane-type diterpene ester (Mark 1997). The flowers and buds contain phenolic compounds that have diuretic, purgative and expectorant effects (Nikaido *et al*. 1987), while it is reported that a di–terpene compound isolated from *D. bholua* exhibit anti-leukemic property (Kasai *et al.* 1981). *D. bholua* contain toxic resins- Taraxerone (Charmakar *et al.* 2021), which often cause nausea and nasal irritation to people involved in its harvesting (Agnihotri *et al*. 2010).

Papermaking: Since the 12th century, traditional handmade paper has been produced in the hills of rural Nepal (Banjara 2007, Biggs and Messerschmitt 2005). Lokta paper has been used in all government documents and religious texts in Nepal. After establishment of Bhaktapur Craft Printers supported by a UNICEF project in 1980s, demand of lokta and its products (wall papers, notebooks, greeting cards) had increased (Jeanrenaud 1984). The handmade papers are used in preparing horoscopes of children, dressing wounds, and wrapping incense for worshipping (Subedi *et al.* 2006).

2.2.2 *Edgeworthia. gardneri* (Wall.) Meisn

E. gardneri is a multi-branched evergreen shrub locally known as Argeli, Aryoli, Arkale pat, Tinhange, Tinpate, Lokati, Pahenle (Ghimire *et al.* 2008b). It is found in temperate regions of Central and Eastern Nepal. The inner bark of Argeli is used for manufacturing Nepalese handmade paper. Similarly, the semi-processed bark of Argeli is exported to Japan to print the Japanese currency, passports, and postal tickets (Pyakurel and Baniya 2011). Apart from this, the bark is used by local communities to make ropes. Argeli propagates by seeds, root suckers and stem cuttings (Ghimire *et al.* 2008b).

Taxonomy and morphology: Small trees or shrubs of 3-4 m tall. Stem brownish red; branches arise from each node, glabrous or rarely sericeous at apex. Petiole 4 - 8 mm, pubescent; leaf blade 6 - 10 × 2.5 - 3.4 cm, elliptic-lanceolate to narrowly elliptic, glabrous above and pubescent beneath, crowded near the end of branches, base cuneate, apex acute; lateral veins 8 or 9 pairs, conspicuous. Inflorescences 3.5 -4 cm in diameter, 30 - 50 flowered terminal and axillary, capitate; pendulous peduncle, 2 - 2.5 cm, white sericeous, at anthesis glabrous; bracts caducous, leaf-like, narrowly lanceolate. Calyx about 15 mm, exterior densely sericeous; Corolla lobes 4, yellow adaxially, ovate, about 3.5 × 2.5 mm, abaxially densely sericeous, apex acute or rounded. Scales of disk flowers lacerate. Ovary about 5 mm, ellipsoid, uniformly densely grayish white sericeous; style about 2 mm, pubescent; stigma about 3 mm, globose. Drupe ovoid, densely sericeous. Flowering in late winter and early spring, fruiting in summer (November to July) (Polunin and Stainton 1984).

Habitat and distribution: *E. gardneri* is a fast-growing shrub and often attains maturity in three years. It either occurs as a shrub in open places, or as a second storey shrub in temperate forests. It is found within the altitudinal range of 1500 m to 3000 m and found in Uttar Pradesh, India, Central and Eastern Nepal, northern Myanmar and up to South West China (Polunin and Stainton 1984). It is found in Parbat, Myagdi, Lalitpur, Nuwakot, Rasuwa, Sindhupalchowk, Kavrepalanchowk, Ramechhap, Dolakha, Okhaldhunga, Solukhumbu, Tehrathum, Ilam, Panchthar, and Taplejung of Nepal (Ghimire *et al.* 2008a). The species is also found in the forests of *Rhododendron arboreum*, *Quercus semecarpifolia*, *Alnus nepalensis*, *Lyonia ovalifolia*, and *Arundinaria maling*. It generally favours north-west and south-west slopes. Soil moisture, humid climate and partial shade are basic requirements for its optimum growth but it thrives well in all types of soil (Ghimire *et al*. 2008a).

Medicinal and ecological uses: The juice of the root and stem is used for eye disorder, while its bark and leaves are used as fish poison (Manandhar 2002). The roots are sometimes used to treat pimples and skin diseases (Basnet 1999). Since *E. gardneri* have well-developed root system, they prevent soil form erosion. Thus, it can be used as a fencing in areas prone to erosion and to maintain greenery. Similarly, in rural areas, unprocessed bark is used to manufacture rope. Compounds like biscoumarin-edgeworthin and daphnoretin can be isolated from the stem bark which are known to inhibit the lyase activity of DNA polymerase. (Rastogi and Mehrotra 1993b). Unlike *D. bholua*, it can be used as fuel after bark harvesting.

Paper Making: Handmade paper is manufactured from the inner bark of *E. gardneri*. *E. gardneri* is preferred less than *D. bholua* because of yellow colouration on the paper. Also, it is slippery and smooth. The quality of paper are reported as lower grade than *D. bholua*. Semi-processed bark is exported to Japan for the paper used in the production of the Japanese currency, postal tickets, and passports (Kandel 2014).

2.3 Methods

2.3.1 Reconnaissance

Consent was acquired from both Federation of Community Forestry Users Nepal (FECOFUN) located in Duwakot, Bhaktapur and from Sushpa Community Forest User Committee situated in Deurali, Dolakha, to conduct the research (Appendix III). The first visit to study area was in August, 2019 and then next visit was conducted in November in the same year for field data collection. Prior to collecting field data, appropriate locations were determined through informal group discussions with the community members. Information provided by the locals was subsequently utilized to create a data collection plan. Both *Daphne bholua* and *Edgeworthia gardneri* were present in the study area and were able to be identified correctly because of flowering period. Identification of the species was done by following standard literature (Press *et al.* 2000, Polunin and Stainton 1984, Shrestha 2018), expert consultation and comparing with specimens at TUCH and KATH. According to locals, *Edgeworthia gardneri* and *Daphne bholua* individuals could occur from 1850 m to 2600 m and 2400 m to 3300 m respectively in the study site. After proper identification using floras, *Daphne bholua* found from 2400 m to 3000 m was identified as *Daphne bholua* var *bholua*. Dispite the community forest covering an extensive area of 3300 meters, the field based study was limited to elevations below 2800 meters due to challenges related to accommodation and distance.

2.3.2 Population sampling

The study of plant populations of *D. bholua* and *E. gardneri* utilized a stratified random sampling method. The distribution range of these species was considered to be from 2400 m to 2800 m was considered for *D. bholua* and from 2000 m to 2400 m for *E. gardneri*. To ensure representative sampling across elevational gradients and anticipate ample habitat diversity, the study area was stratified into three elevational categories for each species within the same range. The categories were defined as high elevation (Dule 2750 m to 2800 m), mid elevation (Hile 2550 m to 2600 m) and low elevation (Khoria 2350 m to 2400 m) for *D. bholua*, and high elevation (Khoria 2350 m to 2400 m), mid elevation (Chhitpole 2150 m to 2200 m) and low elevation (Deurali 1850 m to 2000 m) for *E. gardneri*. These categories were developed based on the level of anthropogenic disturbance in each area, with Dule being far from human settlement and characterized by very low disturbance, while Deurali was located near human settlement and thus received high disturbance. This approach was used to ensure that the study area was adequately sampled across different elevations and levels of human impact, providing a comprehensive understanding of the plant populations under study.

For both species, a total of 10 plots of sized 10×10 m^2 were laid randomly in each elevation category. The distance between each plot was maintained at a least of 10 m and the plots were at least 30 m far from forest trails. In the both species, *D. bholua* and *E. gardneri*, large plants appeared to be multiple individuals. But on closer inspection, they were clones of root suckers from a single plant (Jeanrenaud 1984). Due to the extensive clonality, distinction of individuals was confusing. Thus we focused our study on ramet level.

In each plot, individual plants from ground i.e. rametes were counted; their girth 20 cm above ground and height were measured; reproductive stage at the time of study was also noted. As fruits were not observed at the time of data collection, only buds and flowers if present were noted. Even small individuals were flowering and producing buds. So, the distinction of plants into new ramet recruit, juvenile and adult stages was done using height and girth of the individual (Table 1). Small individuals without flowers/ buds and ≤ 30 cm height were recorded as new ramet recruits. Associated species, canopy type, were also noted on each quadrat.

Ramets of *D. bholua* and *E. gardneri* found in the quadrats were categorized under three size classes based on stem girth measured at 20 cm above ground level. For *E. gardneri*, adult plants were further distinguished into two categories adult 1 (having girth <15 cm), and adult 2 (girth > 8 cm) unlike *D. bholua*. This is because, large girth sized *D. bholua* individials were present in small number.

Table 1: Girth size of plants in different life stages

Species	Life stages			
	New ramet recruit	Juvenile	Adult 1	Adult 2
D. bholua	< 1 cm	1≤ 4 cm	≥ 4 cm	
E. gardneri	< 1 cm	1≤ 4 cm	< 15 cm	> 15 cm

Individual stem girth was measured at 20 cm above ground (Ghimire and Nepal 2007). Altogether 30 quadrats of each study species were sampled along three elevational bands. Topographical features such as latitude, longitude and altitude of each plot were recorded by Gramin etrex GPS while slope and aspect was measured by clinometer. Slope and aspect were kept almost similar for each plot.

2.3.3 Individual sampling for bark sample collection:

Site division: The same elevation bands categorized in population sampling was used for individual sampling to collect bark samples. Then, in each elevation band, three types of canopy population were selected for the study. The canopy types were categorized as: open (individuals having <25% tree canopy coverage), semi-close (individuals having >25% and <75% tree canopy coverage) and close (individuals having >75% tree canopy coverage) (Shrestha 2012). Again, inside each canopy type, the plants found were of different girth sizes. So, each canopy type was once more divided into populations of different girth size classes. Overall harvestable plants were partitioned into two girth size classes for *D. bhoula* (<10 cm and ≥10 cm) and three girth size classes for *E. gardneri* (<15, <20 ≥15 and >20 cm) (Table 2).

Table 2: Girth size classes for *D. bholua* and *E. gardneri*

Plant species	Girth size population differentiation		
	A	B	C
D. bholua	< 10 cm girth	>10 cm girth	
E. gardneri	<15 cm	≥ 15< 20 cm	>20 cm

The minimum harvestable diameter size for both species was above 3 cm. This harvestable size suggest plant to be of 5 years (Jeanrenaud 1986). So, individual plants exceeding 3 cm in diameter were only selected.

Bark sample collection: Individual plants for collecting the bark sample were selected at a least distance of 30 m from forest trail. Altogether, 15 bark samples (one sample per individual) per species per girth size were collected for the measurement of bark related traits. The samples were bark stripe of about 4 cm long and 3 cm breadth cut by a knife in individual plant at a height of 20 cm above ground without harming inner tissue. To avoid collecting bark samples from individuals propagated through root suckers from the same mother plant, only plant individuals that were at least 5 meters apart were selected for sample collection (Jeanrenaud 1984; Ghimire *et al.* 2008a; Pyakurel 2010). During sample collection, height of plant, girth, bud and flower number if present were noted. Then from the sample, bark thickness and fresh weight of each individual were measured. Each sample were tagged with a specific number and packed in press-seal bags from field to laboratory.

Bark thickness measurement: Bark thickness in individual stem sample was measured using Vernier caliper for each sample in each day after field work. Collected bark include only inner bark made up of phloem.

2.3.4 Laboratory protocol

Laboratory analysis was performed in the lab of Central Department of Botany, T.U. Fibre was manually separated from bark and was divided into equal halves according to weight. Half portion of sample was utilized for fibre length measurement while other half for drying process. The sample use for fibre length measurement was stored in 15% ethanol.

Bark weight measurement: Each sample were dried in oven at 70 degree Celsius for about 48 hours to measure dry weight of the bast.

Fiber length measurement: The fibre samples preserved in alcohol were taken out and washed in the tap water. Then, small samples of white bast fibres were peeled (Johansen 1940) and kept in the test tubes containing solution of nitric acid (10%) and chromic acid (10%) in the ratio 2:1 (modified Jeffery's reagent). The fibres were kept in the solution for next 24 hours. Next day, the same fibres were separated from each other. Before measurement, fibres were diluted using distilled water and temporary slides were prepared. The temporary slides were observed under digital microscope with the magnification power of 50 in the T.U. laboratory. The length of fiber was measured using calibrated ocular micrometer as well as ImageJ software of version. Three replicate measurements of fiber length from each sample was performed. All 15 bark samples collected from each girth size classes were observed to determine length of fibre in both species. Microphotographs were taken for further measurement. To account for the length of individual fibers exceeding the field of view of the microscope, three photographs of the same fiber were taken with a reference scale to capture its entire length. The length measured from each picture was then combined to obtain the precise length of the fiber.

2.3.5 Herbarium collection

Herbarium specimens of *D. bholua* and *E. gardneri* in their flowering stage were prepared. Some unknown associated species collected from the study sites were also mounted into herbarium specimens. All herbarium specimens were deposited in TUCH.

2.3.6 Data analysis

From the data collected, data input, their tabulation and editing was done in Microsoft excel version 2007.

For determining density and rejuvenation ratio of the each elevation, following formula (Subedi 2016) was computed.

$$\text{Density per hectare} = \frac{\text{Total number of individuals in all plots}}{\text{Total number of plots in a site} \times \text{size of plot}} \times 100 \times 100$$

$$\text{Rejuvenation ratio} = \frac{\text{new ramet recruit density} + \text{Juvenile density}}{\text{Adult density}}$$

After that, for preliminary analysis of population data, charts and graphs were constructed in the same excel files. For the individual bark sampling data, after preliminary analysis in excel files, they were subjected for normality tests. As per results, parametric tests were selected. Collection of sample was in nested design i.e. within elevation, the three canopy types were nested and again inside each canopy, different girth size individuals were nested. For bark-related traits data, the comparison of average value for bark-related traits along elevation and canopy types was done using one way ANOVA and multiple comparison based on Tukey HSD test. Correlation of the same traits with elevation and canopy was performed to know the relation between measured variables of plants: girth and height with environment parameters studied. Linear mix model analysis was computed to identify how combine factors effects on bark-related traits. Fixed effects were elevation, canopy and girth size while random effects were individual species selected for bark collection. For the statistical analysis, SPSS version 25 package was used.

CHAPTER THREE: RESULTS

3.1 Population characteristics

The study area covered an elevation range of 2400 m to 2800 m, where the population of *Daphne bholua* was investigated. The study focused on analyzing the variations in the number and density of different life stages of plants along the elevation gradient, which was classified into three categories: high, mid, and low. The high elevation range for *D. bholua* was observed at around 2800 m, comprising locations such as Dharma-dwar and Dule. The mid-elevation range was found at around 2600 m, including places like Hile and Odare, whereas the low-elevation range was observed around 2400 m, including locations such as Daduwa and Khoria.

The study of *Edgeworthia gardneri* was conducted within an altitude range of 2000m to 2400m. Deurali, which is located within the lower elevation of 2000m, Chhitpole at around 2200m, and Khoria and Daduwa at high elevation within 2400m, were the areas studied for this plant species.

3.1.1 Population size along elevation gradient

***D.* bholua**: The population of D. bholua individuals exhibited a gradual increase from the lower elevation of 2400 m (394 individuals per 100 m2) to the higher elevation of 2800 m (1070 individuals per 100 m2), as shown in Figure 2.

Dule and Dharmadwar showed high numbers of ramete as well as gamete individuals of *D. bholua* (including new ramet recruits, juvenile and adults) while lowest elevation Khoria and Daduwa showed decreased number of individuals. So, the pattern of individuals number along elevation was somewhat was increasing from lower elevation to higher elevation.

Edgeworthia gardneri: In the study of *E. gardneri* from 2000 m to 2400 m, total of 546 individuals per 100 m^2 were recorded which include new ramet recruits, juvenile and adults. The number of ramet individuals increased from Deurali (low elevation) with 171 individuals per 100 m^2 to Chhitpole (mid-elevation) with 257 individuals per 100 m^2, and then gradually decreased to 120 individuals per 100 m2 in Khoria (high elevation) (Figure 3).

In 2400 m elevation range, both *D. bholua* and *E. gardneri* individuals were studied. In contrast to *D. bholua*, *E. gardneri* showed preference of mid elevation i.e. Chhitpole, rather than lower and higher elevations. Additionally, number of *D. bholua* individuals was higher than *E. gardneri* individuals observed in the same study area.

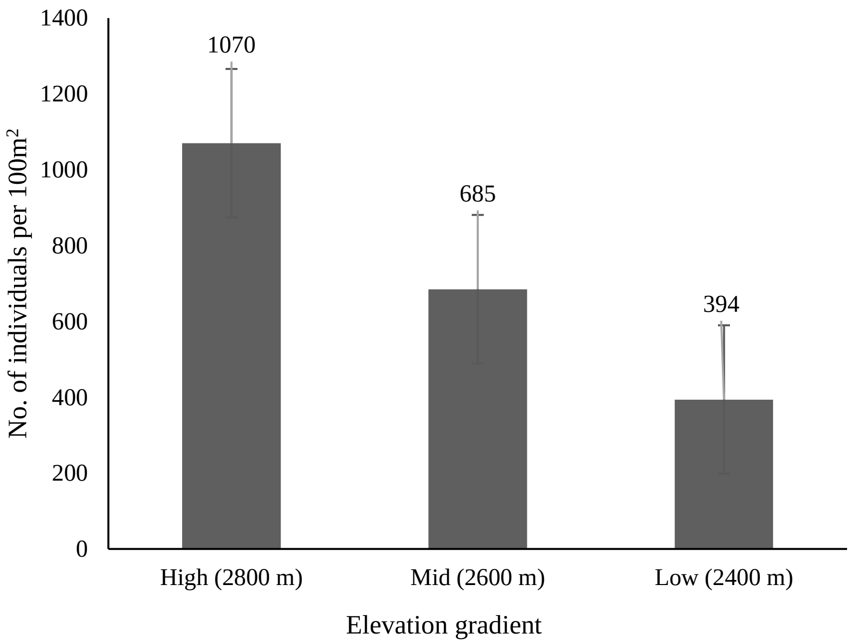


Figure 2: Total number of individuals of *D. bholua* recorded along elevation gradient

3.2.2 Population structure (density and rejuvenation capacity) along elevation gradient

D. bholua**:** In the study area, the *D. bholua* population density was determined by analyzing the plants present in the sampling plots. Due to the limited number of individuals of adults above 8 cm girth in the plots, only three life stages: new ramet recruits, juveniles, and adults were identified for *D. bholua* (Table 2). To account for this, adults above 8 cm girth were combined with adults below 8 cm girth size measured at 25 cm above ground and considered as the same adult class.

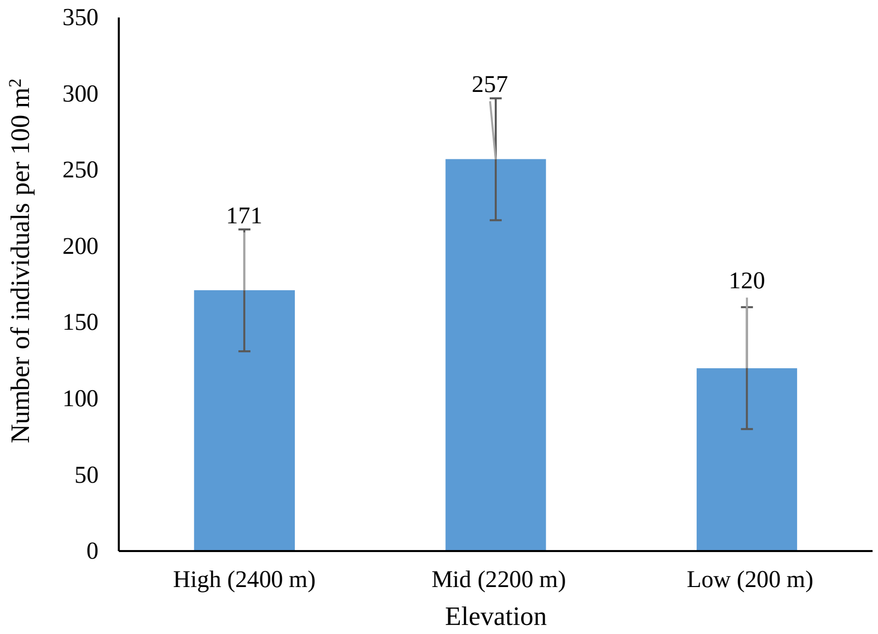


Figure 3: Total number of individuals of *E. gardneri* along elevation gradient

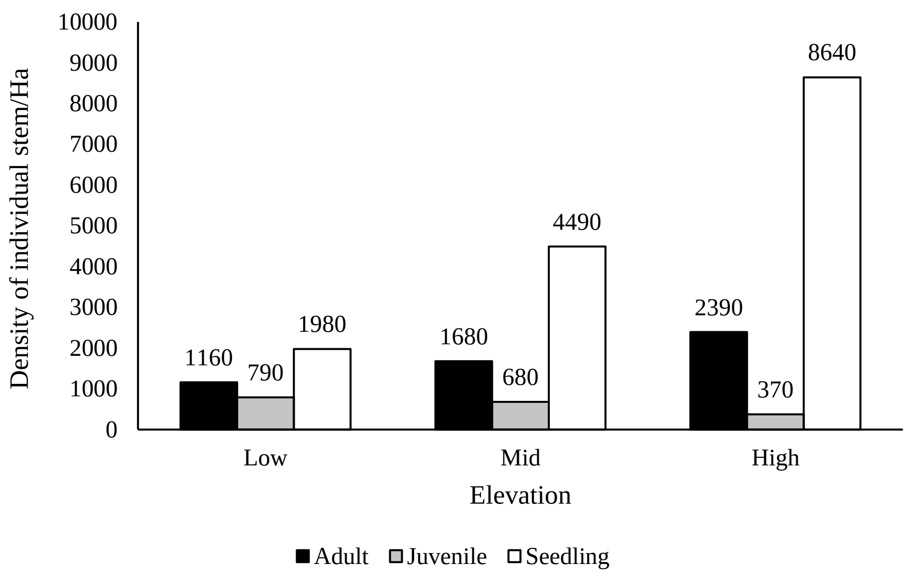


Figure 4: Density of *D. bholua* in different life stages along elevation gradient.

The density of new ramet recruits was the highest among all three life stages, while juvenile density was the lowest. Remarkably, the highest density of new ramet recruits was recorded in Dharmadwar and Dule (2800 m) with 8640 stems/Ha, followed by Hile (2400m) with 4490 stems/Ha and Khoria and Daduwa (2400 m) with 1980 stems/Ha. In contrast, the density of juvenile plants was highest in Khoria and Daduwa (790 stem/Ha) followed by Hile (680 stem/Ha) and Dule (and Dharmadwar) areas (370stem/Ha), which is contrary to the pattern observed in new ramet recruit and adult density along the elevation gradient. Similarly, the density of adult plants in Dharmadwar and Dule was 2390 stems/Ha, followed by Hile (1680 stems/Ha) and Khoria (1160 stems/Ha) (Figure 4).

The density of new ramet recruits and adult plants exhibited an increasing trend with increasing elevation, while the density of juveniles decreased with increasing elevation. The highest suitability for *D. bholua* was observed in Dharmadwar and Dule. Additionally, *D. bholua* showed a higher rejuvenation value at high elevations, particularly in Dharmadwar and Dule, followed by mid and low elevations.

The results indicate a stronger regeneration ability of *D. bholua* in high elevation areas compared to mid and low elevation areas. Notably, the minimum rejuvenation value was observed in the low elevation area (Figure 5).

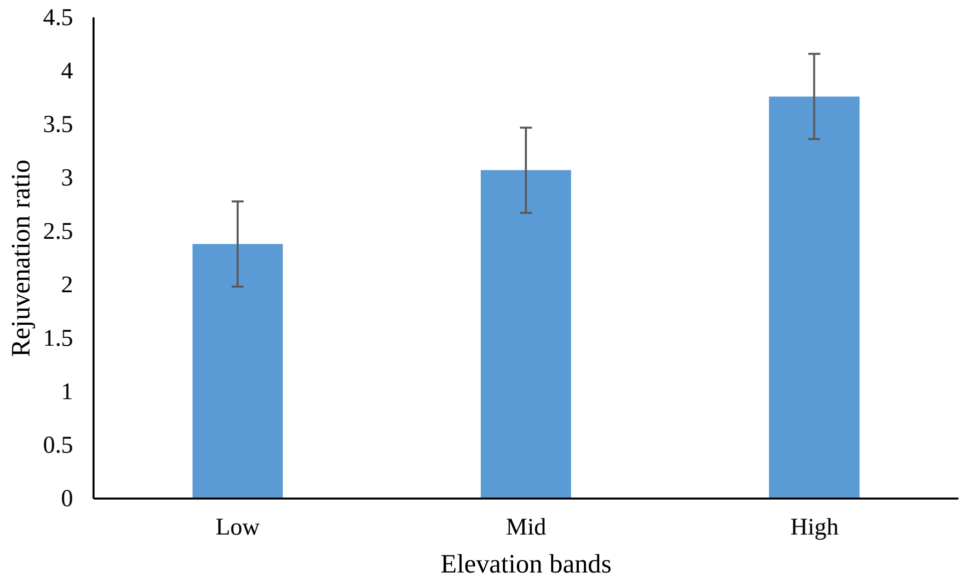


Figure 5: Rejuvenation of *D. bholua* along three elevation bands. Rejuvenation expressed as sum of new ramet recruit and juvenile density divided by adult density.

E. gardneri**:** It is surprising to note that the density of new ramet recruits was absent in both high and mid elevations, and was almost non-existent in the mid elevation with only 2 individuals recorded. The density of juvenile individuals was found to be higher in Deurali with 230 stems/Ha, as compared to Chhitpole and Khoria, where the density was 130 stems/Ha and 150 stems/Ha, respectively.

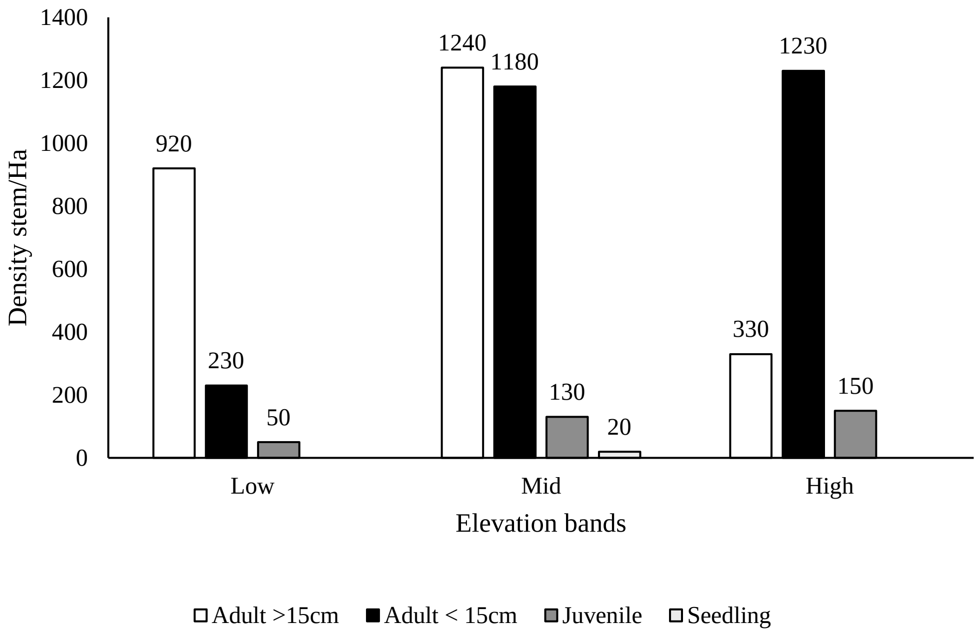


Figure 6: Density of *E. gardneri* in different life stages along elevation gradient.

In Khoria, the density of adult individuals with a girth size of less than 15 cm was found to be high at 1230 stems/Ha, followed by Chhitpole with 1180 stems/Ha and Deurali with 920 stems/Ha. This was in contrast to the density of juvenile individuals. On the other hand, the density of adult individuals with a girth size greater than 15 cm was highest in Chhitpole with 1240 stems/Ha, followed by Deurali with 920 stems/Ha and Khoria with 330 stems/Ha (Figure 6). Overall, the adult density of both >15 cm girth and <15 cm girth was more consistent in Chhitpole, which is a mid-elevation area, compared to higher and lower elevations.

The figure (Figure 7) shows that a high rejuvenation value was observed in plants at high elevations, whereas lower values were observed in plants at lower elevations. This indicates that the species has poor regeneration capacity in low elevation areas. In contrast to *D. bholua* individuals, the absence of new ramet recruit density in all elevation bands of the study area suggests a lower rejuvenation ratio for *E. gardneri*. This highlights a significant difference in the rejuvenation capacity between the two species, with the rejuvenation ratio value being more than 2 in *D. bholua* and below 1 in *E. gardneri*.

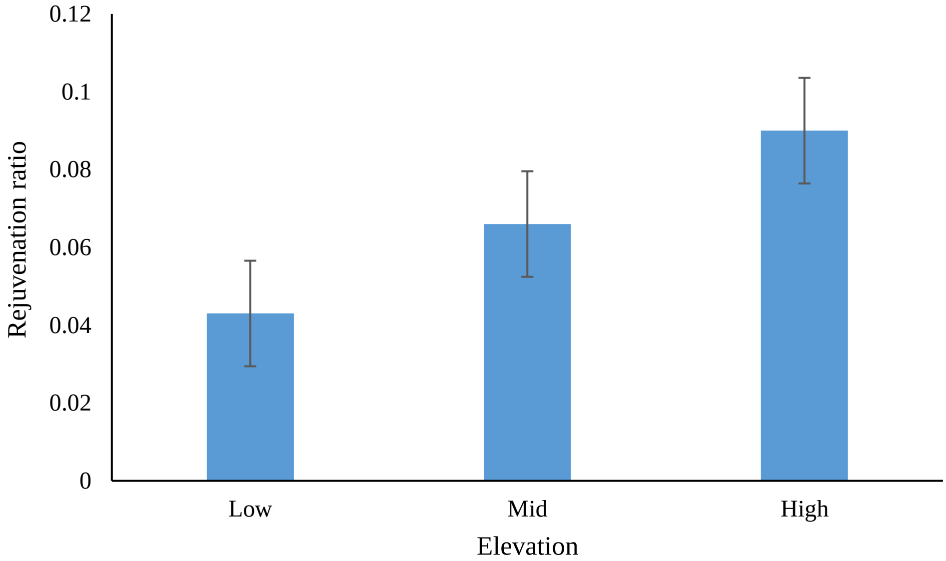


Figure 7: Rejuvenation rate of *E. gardneri* along elevation gradient.

3.2 Comparison of plant traits along elevation and canopy gradient

D. bholua: In *D. bholua*, plant's average girth was observed to be the highest at 11.9 cm in an open canopy site at an elevation of 2800 m. Similarly, the tallest mean value for height was 2.78 m and was also observed at a high elevation, but in a close canopy site. Additionally, the highest mean bark width of 5.79 mm was observed in a high elevation area with a semi-close canopy. The bast dry weight was found to be the highest at an elevation of 2800 m (highest) with a close canopy, at 1.28 g. Lastly, the longest fiber length of 7.78 mm was observed at an elevation of 2800 m (highest) with a semi-close canopy. (Appendix I).

E. gardneri: In the case of E. gardneri, the highest average girth value of 23.73 cm was found in plants at a high elevation with a semi-close canopy. Likewise, the tallest average height value of 4.86 m was observed in plants at a low elevation with a close canopy. Among the calculated mean values, the widest bark width of 5.4 mm was observed in plants at a low elevation with a close canopy, while the highest dry weight of 1.61 g was recorded. The longest length was measured at 5.97 mm in plants at an elevation of 2200 m (mid elavation) with a semi-close canopy.

The mean ± S.E. value of the plant traits along elevation and canopy are shown in table 7 and 8. The values were average mean value of the three girth sized individuals. Even though each value of trait differed in each size class, the significant value remained same (Appendix II).

3.2.1 Variation of plant traits along elevation gradient

***D. bholua*:** On comparison of *D. bholua* traits along three elevation bands, the variation of mean values obtained were slightly significant. The bark related traits and growth related traits slightly varied in terms of elevational difference in the study site.

Height, girth, dry bark mass, and fibre length of the individuals varied significantly among the three sites (F = 5.99, P = < 0.01; F = 3.42 P = 0.034; F = 9.31, P = < 0.01; F = 22.27, P = < 0.01 respectively). However, for bark width, the variation was not significant according to multiple comparison based on Tukey HSD test (F= 0.477, P= 0.621) (Table 3). Plant height of *D. bholua* was highest in Dule with value of 2.5 ± 0.08 m, followed by Hile (2.021± 0.09 m) and Khoria (2.13 ± 0.09 m). Similarly, stem girth was highest in Dule (9.85 ± 0.19 cm) than Hile and Khoria. Individuals in Dule contained more dry bast weight (1.07 ± 0.02 g) than that of Hile (0.91 ± 0.03 g) and Khoria (0.89 ± 0.02 g) (Table 3).

In addition, bast fibre length of *D. bholua* was 7.55 ± 0.07 mm in Dule which was highest among all elevation bands (Table 3). Thus, higher value of growth traits and bark properties was found in Dule (high elevation) among three elevation. However, mean value of height, girth, bark width and fibre length in between low (Hile) and mid (Khoria) elevation didn't varied significantly.

Table 1: Plant growth traits and bark traits along three elevation bands. Values shown are mean ±S.E.

Traits	Low	Mid	High	F	P
Girth (cm)	9.31 ± 0.18^a	9.24 ± 0.17^a	9.85 ± 0.19^b	3.420	0.034
Height (m)	2.13 ± 0.06^a	2.21 ± 0.09^b	2.5 ± 0.08^{ab}	5.995	<0.01
Bark width (mm)	3.16 ± 0.09^a	3.31 ± 0.08^a	3.53 ± 0.084^a	0.477	0.621
Bast dry wt. (g)	0.89 ± 0.02^a	0.91 ± 0.03^a	1.07 ± 0.02^b	9.314	<0.01
Fibre length (mm)	6.66 ± 0.11^a	6.80 ± 0.11^a	7.55 ± 0.07^b	22.276	<0.01

Value of F and p based on one–way ANOVA. Values associated with the same superscript letter are not statistically significant (p>0.05). Multiple comparisons based on Tukey HSD test. n = 90 for all growth-related traits

***E. gardneri*:** Only length of fibre was significantly varied (F= 6.049, P= < 0.003) along elevation (Table 4). The length of fibre was high in high elevation i.e. Khoria (5.23 ± 0.07

mm), followed by mid elevation i. e. Chhitpole (4.94 ± 0.09 mm) and lower elevation Deurali (4.81 ± 0.08 mm). Girth, bark thickness of stem and dry bark weight did not vary significantly with elevation.

Table 4: Variation in growth and bark traits of *E. gardneri* along elevation. Values shown are mean ±S.E.

Traits	Low	Mid	High	F	P
Girth (cm)	16.69±0.43^{a}	17.15±0.48^{a}	16.67±0.39^{a}	0.379	0.685
Height (m)	3.45±0.11^{a}	3.33±0.1^{a}	3.66±0.09^{a}	2.532	0.081
Bark width (mm)	3.84±0.1^{a}	3.67±0.07^{a}	3.94±0.09^{a}	2.092	0.125
Bast dry wt. (g)	1.17±0.03^{a}	1.13±0.04^{a}	1.09±0.02^{a}	1.342	0.262
Fibre length (mm)	4.81±0.08^{a}	4.94±0.09^{a}	5.23±0.07^{b}	6.049	0.003

Value of F and p based on one–way ANOVA. Values associated with the same superscript letter are not statistically significant (p>0.05). Multiple comparisons based on Tukey HSD test. n = 125 for all growth-related traits.

3.2.2 Variation of plant traits with change in canopy

***D. bholua*:** In the similar manner, the variation of mean ± S.E. value of the plant traits were measured along canopy types (close, semi-close and open) without considering change in elevation. But neither of the traits were significantly different with the change in canopy types (Table 5). Canopy type was unable to influence plant traits; height, bark width in stem, girth, dry bast weight and fibre length of the *D. bholua*.

Table 5: Plant growth traits and bark traits in three canopy types. Values shown are mean ±S.E.

Traits	Close	Semi-close	Open	F	P
Girth (cm)	9.47±0.14^{a}	9.48±0.18^{a}	9.45±0.21^{b}	0.008	0.992
Height (m)	2.23±0.07^{a}	2.22±0.08^{b}	2.39±0.07^{ab}	1.3	0.274
Bark width (mm)	3.1±0.09^{a}	3.47±0.34^{a}	3.33±0.34^{a}	0.415	0.661
Bast dry wt. (g)	0.98±0.03^{a}	0.97±0.03^{a}	0.93±0.03^{b}	0.656	0.520
Fibre length (mm)	7.11±0.1^{a}	6.98±0.11^{a}	6.93±0.11^{b}	0.713	0.491

Value of F and p based on one–way ANOVA. Values associated with the same superscript letter are not statistically significant (p>0.05). Multiple comparisons based on Tukey HSD test. n = 90 for all growth-related traits.

***E. gardneri*:** Canopy wise variation in the mean girth, width of bark and dry weight of bast was not significant (Table 6). But the length of bast fibre differed significantly (F=10.034, P= <0.001) with the canopy types. Equivalently, difference in height of *E. gardneri* along elevation gradient was significant at F= 4.713 and P= 0.009.

Table 6: Variation in growth and bark traits of *E. gardneri* plants in canopy types. Values shown are mean ±S.E

Traits	Close	Semi-Close	Open	F	P
Girth (cm)	17.27±0.49^a	16.6±0.43^a	16.3±0.39^a	0.724	0.485
Height (m)	3.26±0.1^a	3.45±0.1^a	3.71±0.09^b	4.713	0.009
Bark width (mm)	3.78±0.09^a	3.9±0.09^a	3.74±0.09^a	0.777	0.461
Bast dry wt. (g)	1.18±0.03^a	1.08±0.03^a	1.12±0.03^a	1.835	0.161
Fibre length (mm)	4.72±0.09^a	4.99±0.08^a	5.26±0.07^b	10.034	<0.001

Value of F and p based on one–way ANOVA. Values associated with the same superscript letter are not statistically significant (p>0.05). Multiple comparisons based on Tukey HSD test. n = 125 for all growth-related traits.

3.2.3 Relation of plant traits with elevation and canopy gradient

To know the exact variables affecting plant growth traits and bark traits, correlation between plant traits, elevation and canopy was performed.

D. bholua: The results obtained were as in the table 5 showed most of the correlation was weak. The table 7 showed correlation of height, girth, dry weight and length of fibre to have weak positive correlation with elevation (0.153, 0.127, 0.233 and 0.352 respectively).

In addition, height, bark width and dry bast weight were weak positively correlated with girth size of plant (Table 5). Again, the girth size was correlated with height of plant (0.291). Dry bark weight was seen positively related to height, girth of stem and bark width (0.191, 0.465 and 0.264 respectively). Length of fibre was also very weakly correlated to dry weight of bast with value of 0.186 (Table 7).

E. gardneri: Further, the correlation between (Table 8) variables (plant traits, elevation and canopy) showed fibre length had weak positive correlation with elevation, canopy and bark width (0.113, 0.218 and 0.146 respectively). However, girth was negatively correlated with canopy types by the value of -0.151 and positively correlated with girth size and diameter (0.543 and 0.505). Width of bark and dry weight of bast was found positively correlated with diameter size, girth and height of plant (Table 8). In addition, dry bast weight was also positively correlated with bark width.

Table 7: Correlation coefficients between plant traits and environmental variables

	Elevation	Canopy type	Girth size	Height (m)	Girth (cm)	Bark width (mm)	Bast dry wt. (g)	Fibre length (mm)
Elevation	1							
Canopy type	0.000	1						
Girth size	0.000	0.000	1					
Height (m)	**0.153***	0.084	**0.157****	1				
Girth (cm)	**0.127***	-0.005	**0.806****	**0.291****	1			
Bark width (mm)	0.048	0.034	**0.192****	0.091	**0.192****	1		
Bast dry wt. (g)	**0.233****	-0.067	**0.391****	**0.191****	**0.465****	**0.264****	1	
Fibre length (mm)	**0.352****	-0.071	-0.049	0.106	0.048	0.000	**0.186****	1

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

Table 8: Correlation coefficients between plant traits and environmental variables of *E. gardneri*

	Elevation	Canopy type	Girth size	Girth (cm)	Height (m)	Bark width (mm)	Bast dry wt. (g)	Fibre length (mm)
Elevation	1							
Canopy type	0	1						
Girth size	0	0	1					
Height (m)	-0.0019	-0.0505	**0.916****	1				
Girth (cm)	0.0684	**-0.151****	**0.505****	**0.543****	1			
Bark width (mm)	0.0256	-0.01593	**0.611****	**0.608****	**0.408****	1		
Bast dry wt. (g)	-0.081	-0.05809	**0.414****	**0.430****	**0.192****	**0.409****	1	
Fibre length (mm)	**0.113***	**0.218****	0.05066	-0.0186	0.0476	**0.146****	0.0902	1

*. Correlation is significant at the 0.05 level (2-tailed). **.Correlation is significant at the 0.01 level (2-tailed).

3.2.4 Effect of nested factors of elevation and canopy on plant traits

Since the data was in the nested form, linear mix model analysis was conducted.

***D. bholua*:** Length of bast fibre was significant along of elevation only (F = 19.225, P = < 0.01) (Table 9). Similarly, dry weight of bast was significantly affected by combine effect of elevation, canopy types and girth size (F = 2.57, P = <0.001), elevation only with F = 7.2, P = < 0.001, both girth size category and canopy nested within elevation (F = 2.9, P = 0.02). Width of bark was not affected by any of the variables. Height and Girth was significantly affected by elevation and combined effect of three factors: elevation, canopy and girth size (F = 12.82, P = < 0.001 and F = 7.42, P = < 0.001 respectively) (Table 9).

The result of linear mix model revealed significant effects of elevation (F = 4.32, P = 0.014), canopy types (F = 4.96, P = 0.007) and combine effect of three factors: girth size, canopy types and elevation (F = 1.92, P = 0.014) for fibre length of *D. bholua* (Table 9).

E. gardneri: Dry weight of bast was significantly affected by combine effect of elevation, canopy types and girth size (F = 2.57, P = < 0.001) as well as canopy nested within elevation categories (F = 2.55, P = 0.03). Equivalently, bark width was significantly affected by girth size of individuals (F =22.84, P = <0.001). Height was significantly affected by the combine effect of elevation, canopy and girth size as well as canopy nested within elevation. Girth however was significantly affected by combination of elevation, canopy and girth size only (Table 10).

From analysis, fibre length was found significant with elevation at F = 1.92, P = 0.014, with combine effects of elevation and canopy at F = 4.99, P = 0.007 and lastly with combine factor of elevation, canopy and girth at F = 4.32, P = 0.014.

Table 9: Variation of *D. bholua* traits along elevation and canopy. Results of linear mix model.

Plant traits	Factors	F	*P*
Fibre length (mm)	Elevation(Canopy types(Girth size))	0.938	0.493
	Elevation(Canopy types)	1.051	0.382
	Elevation	19.225	**<0.001**
	Canopy types	0.986	0.375
	Girth (cm)	0.342	0.559
	Height (m)	1.102	0.295
Bast dry wt. (g)	Elevation(Canopy types(Girth size))	2.31	**0.01**
	Elevation(Canopy types)	2.9	**0.02**
	Elevation	7.2	**<0.001**
	Canopy types	0.98	0.37
	Girth (cm)	15.5	**<0.001**
	Height (m)	0.2	0.65
Bark width (mm)	Elevation(Canopy types(Girth size))	1.218	0.284
	Elevation(Canopy types)	1.546	0.189
	Elevation	0.096	0.908
	Canopy types	0.453	0.636
	Girth (cm)	1.430	0.233
	Height (m)	0.825	0.365
Height (m)	Elevation(Canopy types(Girth size))	2.597	**0.007**
	Elevation(Canopy types)	0.777	0.541
	Elevation	7.429	**0.001**
	Canopy types	2.119	0.122
Girth (cm)	Elevation(Canopy types(Girth size))	73.382	**<0.001**
	Elevation(Canopy types)	3.785	0.005
	Elevation	12.821	**<0.001**
	Canopy types	0.029	0.972

F and p value based on linear mix model.

Table 10: Variation of *E. gardneri* traits along elevation and canopy. Results of linear mix model fixed factors elevation and canopy.

Plant traits	Factors	F	*P*
Fibre length (mm)	Elevation(Canopy types(Girth size))	4.32	**0.014**
	Elevation(Canopy types)	4.96	**0.007**
	Elevation	1.92	**0.014**
	Canopy types	0.53	0.707
	Girth (cm)	1.35	0.24
	Height (m)	0.83	0.36
Bast dry wt. (g)	Elevation(Canopy types(Girth size))	2.57	**<0.001**
	Elevation(Canopy types)	2.55	**0.039**
	Elevation	1.55	0.21
	Canopy types	0.66	0.51
	Girth (cm)	19.63	**<0.001**
	Height (m)	1.82	0.17
Bark width (mm)	Elevation(Canopy types(Girth size))	1.15	0.3
	Elevation(Canopy types)	1.44	0.21
	Elevation	2.92	0.05
	Canopy types	2.58	0.07
	Girth (cm)	22.84	**<0.001**
	Height (m)	1.08	0.29
Height (m)	Elevation(Canopy types(Girth size))	7.73	**<0.001**
	Elevation(Canopy types)	3.76	0.005
	Elevation	3.67	**0.026**
	Canopy types	3.51	**0.031**
Girth (cm)	Elevation(Canopy types(Girth size))	81.70	**<0.001**
	Elevation(Canopy types)	1.74	0.13
	Elevation	1.98	0.13
	Canopy types	2.67	0.07

F and p value based on linear mix model.

CHAPTER FOUR: DISCUSSION

The study of *D. bholua* and *E. gardneri* along elevation gradient (2400 m to 2800 m and 2000 m to 2400 m asl respectively) and canopy types (close, semi-close and open) focuses on population structure and variation of plant growth traits as well as bark traits in the Sushpa Community Forest of Dolakha district in Central Nepal.

4.1 Population size along elevation gradient

Distribution of species along an elevation gradient may seek varying patterns. Some studies have found an increase in species richness pattern from low elevation to high elevation (Baruch 1984), or decrease in species richness patterns from low to high elevation (Sharma *et al.* 2009; Trigas *et al.* 2013) while some studies have identified a hump-shaped pattern of species richness, which shows a peak at mid-elevations (Acharya *et al*. 2011, Ren *et al.* 2012). However, other researchers have observed lowest species richness at mid-elevations (Peet 1978), while some have found no definitive correlation between species richness and elevation (Lovett 1999).

D. bholua: The present study recorded increased individuals (including new ramet recruits, juvenile ramets and adults) of *D. bholua* at Dule (higher elevation) rather than in Hile (mid elevation) and Khoria (lower elevation). This indicated *D. bholua* individuals preferred higher elevation habitat i.e. Dule rather than lower elevations in the study site. The increasing pattern of *D. bholua* population along elevation gradient in the study area was similar to the findings in previous study in the same species in Nepal (Ghimire and Nepal 2007). They found J-shaped distribution pattern of population. The present study resembles same pattern of individuals along elevation indicate the classic example of species in climax undisturbed forest (Rao *et al* 1990).

D. bholua is an understory shrub that prefers moist soil with low biotic disturbances and tree falls gap with relatively low litter accumulation (Ghimire and Nepal 2007, Khadgi *et al.* 2013 Chapagain and Rai 2014). Several previous studies (Jeanrenaud 1984, Dutt 1994, Ghimire and Nepal 2007, Pyakurel and Baniya 2011; Khadgi et al 2013) have found high population of *D. bholua* in habitat that are associated with *Quercus semicarpifolia*, *Rhododendron arboretum*, *Quercus lanata*, *Tsuga dumosa*. This type of habitat suitability in terms of soil type, vegetation association, nutrients availability and moisture content in high elevation areas of the study area may have encouraged vigorous growth of species.

However, the growth of the species is sensitive to haphazard destruction, forest fire and unscientific habitat threatening overgrazing (Jeanrenaud 1984). As the lower elevation is most accessible to community people, it experience such high anthropogenic activities specially the haphazard harvest. These activities might be the cause of population decrease in lower elevations (Koirala 2004; Khadgi *et. al* 2013).

***E. gardneri*:** Similarly, hump shaped pattern of population distribution was observed for *E. gardneri* in which, a species richness peak was observed in mid elevation (Hile). In study of *E. gardneri* in Sindhupalchowk VDCs by Sharma and Kandel (2014), 2200m was found most suitable for the plant. This study in Sushpa Community forest also recorded 2200 m (Chhitpole) was preferred by the species. The low species number in lower elevation (Deurali) might be due to high anthropogenic activities (Khadgi *et al.* 2013) invited by human settlements in Deurali region. On the top of that, the community have been using lower elevation forest areas of for cultivation programs of *Swertia chiryaita* and *Taxus wallichiana*. Moreover, forest in the present study area was not continuous, but were interrupted by patches of grazing lands. Hence population of *E. gardneri* was more often disturbed which might have contributed to low population and individuals in the lower elevation than in higher elevations. Besides, for *E. gardneri*, decline in individuals at the highest elevation than mid elevation might be attributed to its limitation to grow above certain the elevation range due to various environment conditions. So, both species favored specific elevation.

E. gardneri individuals were subjected to more disturbance than *D. bholua* due to which individual number of *E. gardneri* per 100 m^2 were less in comparison to the individuals of *D. bholua* found. This huge decrease in individuals may be caused by premature over-harvesting, unscientific harvesting methods, open grazing, and forest fires threatening sustainability of Argeli (Khadgi *et al.* 2013).

4.2 Population structure along elevation gradient

Ecologists often use age distribution to indicate the health of the population (Zhang *et al.* 2015). Two factors are said to influence this demographic pattern i.e., low harvest and high recruitment. Presence of adequate proportion of new ramet recruit, juveniles, and reproductive adults in any population of a species mean long term endurance and successful regeneration (Saxena and Singh 1985; Saikai and Khan 2013).

***D. bholua*:** The study site incorporate high density of new ramet recruit density than adult and juvenile stages in case of *D. bholua*. During discussion with locals, the site was found subjected to recent past harvest of *D. bholua*. So, the individuals were unlikely to be matured at the time of study as they need 8 years to recover and be of harvestable size again (Ghimire and Nepal 2007). Thus, most of individuals counted in sampling plots were new ramet recruits rather than juvenile ramets and adults. Due to the same reason, adults >10 cm girth were difficult for collection of bark samples.

The high density of new ramet recruits seen in present study area implies high reproduction success in a population (Cousins *et al.* 2014) (Figure 3). Similarly, low density of juvenile in *D. bholua* might correspond to the influence of environment and genetic factors on juvenile period (Hackett 1985). Juvenile period can usually be marked by a phase of rapid vegetative growth that may be slowed down significantly after reaching maturity (Meilan 1997). During juvenile period, progressive changes occur which involve morphological, anatomical, physiological and developmental differences. Length of juvenile phase affects plant breeding efficiency and plant propagation hence it is a crucial phase for a plant (Hackett and Murray 1996).

Vegetative propagating plants like *D. bholua* and *E. gardneri* are dependent on the rejuvenation mechanism. Rejuvenation of plant refers to the process of reversing the adult phase of a plant and resorting some or all of its juvenile characteristics. As noted by Zhang *et al.* (2020), rejuvenation can lead to an improvement in the reproductive capacity and growth of plants. Thus juvenile phase is crucial phase that determine health of future plant population in an area.

E. gardneri: Similarly, absence of new ramet recruits of *E. gardneri* and presence of high girth sized plants indicated harvest of the plant was not done for many years. The intensity of harvesting is a crucial factor thatcan have a significant impact on the survival, growth, and reproductive success of individual plants, as well as the structure and dynamics of plant populations. According to Zhang *et al.* (2021), this factor is easily controllable. By appropriately harvesting bark, coppices can sprout faster and healthy plant populations can be maintained in natural habitats, as noted by Pyakurel (2010). However, the lack of new ramet recruits in the study area suggests low reproductive success for *E. gardneri*. On the top of that, the plant itself covers wide canopy. Large sized individuals and their canopy might have developed high competition in the same area between the same species thus decreasing recruitment of new ramets. Also, the anthropogenic activities and grazing in lower elevations might have limit the reproduction success thus decreasing rejuvenation capacity of the species in study site (Figure 7).

Other factors affecting plant density and plant population is seed viability. *D. bholua* seed viability was reported to be very short. In addition, heavy weevil affects the seed maturation limiting the viable seed (Campbell 1980, Ghimire and Nepal 2007). Similarly, Jeanraund (1984) also mentioned that the fruit of *D. bholua* is very attractive to frugivore birds which also causing the reduction on mature fruits per plant. The positive correlation of *D. bholua* density with soil nutrient availability was an important factor affecting plant density (Gentry 1988; Ashton 1989; Aiba and Kitayama 1999; Givnish 1999).

Variations in population size and density within a species distribution may result from numerous factors, such as disturbance between sites (Helm and Witkowski 2012) and habitat degradation and fragmentation (Witkowski and Lamont 1997). The successful regeneration capacity can be predicted based on the knowledge of current population growth performance, its structure and reproductive output (Guedje *et al.* 2003).

4.3 Variation of plant traits along elevation and canopy

Fibre length: Length is one of the most important characteristics for determining the quality of hand-made papers. A long fibre create space for more bond with other fibres to be held more strongly in the network than a short fibre. This mean the tensile strength of paper along with breaking strain and toughness of a paper improves rapidly with increase in fibre length (Niskanen 1998).

During this study, fibre length in *D. bholua* recorded longest in high elevation (Dule) as 7.78 mm (Appendix I) which was identical to earlier studies by Jeanrenaud (1984) and Trier (1972). They found fibre length of *D. bholua* ranged from 2 mm to 12 mm with an average between 5 and 7mm. Similarly, the longest fibre length for *E. grdneri* was found as 5.97 mm which was similar to the finding by Trier in 1972 (1.5 mm to 5 mm, average 7.5 mm). Trier (1972) also found fibre length for other Thymelaceae family as: 0.5 cm to 3.5 cm for *Stellera chamaejasme* and 1.5 mm to 4mm for *Wikstroemia canescens*. The comparison of fibre length among Thymelaceae showed *D. bholua* to have longest fibre length than others. The extreme long fibres present in *D. bholua* permit the manufacture of strong and high quality handmade-papers (Jeanrenaud 1984) that have tear resistance and flexibility (Maiti 1979). Though the papers made from *E. gardneri* were thin and smooth, it had less satisfactory results on writing purposes (Trier 1972).

In the study, fibre length was found increasing along elevation gradient for both of the species studied. Upon the canopy change in *D. bholua*, variation in fibre length was not observed but fibre length of *E. gardneri* decreased with the increase in canopy coverage i.e. longer in open canopy and shorter in close canopy. This variation in fibre length in both species affected by elevation gradient can be attributed to environmental factors like precipitation, temperature, moisture, humidity, wind velocity, aspects, slope, etc (Nashiro and Suzuki 2001).

Decline in length of vessels and fibre along the elevation gradient has been reported for Iles sp. (Bass 1983). But for *Syringe oblate* var. *giraldii*, length of vessel and fibre was increased with elevation (Zhang *et al.* 1988). This comparison show that species may respond differently to elevation gradient and associated environmental changes. The increased length of *D. bholua* fiber from low elevation to high elevation might be the cause of environmental factors responsible. The increased average fibre length of *D. bholua* individuals in semi-close canopy and of *E. gardneri* in open canopy type in the present study supports that certain level of canopy gap is needed for the better performance of the plant (Jeanrenaud 1984; Dutt 1994; Peterson *et al.* 2007; Pyakurel 2007). Likewise when only one factor was unable to explain the variation in fibre length, combination of factors (elevation, canopy and girth size of individuals) was found significant for the variation.

Bark width and dry bark weight: Inner bark refers to the living organs of the bark that includes phloem and the living tissue up to the last formed periderm, namely phellogen and phelloderm. The inner bark located outside of xylem tissue and inner to periderm is therefore, the main conducting tissue (Junikka, 1994). They form a strength-giving protective layer around the woody central portion of the stem, and are themselves protected by an outermost cuticle. They are the source of fibre for the production of traditional hand-made papers.

Present study exhibit increment in bark thickness as well as dry bark weight with the gradual addition in girth size of both species (Table 5 and Table 9). Bark thickness generally depends on stem age and its diameter so increases along with them (Cunningham 2001) and exist as straight-line relationship (Borger 1973). The thickness of the bark may also be genetically controlled, and vary with tree growth, age and exposure to environment conditions. Bark thickness therefore, can vary considerably with changes in stem girth.

Bark thickness increases with tree size only up to certain height. Then it decreases with height up the stem (William et al 2007). In a study on *Pinus kesiya* in Tanzania, bark thickness was shown to attain its highest value closest to the ground and decrease with increasing height up the stem (Eerikäinen 2001). But present study did not find any relationship of height with bark thickness as the girth size taken and bark sample collected were at the same level of height.

Other measured factors, elevation and canopy did not show any significant effects for bark thickness. However, some direct factors like site quality and soil fertility may influence bark thickness directly, or indirectly by affecting the tree growth rates. Likewise, the thickness of tree bark might be regulated indirectly by the density of the forest, which affects the growth and shape of trees, and can be modified through forest management practices. As both *D. bholua* and *E. gardneri* reproduce vigorously through root suckers on same plant, within stand density may also be the cause of irregular bark thickness even in same girth sized plants.

Both *D. bholua* and *E. gardneri* stems consist of about 7% outer bark, 18% inner bark and 75% wood in terms of weight (Jeanrenaud, 1984). Plants having erect single stem, low tapering, apical branching, large diameter with adequate height yields superior quality barks (Dutta 1994). Plant with less than 3 cm diameter at 30 cm from the ground should not be harvested to allow adequate time for the resource regeneration and to maximize the weight of inner bark yield (Jeanrenaud and Thompson 1986). Despite that, after the age of 15 years, bark convert to dark colour thus becomes less desirable and fetches lower price in market. From a mature 1.5 to 2 m plant, 30 to 70g approximate wet weight of bast can be extracted (Pyakurel 2011). Bark from very old plants are difficult to digest and that from young plants yield paper of inferior quality. Further weight loss during drying is higher for young plants. It is believed that plants more than 1.5 m in height are considered mature. The harvestable plant must be at least 1inch in diameter and 10 to 20 cm above the ground level to yield superior quality bark.

Height and girth: The maximum height of *D. bholua* was found to increase with increased elevation while being unaffected by canopy types. More being on the side of shade-requiring than *E. gardneri*, *D. bholua* might not depend on canopy as it does with elevation. It was rather important to get elevation related conditions than being in canopy or not. Obviously, number of individuals may be less in open canopy but after growing, their growth was not much affected by shade and light present. Apparently, height of *E. gardneri* was rather not influenced by elevation but canopy had negative impact. Very dense tree canopy cover tend to decrease height of the *E. gardneri* species which was similar to the study done by Khadgi *et al*. (2013) in Annapurna conservation area for *D. bholua*. Though *E. gardneri* is a moderately shade loving plant, the habitat with high canopy cover was unsuitable for its proper growth (Dutt 1994). Height of a plant is a functional trait of plant that indicate variability in plant form and function (Swenson and Enquist 2007). It determine strategy of plants to obtain light and are associated with other traits like flowering period, seed reproduction and seed dispersal (Thomson *et al.* 2011).

In case of girth, elevation was found to impact positively for *D. bholua* while neither of the environment variable studied was able to influence girth of *E. gardneri*. The results indicate these two environmental variables are insufficient for the study of plant growth traits. The soil related variables like moisture content, nutrient availability, etc. must be included to point out actual influence of environmental variable in plant.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

D. bholua individuals (new ramet recruits, juvenile ramets and adults) per 100 m^2 were comparatively higher in higher elevation (Dule) rather than in lower elevation (Khoria). This implies, in the present study area, *D. bholua* individuals preferred higher elevation habitat above 2600 m in terms of total species density. Similarly, large individuals of *E. gardneri* per 100 m^2 in mid elevation (Chhitpole) and low individuals in low and high elevation (Deurali and Khoria respectively) implied its preference of mid elevation (2200 m).

D. bholua had a higher density of new ramet recruits as well as overall population suggesting its greater capacity for successful regeneration and reproduction than *E. gardneri*. Similarly, lower elevation being close to human settlements, had lower regeneration success than higher elevation sites.

The primary factor contributing to the increased length of fiber in both species was elevation, with *D. bholua* exhibiting longer fiber length than *E. gardneri*. This longer fiber length resulted in higher quality paper, according to researchers. In the case of *D. bholua*, openness or closeness of the canopy in the growing areas did not have an impact on bark-related traits. However, for *E. gardneri*, both dense canopy and elevation contributed equally to an increase in size of bark-related traits, with the exception of girth size, which decreased with an increase in dense canopy. While elevation and canopy did have an effect on bark characteristics, they were not particularly strong driving forces that could significantly alter their measurement values in response to changes in these factors.

The combined influence of elevation and canopy had a more significant impact on plant traits compared to their individual effects. These factors worked together as a unit to promote plant growth, rather than acting independently. However, it is important to note that the study was only focused on elevation and canopy factors, which are themselves a combination of various micro-variables. To gain a more accurate understanding of the variables that influence plant growth, long-term research that includes a variety of other factors, particularly edaphic factors, is required.

5.2 Recommendations

The study recorded a good potential of *D. bholua* and *E. gardneri* population in the study area. Even so early harvesting of *D. bholua* bark is not recommended as matured individuals were limited and disturbance to new ramet recruits may danger future harvesting source. In case of *E. gardneri*, quick action should be taken to improve regeneration while harvesting the fully matured individuals. The results in this study was based only on few months of field works. So, to gather a detail and complete status of these species, long duration and wide area covering research is required. There is a need in preparing long-term plan to minimize anthropogenic disturbances and manage grazing practices in forests. Trainings on sustainable harvesting techniques and paper making should be provided to the local people for the improvement of livelihood of locals. Further research incorporating demographic modelling over several years is necessary to assess whether the populations of both species are increasing or decreasing in the study area.

REFERENCES

Acharya, K. P., Vetaas, O. R. and Birks H. J. B. 2011. Orchid species richness along Himalayan elevational gradients. *Journal of Biogeography* **38**(9): 1831-1833

Agnihorti, S., Wakode, S. and Agnihorti, S. 2010. An overview on anti–inflammatory properties and chemo–profiles of plants used in traditional medicine. *Indian Journal of Natural Products and Resources* **1**: 150–167.

Aguilar-rodríguez, S., Terrazas, T. and López-mata, L. 2006. Anatomical wood variation of Buddleja cordata (Buddlejaceae) along its natural range in mexico. *Trees* **20**: 253–261.

Aiba, S. and Kitayama, K. 1999. Structure, composition and species diversity in an altitude–substrate matrix of rain forest tree communities on Mount Kinabalu, Borneo. *Plant Ecology* **140**: 139–157.

ANSAB (Asia Network for Sustainable agriculture and Bioresources). 2009. *Challenges and Opportunities for Nepal's small and Medium Forest Enterprises (SMFEs)*. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Ashton, P.S. 1989. Species richness in tropical forests. *Tropical Forests* (eds L.B. Hohn-Nielsen, I.C. Nielsen & H. Baislev) Academic Press, London: 239 251

Baptista, P., Costa, A. P., Simoes, R. and Amaral, M. E. 2014. *Alianthus altiissima*: An alternative fiber source for paper making. *Industrial Crops and Products* **52**: 32–37.

Banjara, G.B. 2007. *Handmade Paper in Nepal, Upgrading with Value Chain Network*. German Technical Cooperation/Private Sector Promotion. Kathmandu, Nepal.

Baruch, Z. 1984. Ordination and Classification of Vegetation along an Altitudinal Gradient in the Venezuelan Páramos. *Vegetation* **55**(2):115-126

Bass, S. 2002. *The sustainable forestry hand book*. Earthscan publications Ltd London.

Becker, A., Korner, C., Brun, J.J., Guisan, A. and Tappeiner, U. 2007. Ecological and Land-Use Studies along Elevational Gradients. *Mountain Research and Development* **27**: 58-65.

Bhattarai, K.R. and Vetaas, O.R. 2003. Variation in plant species richness of different life forms along a subtropical elevation gradient in the Himalayas, East Nepal. *Global Ecology & Biogeography* **12**: 327–340.

Biggs, S. and Messerschmidt, D. 2005. Social Responsibility in the Growing Handmade Paper Industry of Nepal. *World Development* **33**(11): 1821–1843

Broger, A. 1973. *Development and shedding of bark* T.T. Kozlowski (Ed.), Shedding of Plant Parts, Academic Press, New York: 205-236

Campbell, M.W. 1980. *Plant propagation for reforestation in Nepal*. Nepal–Australia Forestry Project, Department of Forestry, A.N. U.

Chapagain, J. K. and Rai, S. P. 2014. Value chain analysis of forest product in Koshi Hill Districts of Nepal: Challenges and opportunities for economic growth. Forest action Nepal and RRN, Kathmandu.

Charmakar, S., Kunwar, R. M., Bussmann, R.W., Pradhan, D. K., Jan H. A., Abbasi, A. M. and Zambrana, N. P. 2021. *Daphne bholua Buch.-Ham. ex D. Don. Daphne mucronata Royle Daphne papyracea Wall. ex G. Don. Thymelaeaceae*. In: Kunwar R. M., Sher, H., Bussmann,R. W. (eds) Ethnobotany of Himalayas. Ethbotany of Mountain Regions. Springer, Cham. 1-19

Cousins, S.R., Witkowski, E.T.F. and Pfab, M.F. 2014. Elucidating patterns in the population size structure and density of Aloe plicatilis, a tree aloe endemic to the Cape fynbos. South Africa. *South African Journal of Botany* **90**: 20–36.

Cunningham, A.B. 2001. *Applied Ethnobotany: People, Wild Plant Use and Conservation*. A People and Plants Conservation Manual. Earth scan, London

Denslow, J.S., Schultz, J.C., Vitousek, P.M. and Strain, B.R. 1990. Growth responses of tropical shrubs to tree fall gap environments. *Ecology* **71**: 165–179.

Dhungana, A; Khatri- Chhetri, J. 1995. Estimation of Growing Stock and Sustainable Yield of Lokta Bark in Makalu- Barun Conservation Area. Makalu- Barun National Park and Conservation Area Project, Department of National Parks and Wildlife Conservation, HMG / Nepal.

DPR (Department of Plant Resources). 2001. *Flowering Plants of Nepal (Phanerogams)*. Government of Nepal, Ministry of Forests and Soil Conservation, Kathmandu, Nepal.

DPR (Department of Plant Resources). 2002. *Pteridophytes of Nepal.* Government of Nepal. Ministry of Forests and Soil Conservation, Kathmandu, Nepal.

Dutta, G. and Devi, A. 2013. Plant diversity, population structure, and regeneration Status in disturbed tropical forests in Assam, Northen India. *Journal of Forestry Research* **24**: 715–720.

Dutt, P. 1994. *Lokta Daphne species. The Supply situation in the Basantapur Area*. Project Report, Nepal– UK Community Forestry Project, Coordinators Office, Kathmandu, Nepal. Filazzola, A., and Lortie, C.J. 2014.

Eerikainen, K. 2001. Stem volume models with random coefficients for *Pinus kesiya* in Tanzania, Zambia and Zimbabwe. *Canadian Journal of Forest Research* **31**:879-888.

Federation of Handicraft Association of Nepal (FHAN). 2078. *Export statistics*. http:fhan.org.np/dashboard/menu. 10th April, 2019.

Forestry Services (FSRO). 1983. *Daphne Forest Survey of Hatiya Forest Range, Dhaulagiri Forest range, Division, Baglung, Forestry Services*. Submitted to UNICEF/Nepal. Kathmandu, Nepal.

Forestry Services (FSRO). 1984. Management plan for sustained harvest and utilization of *Daphne* (Lokta) from the Kalinchok and Sailung forest areas, conservation and development objectives. *Ecological Economics* **39**: 437– 447.

Gentry, A.H. 1988. Changes in plant community diversity and floristic composition on environmental and geographical gradients. *Annals of Missouri Botanical Garden* **75**: 1–34.

Ghimire, S.K. and Nepal, B.K. 2007. *Developing a Community–based Monitoring System and Sustainable Harvesting Guidelines for Non–Timber Forest Products (NTFP) in Kanchanjunga Conservation Area (KCA), East Nepal*. WWF Nepal Program, Kathmandu, Nepal.

Ghimire, S. K., Pyakurel, D., Nepal, B. K., Sapkota, I. B., Parajuli, R. R. and Oli, B. R. 2008a. *A Manual of NTFPs of Nepal Himalaya (Gair Kastha Ban Paidawar Digdarshan)*. WWF Nepal, Kathmandu,Nepal. (In Nepali).

Ghimire, S. K., Sapkota, I. B., Oli, B. R. and Parajuli-Rai, R. 2008b. *Non Timber Forest Products of Nepal Himalaya: Database of Some Important Species Found in the*

Mountain Protected Areas and Surrounding Regions. WWF Nepal, Kathmandu, Nepal.

Given, D.R. 1975. Conservation of rare and threatened plant taxa in Newzealand– some principles. *Proceeding of the Newzealand Ecological Society* **22**: 1–6.

Gracia, M. and Retana, J. 2004. Effect of site quality and shading on sprouting patterns of holm oak coppices. *Forest Ecology and Management* **188**: 39–49.

Guedje, N.M., Lejoly, B.A., Nkongmeneck, B.A. and Jonkers, W.B.J. 2003. Population Dynamics of Gracinia lucida (Clusiaceae) in a Cameroonian Atlantic Forests. *Forest Ecology and Management* **117**: 231–241.

Hackett, W. P. 1985. Juvenility, maturation and rejuvenation in woody plants. *Horticultural Review* **7**: 109-155.

Hackett, W. P., Murray J. R. 1996. *Maturation or phase change. In: Molecular and morphological markers for juvenility, maturity, rejuvenation and somatic embryogenesis in woody plant species.* Thompson D, Welander M, (eds.). European Comission, Malmo, Sweden, 7-22

Handicraft Association of Nepal. 2000. Monthly Bulletin. Year 7, No 11

Helm, C.V and. Witkowski, E.T.F. Forest. 2012. Characterising wide spatial variation in population size structure of a keystone African savanna tree. *Ecology and Management* **263**: 175–188.

Helman-Wazny, A. 2014. *The archaeology of Tibetan books*.

HMGN/MFSC. 2002. *Nepal Biodiversity Strategy*. Kathmandu: His Majesty Government of Nepal, Ministry of Forest and Soil Conservation.

Horn, R. A. 1974. *Morphology of wood pulp fiber from softwoods and Influence on paper strength*. USDA Forestry Services Research Paper FPL 242. For. Prod. Lab., Madison

Hubbe, M. A. and Bowden, C. 2009. Handmade paper: A review of its history, craft, and science. *BioResources* **4**(4): 1736-1792.

International Trade Center (ITC) and Government of Nepal (GoN). 2017. *Nepal National Sector Export Strategy, Handmade paper and Paper products* (2017 – 2021).

Jeanrenaud, J. P. (1984). *D. bholua (Lokta), Some Silvicultural Considerations*. In Proceedings Workshop and Seminar on Lokta (*D. bholua*) and Craft paper Making in Nepal. Department of Forest and UNICEF, Kathmandu, Nepal.

Jeanrenaud, J. P. 1985. *Propagation and Silviculture of Lokta (D. bholua) in Nepal*. Department of Forestry, Forest Survey and Research Office, Babarmahal, Kathmandu, Nepal

Jeanrenaud, J. P. and Thompson, I. 1986. *D. bholua* (lokta), bark biomass production management implications for paper making in Nepal. *Commonwealth Forestry Review* **65**(2): 117-130.

Jeffery, E. C. 1917. *Anatomy of wood plants.* University of Chicago press, Chicago IL

Jnawali, B. 2019. *Population Characteristics, Habitat Preference and Bark Harvest Potential of D. bholua bholua in Madane Protected Forest, Gulmi, Nepal* (Doctoral dissertation, Central Department of Botany).

Johansen, D. A. 1940. *Plant microtechnique*. McGraw Hill, New York

Joshi, L. 2000. *Ecological Wood Anatomy of Alnus nepalensis (Betulaceae) in Central Nepal*. Chonnam National University Press, Kwangju.

Junikka, L. 1994. Survey of English Macroscopic Bark Terminology. *Iawa Journal* **15**(1): 3-45

Kandel, P. N. 2007. Effects of forest certification towards sustainable community forestry in Nepal. *Banko Janakari* **17**(1): 11–16.

Kasai, R., Lee, K.H. and Huang, H.C. 1981. Genkwadaphnin, a potent anti–leukaemic diterpene from Daphne genkwa. *Phytochem* **20**: 2592–2594.

Khadgi, N., Shrestha, B.B. and Siwakoti, M. 2013. Resource assessment and Habitat analysis of *D. bholua bholua* in Bhujung of Annapurna Conservation Area, Central Nepal. *Research Journal of Agriculture and Forestry Sciences* **1**(4): 1-9.

Kim, E. and Donohue, K. 2011. Demographic, developmental and life–history variation across altitude in Erysimum capitatum. *Journal of Ecology* **99**: 1237–1249.

Klimes, L. 2003. Life-Forms and Clonality of Vascular Plants along an Altitudinal Gradient in E Ladakh (NW Himalayas). *Basic and Applied Ecology* **4**: 317-328.

Koirala, M. 2006. Vegetation composition and diversity of Piluwa micro-watershed in Tinjure-Milke region, east Nepal. *Himalayan Journal of Sciences* **2**(3)

Kunwar, R. M., Fadiman, M., Thapa, S., Acharya, R. P., Cameron, M. and Bussmann, R. W. 2020. Plant use values and phytosociological indicators: implications for conservation in Kailash Sacred Landscape, Nepal. *Ecological Indicators* 108: 105679

Lomolino, M.V. 2001. Elevation gradients of species–richness, historical and prospective views. *Global Ecology and Biogeography* **10**: 3–13

Lopez-Binnqüist, C. L., Quintanar–Isaías, A. and Vander-Meeren, M. 2012. Mexican bark paper: Evidence of history of tree species used and their fiber characteristics. *Economic Botany* **66**(2): 138-148.

Lovett, J.C. 1999 Tanzanian forest tree plot diversity and elevation. *Journal of Tropical Ecology*: 689-694.

Maiti, R.K. 1979. A Study of the Microscopic Structure of the Fiber Strands of Common Indian Bast Fibers and Its Economic Implications. *Economic Botany*. 33(1): 78-87

Manandhar, N. P. 2002. *Plants and People of Nepal*. TimberPress, Inc., Portland

Marks, T.R. 1997. Micropropagation of Daphne L. In, Bajaj Y.P.S. (eds) High–Tech and Micropropagation VI. Biotechnology in Agriculture and Forestry., Berlin, Heidelberg. *Springer* **40**: 113-130.

Meilan, R. 1997. Floral induction in woody angiosperms. *New forests* **14:** 179-202

Nadkarni, N. M., Merwin, M. C., and Nieder, J. 2001. *Forest canopies: Plant diversity. In S. Levin (Ed). Encyclopedia of biodiversity*. Academic Press, San Diego, California: 27–40.

Namgail, T., Rawat, G.S., Mishra, C., and Herbert, H.T.P. 2010. Biomass and diversity of dry alpine plant communities along altitudinal gradients in the Himalayas. *Journal of Plant Resources* **125**: 93–101.

Noshiro, S. and Suzuki M. 2001. Ontogenic wood anatomy of tree and sub-tree species of Nepalese *Rhododendron* (Ericaceae) and characterization of shrub species. *American Journal of Botany* **88**(4): 560-569.

Nashiro, S., Suzuki, M. and Joshi, L. 2010. Distinct altitudinal trends in the wood structure of Rhododendron arboretum (Ericaceae) in Nepal. *International Association of Wood Anatomists* **4**: 433-456.

Nashiro, S., Suzuki, M. and Ohba, H. 1995. Ecological wood anatomy of Nepalese Rhododendron (Ericaceae):1 Interspecific variation. *Journal of Plant Research* **108:** 1-9.

Nikaido, T., Ohmoto, T. and Sankawa, U. 1987. Inhibitors of adenosine–cyclic monophosphate phosphodiesterase in Daphne genkwa Sieb. et Zucc. *Chemistry Pharmaceutical Bulletin* **35**: 675–681.

Niskanen, A. 1998. Financial and Economic Profitability of Reforestation in Thailand. *Forest Ecology and Management* **104**: 57-68.

Norman, J., Campbell, G. S., Pearcy, R. W. *et al.* (1989). *Plant Physiological Ecology*. Chapman and Hall

NSCFP. 2001. *Participatory inventory Guidelines for non-timber forest product*. Nepal Swiss Community Forestry Project (NSCFP), Nepal.

NSCFP. 2010. Report on CFUGs' *Self-Monitoring Database of NSCFP Area – Dolakha, Ramechhap, Okhaldhunga and Khotang districts*. Updated version 2010. NSCFP. Kathmandu.

Oberhuber, W. 2004 Influence of climate on radial growth of *Pinus cembra* within the alpine timberline ecotone. *Tree Physiology* **24**(3): 291–301

Oluwadare, A. O. and Sotannde, O. A. 2007. The Relationship between Fibre Characteristics and Pulp-sheet Properties of *Leucaena leucocephala* (Lam.) De Wit. *Middle-East Journal of Scientific Research* **2**(2): 63-68.

Peet, R. K. 1974. The measurement of species diversity. *Annual Review of Ecology and Systematics* **5**: 285–307

Peterson, D.W., Reich, P.B. and Wrage, K.J. 2007. Plant functional group responses to fire frequency and tree canopy cover gradients in Oak Savanas and woodlands. Journal of Vegetation Science **18**: 3–12.

Polunin O. and Stainton A. 1984. *Flowers of the Himalaya*. Oxford University Press, New Delhi, India.

Paudel, D. and Aus der Beek, R. 2001 *Participatory Inventory Guidelines for Non- Timber Forest Products. Nepal Swiss Community Forestry Project* (NSCFP), Kathmandu, Nepal.

Poudyal A. S. 2004. Sustainability of local handmade paper (Nepali kagat) Enterprises: a case study of Dolakha district. *Journal of forest and livelihood* **4**(1).

Press J. R., Shrestha K. K. and Sutton D. A. 2000. *Annotated Checklist of the Flowering Plants of Nepal*. The Natural History Museum, London, UK.

Pyakurel, D. 2010. *Resource Assessment and Value Chain Analysis of Lokta, Argeli and Dhasingre in selected Buffer Zone Community Forests of Nuwakot and Sindhupalchowk district of LNPBZ.* A report submitted to Langtang National Park Buffer Zone Area Support Programme / World Wildlife Fund (LNPBZ-SP/WWF), Rasuwa.

Pyakurel, D. and Baniya, A. 2011. NTFPs: *Impetus for Conservation and Livelihood support in Nepal*. A Reference Book on Ecology, Conservation, Product Development, and Economic Analysis of Selected NTFPs of Langtang area in the Sacred Himalayan Landscape WWF Nepal.

Rantoandro, G. 1983. Contribution a la connaissance du papier Antemoro (Sud-est de Madagascar). *Archipel* **26**: 86–104.

Rao, P., Barik, S.K. and Pandey, H.N. 1990. Community composition and tree population structure in a sub-tropical broad-leaved forest along a disturbance gradient. *Vegetation*. **88:** 151–162.

Rastogi, R.P. and Mehrotra, B.N. 1993b. *Compendium of Indian Medicinal Plants Vol. III*. C.D.R.I., Lucknow and P.I.D, New Delhi.

Raven, P. H., Evert, R. F. and Curtis, H. 1981. *Biology of Plants*. Worth Publishers, New York (N.Y).

Saikia, P. and Khan, M.L. 2013. Population structure and regeneration status of Aquilaria malaccenis Lam. in homegardens of Upper Assam, Northeast, India. *Tropical Ecology* **54**: 1–13.

Saxena, A.K. and Singh, J.S. 1985. Tree population structure of certain Himalayan forest association and implications concerning their future composition. *Vegetation* **58**: 61–69.

Sharma, R. P., Bhandari, S. K. and BK, R. B. 2017. Allometric Bark Biomass Model for *D. bholua bholua* in the Mid-Hills of Nepal. *Mountain Research and Development* **37**(2): 206-215.

Shrestha, S. 2012. *Growth Performance of Daphne bholua in Relation to Harvesting and Ecological Conditions in Langtang National Park, North–Central Nepal*. [M.Sc thesis]. Kathmandu: Central Department of Botany, Tribhuvan University.

Shrestha, PM, Dhillion, S.S. 2003. Medicinal plant diversity and use in the highlands of Dolakha district, Nepal. *J Ethnopharmacol*. **86**: 81-96.

Shrestha, K. K., and Ghimire, S. K. 1996. *Diversity, ethnobotany and conservation strategy of some potential medicinal and aromatic plants of Taplejung, east Nepal (Tamur valley)*. Kathmandu: Report submitted to ANSAB.

Singh, J.S., Singh, S.P. and Gupta, S.R. 2014. *Ecology Environmental Science and Conservation.* S. Chand and Company Pvt. Ltd, Ramnagar, New Delhi.

Subedi, B. P. 2004. *FSC Certification Progress in Nepal, a synopsis*. Asia Network for Sustainable Agriculture and Bio-resources (ANSAB). www.ansab.org

Subedi, B.P. 2006. *Linking Plant-based Enterprises and Local Communities to Biodiversity Conservation in Nepal Himalaya*. Adroit Publishers, New Delhi.

Subedi, B. P., Binayee, S. and Gyawali, S. 2006. *Handmade Paper Value-Chain of Nepal: Prospects and Challenges in Growth, Distributional Equity and Conservation Draft* (A paper prepared for the 11th biennial conference of IASCP in Bali to be held in June 2006 with the financial support from World Resources Institute). Asia Network for Sustainable Agriculture and Bioresources (ANSAB) Kathmandu, Nepal

Subedi, B. P., Ojha, H. R., Nicholson, K. and Binayee, S. B. 2002. *Community Based forest Enterprises in Nepal: Case Studies, Lesson and Implications.* Asia Network for Sustainable Agriculture and Bioresearches and The Netherlands Development organization, Kathmandu, Nepal.

Subedi, P. U. 2016. *Population structure and plant performance of Juniperus squamata Buch.-Ham. Ex D. Don along elevation gradient in Manang, Nepal*. (Doctoral dissertation, Central Department of Botany)

Swenson, N. G. and Enquist, B. J. 2007. Ecological and evolutionary determinants of a key plant functional trait: wood density and its community-wide variation across latitude and elevation. *American Journal of Botany* **94**: 451-459

Thomson, F.J., Moles, A. T., Auld, T. D. and Kingsford R. T. 2011. Seed dispersal distance is more strongly correlated with plant height than with seed mass. *Journal of Ecology* **99**(6):1299–307

Ticktin, T. 2004. The ecological implications of harvesting non-timber forest products. *Journal of Applied Ecology* **41**(1): 11-21.

Trier, J. 1972. *Ancient paper of Nepal*: *Results of Ethno-technological Field Work on Its Manufacture, Uses and History* - *with Technical Analyses of Bast, Paper and Manuscripts.* Jutland Archaeological Society Publications. Copenhagen, Denmark.

Wickens, G.E. 1991. *Management issues for development of non-timber forest products. Unasylva* **42** (165): 3-8

Williams, V.L., Witkowski, E.T.F, Balkwill, K. 2007 Relationship between bark thickness and diameter at breast height for six tree species used medicinally in South Africa. *South African Journal of Botany* **73**: 449-465

Witkowski, E.T.F., Lamont, B.B., 1997. Does the rare Banksia goodii have inferior vegetative, reproductive or ecological attributes compared with its widespread co–occurring relative B. gardneri? *Journal of Biogeography* **24**: 469–482.

Yang, Y., Sun, H., and Korner C. 2020. Explaining the exceptional 4,270 m high elevation limit of an evergreen oak in the south-eastern Himalaya. *Tree Physiology* **40**(10): 1327-1342.

Yinzheng, W., Gilbert, M.G., Mathew, B. and Brickell C.D. 2007. DAPHNE Linnaeus, Sp. Pl. 1: 356. 1753. *Flora of China* **13**: 230–245.

Zhang, J., Young, D.H., Oliver, W.W. and Fiddler, G.O. 2015. Effect of overstorey trees on understorey vegetation in California (USA) Ponderosa pine plantations. *Forestry* **89**: 91–99.

Zhang, L., Luo, T., Liu, X. and Wang, Y. 2012. Altitudinal variation in leaf construction cost and energy content of Bergenia purpurascens. *Acta Oecologica* **43**:72–79.

Zhang, T., Yu, L., Man, Y. 2021. Effects of harvest intensity on the marketable organ yield, growth and reproduction of non-timber forest products (NTFPs): implication for conservation and sustainable utilization of NTFPs. *For. Ecosyst.* **8(**56).

Zhang, X., Deng, L. and Baas, P. 1988. The ecological wood anatomy of liliacs *(Syringe oblate* var. *giraldii)* on Mount Taibei in north western China. *International Association of Wood Anatomists Bull*. **9**: 24-30

Zhang, Z., Sun, Y. and Li, Y. 2020. Plant rejuvenation: from phenotypes to mechanisms. *Plant Cell Rep*. **39**(10): 1249-1262

APPENDIX: I

Table 2: Mean ± S.E. of *D. bholua* traits along elevation gradient and canopy types

Plant traits	Elevation (2800 m)					
	Close Canopy		Semi-close Canopy		Open canopy	
	Girth< 10 cm	Girth > 10 cm	Girth< 10 cm	Girth > 10 cm	Girth< 10 cm	Girth > 10 cm
Girth (cm)	8.91±0.16	10.94±0.22	8.3±0.19	**11.9±0.22**	8.32±0.2	10.76±0.57
Height (m)	2.28±0.21	**2.78±0.18**	2.49±0.16	2.29±0.21	2.64±0.18	2.54±0.25
Bark width (mm)	2.91±0.19	3.76±0.28	2.76±0.25	**5.79±1.95**	2.87±0.25	3.08±0.19
Bast dry wt. (g)	1±0.04	**1.28±0.68**	1.01±0.03	1.19±0.72	0.86±0.06	1.07±0.46
Fibre length (mm)	7.55±0.19	7.4±0.11	7.35±0.29	**7.78±0.1**	7.66±0.12	7.58±0.12
	Elevation (2600 m)					
	Girth< 10 cm	Girth > 10 cm	Girth< 10 cm	Girth > 10 cm	Girth< 10 cm	Girth > 10 cm
Girth (cm)	10.26±0.11	8.01±0.19	8.02±0.18	11.18±0.4	7.57±0.17	10.04±0.13
Height (m)	2.23±0.14	1.83±0.17	1.94±0.17	2.48±0.11	2.16±0.14	2.11±0.09
Bark width (mm)	3.04±0.24	2.68±0.02	2.88±0.19	3.01±0.2	2.5±0.19	4.86±2.03
Bast dry wt. (g)	1.06±0.08	0.8±0.03	0.81±0.05	0.96±0.09	0.71±0.64	1.15±0.13
Fibre length (mm)	6.38±0.17	7.12±0.18	7.21±0.37	6.98±0.25	6.53±0.34	6.6±0.24
	Elevation (2400 m)					
	Girth< 10 cm	Girth > 10 cm	Girth< 10 cm	Girth > 10 cm	Girth< 10 cm	Girth > 10 cm
Girth (cm)	8.25±0.23	10.46±0.19	7.72±2.5	11.±0.15	7.53±0.17	10.93±0.25
Height (m)	2.16±0.22	2.09±0.14	1.64±0.16	2.5±0.31	2.28±0.16	2.6±0.25
Bark width (mm)	2.95±0.19	3.26±0.23	2.55±0.16	3.82±0.26	2.8±0.17	3.8±0.13
Bast dry wt. (g)	0.91±0.66	0.83±0.64	0.73±0.58	1.1±0.69	0.73±0.46	1.06±0.44
Fibre length (mm)	6.56±0.36	6.72±0.31	6.75±0.26	6.73±0.21	6.55±0.29	6.67±0.24

APPENDIX II

Table 3: Mean ± S.E. of *E. gardneri* traits recorded along elevation gradient and canopy types.

Plant traits	Elevation (2000 m)								
	Close Canopy			Semi-close Canopy			Open canopy		
	Girth <15 cm	Girth < 20 > 15 cm	Girth >20 cm	Girth< 15 cm	Girth < 20 > 15 cm	Girth >20 cm	Girth< 15 cm	Girth < 20 > 15 cm	Girth >20 cm
Girth (cm)	11.86±0.33	16.45±0.31	**23.36±0.75**	11.23±0.45	16.02±0.33	21.2±0.51	12.04±0.42	16.32±0.4	21.46±0.55
Height (m)	3.08±0.35	4.26±0.22	**4.86±0.09**	2.51±0.22	3.72±0.23	4.44±0.09	2.98±0.25	3.48±0.18	3.53±0.19
Width of Bark (mm)	3.2± 0.1	3.7±0.2	**5.4±0.3**	3.1±0.13	3.8±0.1	4.6±0.1	3±0.15	3.6±0.2	4.7±0.2
Bast dry wt. (g)	0.86±0.03	0.99±0.06	1.42±0.08	0.83±0.05	1.01±0.06	1.43±0.08	0.82±0.02	1.16±0.09	1.24±0.081
Fibre length (mm)	4.9±0.25	5.02±0.23	5.12±0.16	5.23±0.25	5.17±0.21	5.21±0.068	5.26±0.25	5.38±0.26	5.6±0.25
	Elevation (2200 m)								
Girth (cm)	10.33±0.41	16.34±0.34	21.13±0.67	11.4±0.43	16.907±0.39	22.3±0.36	11.78±0.48	15.86±0.321	22.4±0.4
Height (m)	3.36±0.31	3.3±0.27	4.73±0.11	2.16±0.12	3.59±0.27	4.3±0.266	2.64±0.318	2.573±0.195	3.03±0.13
Width of Bark (mm)	2.9±0.1	3.2±0.1	4.1±0.1	3.3±0.2	4.09±0.18	4.46±0.22	3.02±0.2	3.78±0.22	3.8±0.16
Bast dry wt. (g)	1.24±0.19	1.1±0.08	1.09±0.03	0.98±0.07	1.04±0.052	0.96±0.031	0.88±0.07	1.01±0.07	**1.8±0.16**
Fibre length (mm)	5.17±0.05	5.17±0.05	3.58±0.15	4.36±0.22	4.46±0.179	**5.97±0.163**	4.68±0.22	4.92±0.27	**5.83**±0.14
	Elevation (2400 m)								
Girth (cm)	11.1±0.43	17.2±0.27	21.66±0.51	10.86±0.41	15.86±0.33	**23.73±0.89**	11.37±0.46	16.06±0.47	22.4±0.19
Height (m)	2.6±0.17	3.06±0.3	3.86±0.26	2.22±0.23	3.4±0.32	4.75±0.2	2.48±0.29	4.5±0.26	4.18±0.26
Width of Bark (mm)	3 ± 0.18	3.6±0.2	4.5 ± 0.35	2.7±0.1	3.7±0.29	5.1±0.2	2.6±0.1	4.1±0.23	4.8±0.2
Bast dry wt. (g)	1.26 ±0.18	1.17±0.05	1.45±0.76	0.8±0.05	1.06±0.06	1.61±0.09	0.89±0.84	0.92±0.058	1.33±0.45
Fibre length (mm)	5.25±0.35	4.31±0.36	4.87±0.37	4.82±0.24	5.08±0.39	4.53±0.19	5±0.2	5.53±0.12	5.07±0.13

Appendix III: Letter of permission

सामुदायिक वन उपभोक्ता महासंघ नेपाल आबद्धता नं. ७ दर्ता नं.- १०/०५०/०५१

श्री सुस्पा सामुदायिक वन उपभोक्ता समूह

भी.न.पा.- १, सुस्पा क्षमावती, दोलखा

कोड नं.-SW-FM/COC-NTFP1438-A(D)

पत्र संख्या : ०६८।६९

चलानी नं : २६

श्री रोशिना वासी

मिति:- २०६८।०८।१६

विषय :- अनुमति प्रदान गरिएको सम्बन्धमा।

उपरोक्त सम्बन्धमा सामुदायिक वन उपभोक्ता महासंघ नेपाल राष्ट्रिय महासंघको सचिवालय भक्तपुर को चं.नं १५९ पत्र अनुसार central Department of Botany T.U मा M.Sc 4th semester मा अध्ययनरत विद्यार्थी रोशिना वासीले नेपालको Thymelaeacae वनस्पति परिवारको Daphne र Edgeworthia जाति अन्तर्गतका वनस्पतिहरूमा आधारित Variation in Bast Propeation of Two species of Nepalese Thymelaeaceae Dephne bholua and Edgeworthia gardneri विषय अन्तर्गत Dissertation गरिरहेको हुँदा रोशिना वासी लाई यस सामुदायिक वनमा वनस्पतिहरूको परिक्षणको लागि नमुना संकलन गर्नेका लागि आवश्यक सहयोग गरि दिने राष्ट्रिय सामुदायिक वन महासंघको पत्र अनुसार श्री रोशिना वासीलाई आवश्यक वनस्पतिहरूको नमुना परिक्षण को लागि यस सामुदायिक वनबाट सहमतिका साथ यस अनुमति पत्र दिइएको छ।

कुल बहादुर थामी
अध्यक्ष

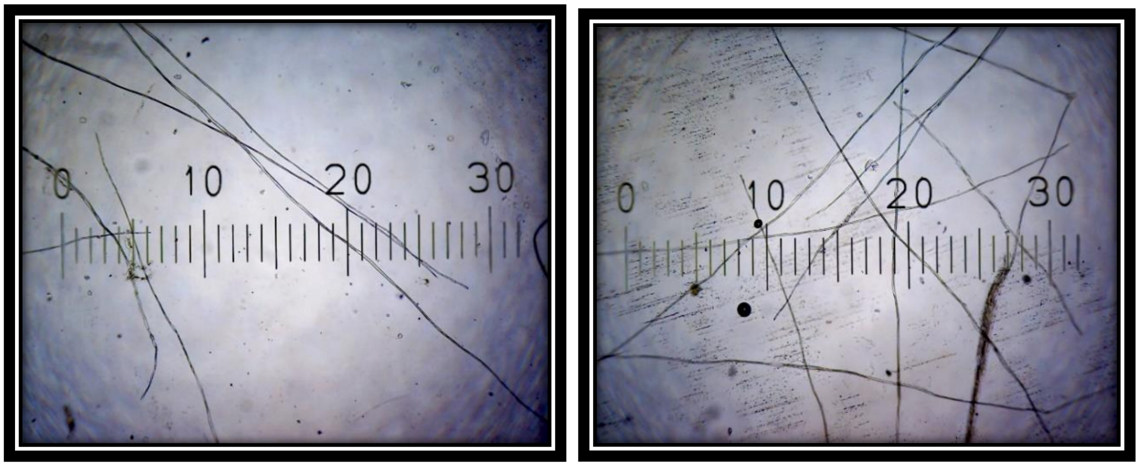
PHOTOPLATES

A. ***E. gardneri*** **in the study area**

B. ***D. bholua*** **in the study area**

C. Discussing about study species with community people

D. Taking samples of *D. bholua*



E. Fiber of *D. bholua* (left) and *E. gardneri* (right) in microscope

F. Bark samples collected

G. Population sampling and population data collection

H. *Taxus wallichiana* cultivation in the study area