IN-SITU LITTER DECOMPOSITION AND NUTRIENT RELEASE IN DIFFERENT TREE SPECIES OF GAURISHANKAR CONSERVATION AREA, NEPAL

A THESIS

SUBMITTED FOR THE PARTIAL FULFILLMENT OF THE REQUIREMENTS

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BY

SAMIKSHA ACHARYA

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M.Sc. BOTANY (PLANT ECOLOGY)

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BATCH 2076

DEPARTMENT OF BOTANY

AMRIT CAMPUS

TRIBHUVAN UNIVERSITY

KATHMANDU, NEPAL

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I, *Samiksha Acharya,* hereby declare that the work enclosed here is entirely my own, except where states otherwise by reference or acknowledgement, and has not been published or submitted elsewhere, in whole or in part, for the requirement for any other degree or professional qualification. Any literature, data or works done by others and cited within this thesis has been given due acknowledgement and listed in the reference section.

Samiksha Acharya
Department of Botany
Amrit Campus
Phone No: 9867044971

Date: 14/08/024

TRIBHUVAN UNIVERSITY
AMRIT CAMPUS
THAPATHALI, KATHMANDU, NEPAL
P.O.Box. No. 102
Amrit Campus

Ref. No. .....

Date 14|08|024

RECOMMENDATION

This is to recommend that the Master's thesis entitled " ***In-Situ* Litter Decomposition and Nutrient Release in Different Forest Types of Gaurishankar Conservation Area, Nepal** " is carried out by Ms. Samiksha Acharya under my supervision. The entire work is based on original scientific investigations and has not been submitted for any other degree in any institutions. I therefore, recommend this thesis work to be accepted for the partial fulfilment of Master's Degree in Botany.

.....

Supervisor
Prof. Dr. Mohan Prasad Devkota
Amrit Campus
Institute of Science and Technology
Tribhuvan University
Kathmandu, Nepal

.....

Co-Supervisor
Asst. Prof. Krishna Prasad Sharma
Trichandra Multiple Campus
Institute of Science and Technology
Tribhuvan University
Kathmandu, Nepal

Date: 14|08|024

ephone No.: Campus Chief 4411637 , Admin Off. 4410408
Hostel 4414236 , Examination 4421476
E-mail: amritcampus@ntc.net.np
contact@amritcampus.ed
Website: amritcampus.edu.np

Institute of Science and Technology

TRIBHUVAN UNIVERSITY
AMRIT CAMPUS

THAMEL, KATHMANDU, NEPAL
P.O.Box. No. 102

Amrit Campus

Ref. No. .....

Date 14|08|024

LETTER OF APPROVAL

This thesis work entitled ***In-Situ* Litter Decomposition and Nutrient Release in Different Forest Types of Gaurishankar Conservation Area, Nepal** submitted to Department of Botany, Amrit Campus, Tribhuvan University by Ms. Samiksha Acharya, 5-2-0050-0239-2015 has been accepted for the partial fulfilment of the requirement for Master's Degree in Botany.

Expert Committee

External Examiner
Prof. Dr. Santosh Raymajhi
Institute of Forestry
Tribhuvan University
Pokhara, Nepal

Internal Examiner
Lecturer Dr. Jaya Prakash Hamal
Botany Department
Amrit Campus
Tribhuvan University

Supervisor
Prof. Dr. Mohan Prasad Devkota
Botany Department
Amrit Campus
Tribhuvan University

Co-Supervisor
Lecturer Krishna Prasad Sharma
Botany Department
Tri-Chandra Multiple Campus
Tribhuvan University

Head of Department
Lecturer Dr. Jaya Prakash Hamal
Botany Department
Amrit Campus
Tribhuvan University

Coordinator
Lecturer Dr. Laxmi Joshi Shrestha
Botany Department
Amrit Campus
Tribhuvan University

Date of Oral Examination

14|08|024

Telephone No.: Campus Chief 4411637 , Admin Off. 4410408
Hostel 4414236 , Examination 4421476

E-mail: amritcampus@ntc.net
contact@amritcampus
Website: amritcampus.edu.

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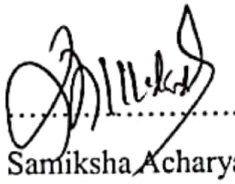

Samiksha Acharya

LIST OF ABBREVIATIONS AND ACRONYMS

%	:	Percentage
°C	:	Degree Centigrade
AET	:	Actual Evapotranspiration
ANOVA	:	Analysis of Variance
C	:	Carbon
CAMC	:	Conservation Area Management Committee.
et al.,	:	And others
Fig	:	Figure
GCA	:	Gaurishankar Conservation Area
GCAP	:	Gaurishankar Conservation Area Project
gm	:	Gram
Ha	:	Hectare
K	:	Potassium
Kg	:	Kilogram
M. esculenta	:	*Myrica esculenta*
Mg	:	Milligram
Mg/gm	:	Milligram per gram
Mg/kg	:	Milligram per kilogram
N	:	Nitrogen
NTNC	:	National Trust for Nature Conservation
P	:	Phosphorus
pH	:	Potential of Hydrogen
SD	:	Standard Deviation
SPSS	:	Statistical Package for Social Science

ABSTRACT

Litter decomposition plays a crucial role in forest ecosystems, significantly influencing the nutrient cycling and soil fertility. This study was conducted in Bigu Rural Municipality of Gaurishankar Conservation Area (GCA) in Central Nepal and had examined the litter decomposition processes in various tree species across the elevation gradient. The research has quantified litter mass loss, identified factors influencing decomposition rates and analyzed nutrient dynamics over one-year period. The rate of litter decomposition was studied using litter bag technique, of the selected tree species, in different forest types between 1010m and 2310m. Results indicated that the rate of decomposition varied in the tree species along the elevation gradient, with faster decomposition at lower elevations and subsequently slower towards higher elevation. Among the species studied, *Pinus roxburghii* exhibited the highest decomposition rate at the lowest elevation, whereas *Pinus patula* decomposed at slower rate. Deciduous species like *Myrica esculenta* decomposed more rapidly than evergreen species such as *Quercus lanata*. Key predictors of reduction of litter weight included initial chemical profile of litter (carbon, nitrogen, phosphorus, and potassium content) and climatic factors (temperature and precipitation). Nutrient release from the litter was in the sequence P> K > C> N, highlighting litter as a potential nitrogen sink due to its slow-release rate. The findings of the research provide valuable baseline information for future studies on nutrient dynamics in the Himalayas and offers insights for forest management and conservation strategies aimed at maintaining biodiversity and ecosystem stability amidst global environmental changes.

Keywords: litter, decomposition rate, mass loss, nutrient dynamics, Nepal Himalaya

सारांश

वन पारिस्थितिकीय प्रणालीमा सोत्तर कुहिने प्रक्रिया अत्यन्त महत्वपूर्ण छ, जसले पोषकतत्त्व को चक्र र माटोको उर्वरता निर्धारण गर्छ। यस अध्ययनले मध्य नेपालको गौरीशंकर संरक्षण क्षेत्रमा सोत्तर कुहिने प्रक्रियाहरूको अन्वेषण गरेको छ, जुन विभिन्न जातको रूख र उचाइको आधारमा गरिएको छ। सोत्तर कुहिने दरलाई प्रभाव पार्ने कारकहरूको पहिचान गर्ने र पोषकतत्त्व को गतिशीलता विश्लेषण गर्ने उद्देश्यले यो अध्ययन गरिएको हो। परिणामहरूले उचाइ अनुसार सड्ने दरमा स्पष्ट भिन्नता देखाएको छ, जहाँ तल्लो उचाइमा छिटो कुहिने पाइयो। सोत्तर कुहिने प्रक्रिया परीक्षण गर्दा सोत्तर थैला विधि प्रयोग गरिएको थियो।अध्ययन गरिएका प्रजातिहरूमा, खोटे सल्लो (*Pinus roxburghii*) ले सबैभन्दा छिटो कुहिने दर देखायो, जबकि पाटे सल्लो (*Pinus patula*) ले सबैभन्दा ढिलो कुहिने दर देखायो। पात झर्ने प्रजातिहरू जस्तै काफल (*Myrica esculenta*) छिटो कुहिने हुने, जबकि सदाबहार प्रजातिहरू जस्तै बाँझ (*Quercus lanata*) ढिलो कुहिने हुने पाइयो। पातको तौल घटाउने मुख्य कारकहरूमा प्रारम्भिक पातको रासायनिक संरचना, C, N, P र K अनि मौसम सम्बन्धी कारकहरू तापक्रम र वर्षा समावेश थिए। सोत्तर बाट पोषकतत्त्व निस्किने क्रम P > K > C > N रहेको पाइयो, जसले पातलाई यसको ढिलो निस्किने दरका कारण नाइट्रोजनको सम्भावित संचित स्रोतको रूपमा देखायो। यो अनुसन्धानले हिमालय क्षेत्रमा पोषकतत्त्व को गतिशीलतामा भविष्यका अध्ययनहरूको लागि महत्त्वपूर्ण आधारभूत जानकारी प्रदान गर्दछ। साथै, यो अध्ययनले वन व्यवस्थापन र संरक्षण रणनीतिहरूलाई मार्गदर्शन गर्नेछ, जसले जैविक विविधता र पारिस्थितिकीय प्रणालीको स्थिरतालाई विश्वव्यापी वातावरणीय परिवर्तनहरूको बीचमा कायम राख्न मद्दत पुऱ्याउँनेछ।

प्रमुख शब्दहरु: सोत्तर कुहिने प्रक्रिया, पोषकतत्त्व चक्र, पोषकतत्त्व गतिशीलता, वन को प्रकार, नेपाल हिमालय

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CHAPTER 1. INTRODUCTION

1.1. Background

In terms of ecology, "litter" refers to two things: dead plant matter that has separated from a living plant or the layer of trash that is visible on the soil's surface (Anderson and Ingram, 1983). Fallen leaves from trees that have senesced make up the aboveground leaf litter. In addition to controlling temperature and moisture, preventing the growth of young shoots, releasing chemicals into the soil, and regulating microbial activity, the layering, placement, and content of leaf litter all affect how much light reaches the soil (Gautam and Mandal, 2017). According to Baltzinger *et al.,* (2012), litter plays a significant role in the positive or negative interactions that organize plant populations. The species variety and biomass of ground vegetation are decreased by the dense layer of litter present in temperate forests, which modifies the growth of adult and seedling plants. Moreover, seasonal variations in the amount of litter on the soil reflect the varied dynamics of litterfall in various ecosystems (Scheer, 2009). These variations might take the form of unimodal, bimodal, or irregular patterns (Zhang *et al.,* 2018). However, in moist tropical forests, the thin layer of litter that results from its quick decomposition promotes the establishment of seeds and seedlings, hence increasing species diversity and biomass (Gautam and Mandal, 2017). Ecologists are now paying more attention to litter since it plays a significant role in ecosystem dynamics that determine productivity and may help in determining the productivity of soil (Guendehou *et al.,* 2014).

It is clear from the studies analyzing the seasonal patterns that major annual litterfall from evergreen woody vegetation occurs during summer. Similarly, in deciduous forests, litterfall occurs during the fall. Due to the variation in growth forms according to the time zones, litterfall is a relatively more continuous process in the evergreen forests of Central Himalaya (Bohara *et al.,* 2020). Plants also obtain organic matter from the process of litterfall and its gradual organic turnover. The two main mechanisms that contribute organic matter to the forest soil and control the nutrient cycling patterns in these ecosystems are litterfall and its decomposition (Bhattarai and Mandal, 2018). As per Yue *et al.,* (2016) and (Bohara *et al.,* 2020), litterfall is the main natural source of nutrients that enter forest ecosystems through decomposition and nutrient recycling. The dynamics of forests and ecosystems are significantly impacted when there is a lot of litter on the forest floor (Olsen,

1963). Litterfall, then, contributes to the establishment and regeneration of the forest floor, safeguards the soil, affects hydrology, and fosters the growth of seedlings, which in turn promotes community succession (Carayugan *et al.,* 2023).

Decomposition refers to the biological breakdown of dead organic materials and the mineralization of complex organic molecules into simpler inorganic forms caused by soil microbes' metabolic activity (Saha *et al.,* 2016). Three interrelated processes—fragmentation, soluble material leaching, and decomposer catabolism—define the decomposition of litter (Swift *et al.,* 1979; Cotrufo *et al.,* 2010). Decomposition mechanisms play a crucial role in nutrient cycling within terrestrial ecosystems. These processes are affected by factors such as macro- and microclimate conditions, the quality of litter, the activity of decomposer organisms, and the nutrient status of the soil (Berger *et al.,* 2010; Berger and Berger, 2012, 2014). The major source of nutrients for plant growth is organic matter that is released in the form of plant-available nutrients (PAN) by the process of decomposition (Vitousek *et al.,* 1994). In a forest environment, where flora is greatly impacted by nutrient recycling from plant litter, litter decomposition is crucial to understanding the nutrient budget (Wedderburn and Carter, 1999). Through soil microbes' and animals' heterotrophic respiration, it releases carbon dioxide back into the atmosphere (Chandrasekhara, 1997). While rapid decomposition helps meet plant intake requirements, slow breakdown leads to the accumulation of organic matter and nutrient stocks in soil (Isaac and Nair, 2005).

Decomposition activities are essential in the cycling of nutrients because they reduce complex organic molecules into forms that plants can use for healthy growth and development (Saha *et al.,* 2016). Likewise, fungi and bacteria play a major role in the breakdown process. Unlike bacteria, fungus have the ability to grow on new substrates, exchange nitrogen with other organisms through hyphae, and produce enzymes that play a major role in the breakdown of structural components (Zeller *et al.,* 2000; Schneider *et al.,* 2012). As a result, the rate of decomposition is solely dependent on microbial activity, which is influenced by the local climate and soil properties (Berg and McClaugherty, 2014). The physicochemical characteristics of the parts (stem, wood, leaves, root, etc.) of the examined species and decomposers present in the soil, as well as biotic and abiotic variables, all influence the breakdown of litter (Saha *et al.,* 2016).

Furthermore, seasonal fluctuations, rainfall, and temperature can all have an impact on the presence of bacteria and other soil fauna, which in turn can have an impact on the rate of decomposition. The activity of soil communities and processes during decomposition are also influenced by the diversity of litter (Chapman and Koch, 2007). Decomposers may specialize in breaking down specific plant species or adopt opportunistic strategies (Moorhead and Sinsabaugh, 2006; Ayres *et al.,* 2009). Specialized decomposers may facilitate faster decay when litter decomposes near its origin (Ayres *et al.,* 2009). As decomposition progresses, microbial communities undergo successional changes (Moorhead and Sinsabaugh, 2006). Various concepts describe the connection between litter decomposition, microbial processes (Moorhead and Sinsabaugh, 2006), and the dynamics of carbon use efficiency (Sinsabaugh *et al.,* 2013). Carbon use efficiency, indicating the ratio of microbial biomass growth to substrate carbon uptake, influences whether carbon is used for biomass production or released into the atmosphere through respiration (Manzoni *et al.,* 2018).

The pace of decomposition is influenced by the C:N ratio and certain chemical properties of the litter materials, such as lignin, polyphenol, cellulose, and hemicellulose (Silveira *et al.,* 2011). According to Brady and Weil (2010), the total amount of carbon dioxide (CO2) released and compounds that contain both carbon compounds and nutrients that are discharged results in the loss of litter mass or degradation. The way nutrients are absorbed, held, transported, and cycled throughout space and time in an ecosystem is known as nutrient dynamics (Hauer and Lamberti, 2006). It is well recognized that the quality of biomass accumulated determines how much nutrition is discharged in a given ecosystem or unit area. The capacity of tree species to increase soil fertility and productivity in degraded areas is determined by factors such as litter production, rate of decomposition, and patterns of nutrient release (Palm and Sanchez, 1990). Furthermore, the kind of litter has an impact on the concentration of nutrients. For instance, the nitrogen-fixing alder genus Alnus has leaf litter with high real nitrogen concentrations that frequently surpass 3%. Conversely, pine needle litter usually has a nitrogen content of less than 0.4%, making it nitrogen-deficient. The value of the litter is primarily determined by the type of plant (Gustafson, 1943).

Generally, the establishment of lots of forest stands has been found on mountains. Because elevation includes a range of strongly auto-correlated factors, including climate fluctuation,

soil chemistry, macro- and microbiology, and botanical aspects of the plant and snow cover, it is, therefore, important to consider when analyzing the breakdown of litter (Berger *et al.,* 2015). Research conducted along an elevation gradient examined the soil organic matter beneath forest stands and discovered an overall negative effect of elevation, suggesting the significance of higher elevation forests as potential sinks for atmospheric carbon sequestration as well as potential locations for the stabilization of carbon already sequestered in the soil (Bangroo *et al.,* 2017). This research work aims to explore the rate of *in-situ* litter decomposition in different forest types of the Gaurishankar Conservation Area, as well as examine the litter nutrient dynamics, release pattern, and physico-chemical analysis of litter and soil.

1.2. Rationale

A large human population in the Gaurishankar Conservation Area (GCA) is composed of subsistence farmers and depend on local forest resources from which they receive ecosystem services. Harvesting leaf litter from forests is a common practice which is used for animal bedding and later transferred to the fields as manure. A three-way link exists between the forest, agriculture, and animals in Nepal's traditional mountain farming system. The practice of collecting litter from forests for agricultural use has been a supplementary activity, since trees offer nutrients to the soil in the form of litter. Lack of knowledge in the farmers of study area towards understanding the types of leaf litter and decomposition mechanism is not always beneficial for them. The outcomes of the research can contribute the information regarding the leaf litter decomposition rate of the major tree species and the patterns of nutrient release into the soil. This may help to assess and compare soil and litter quality in different forest sites, which will, in turn, be very productive to the farmers to improve the productivity of farmlands. Additionally, educating local communities about litter decomposition and its ecological importance can enhance conservation efforts. Increased awareness can lead to better stewardship of forest resources and sustainable practices that benefit both the environment and local livelihoods.

Beyond agriculture, litter decomposition is crucial for nutrient cycling, returning essential elements like nitrogen and phosphorus to the soil. This process supports plant growth and maintains ecosystem health, which is vital for the stability and resilience of forest ecosystems. Understanding the litter decomposition rate of various tree species along the elevation gradient in GCA will contribute in understanding the nutrient dynamics of major

forest types. Further, the study can be helpful in evaluating the health and productivity of forest ecosystems, providing insights into forest dynamics and succession patterns supporting both natural vegetation and agricultural productivity. The findings can also contribute to developing effective conservation strategies by understanding how the rate of litter decomposition can contribute to soil health, and reasonable decisions can be made to protect and manage forest resources sustainably.

Additionally, there is inadequate information available on litter decomposition and dynamics as few studies have been carried out in the middle mountain regions Nepal. Therefore, it will be the first attempt of its kind in the GCA that will provide valuable baseline information, paving the way for future research and monitoring efforts and helping to track changes in the ecosystem over time.

1.3. Research Questions

The primary research questions are given below:

I. How does the rate of litter decomposition of different trees species changes with the elevation?
II. What is the rate of litter mass loss and nutrient release in different seasons?

1.4. Objectives

1.4.1. General Objective

To focus on the *in-situ* litter decomposition and the nutrient dynamics of the litter-soil system for tree species in different forest types of Bigu Rural Municipality of GCA, Central Nepal.

1.4.2. Specific Objectives

I. To quantify the Loss of Litter Mass (gm) in different forest types against the seasonal changes.
II. To estimate the Nutrient Composition of soil (CNPK) and litter (CNPK) from the study sites.
III. To estimate and compare the Nutrient Release by Litter (%) of selected tree species in different forest types against the seasonal changes.

IV. To investigate and quantify the Loss of Litter Mass Over Time (%) of selected tree species in different forest types against the seasonal changes.

1.5. Limitations

I. Effects of unusual weather events and unforeseen climatic fluctuations are not considered as part of the study.

II. Role of the microbial communities and soil fauna across different sites is not included as a part of the study.

III. The study could not cover a wider altitudinal range with different forest types due to difficult mountain terrain and unavailability of working facilities in the field. As a result, the remote areas of Bigu Rural Municipality could not be covered due to security reasons, as well.

1.6. Research Matrix

Table 1. Research matrix for the litter decomposition experiment in different tree species of GCA.

S.N.	**Objective/ Calculations**	**Relevant Methodology**	**Statistical Analysis**
1	Litter Mass Loss (gm)	Initial Weight of Litter - Final Weight of Litter (in grams)	Descriptive
2	Soil Nutrient Composition (CNPK)	Received from laboratory	Inferential
3	Litter Nutrient Composition (CNPK)		
4	Nutrient Release by Litter (%)	Nutrient Release Equation (%)	Inferential
5	Loss of Litter Mass Overtime (%)	Decay Rate Coefficient Equation (per time)	Inferential

1.7. Conceptual Framework

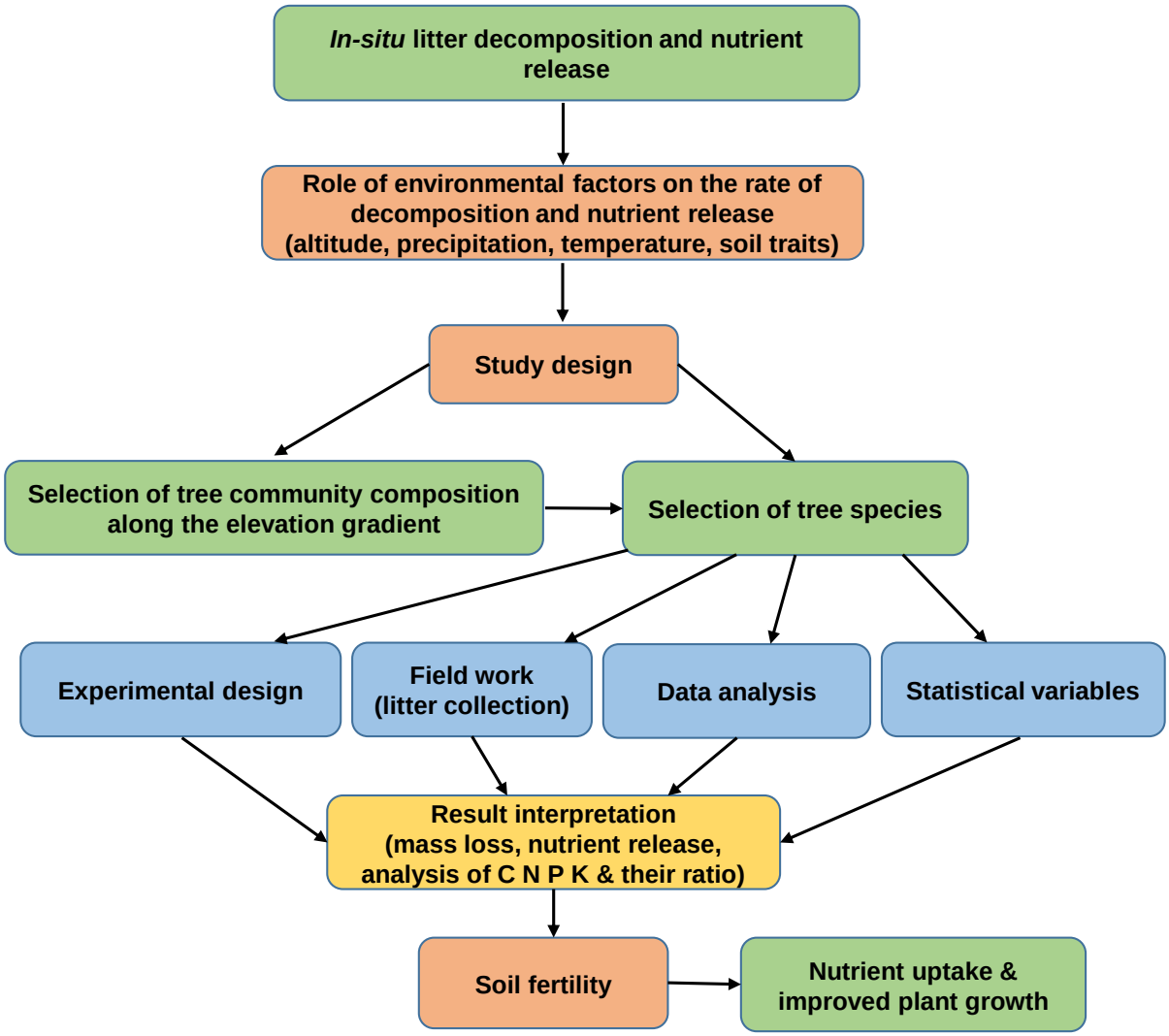

Figure 1. Conceptual Framework of the Research

CHAPTER 2. LITERATURE REVIEW

2.1. Approaches in Litter Research

Since direct measurement is too time-consuming or costly, the mass balance technique is frequently used to estimate the breakdown of litter for entire ecosystems (Olson, 1963). The mass balance technique, when applied to aboveground litter decomposition, indicates that, if the mass of detrital litter stored in the ecosystem is constant, annual litter decomposition should equal the annual intake of fresh litter. Consequently, the mass balance approach has been applied separately to calculate the decomposition of litter or to validate model predictions (Hedin, 2000).

However, the litterbag method measures changes in mass, nutritional content, and carbon chemistry over time by confining pre-weighed debris inside mesh bags (Falconer *et al.,* 1933). Similarly, tethered leaves technique involves tying individual leaves together in bundles and leaving them in the field to decompose, allowing for the study of decomposition rates and nutrient release under natural conditions. The tethered leaves method is found to be particularly helpful in investigating the early phases of decomposition. It is comparable to the litterbag methodology, with the exception that individual leaves are tied together in bundles rather than placed in litterbags. (Karberg *et al.,* 2008).

Thus, litterbags tend to be the traditional method of determining decomposition rates in the field, despite drawbacks such as the removal of macroinvertebrates, soil contamination, and a mixture of litter species and constituents. Because of being fit to empirically measure decay rates at multiple time scales and the influence of different components, this method is found to be very helpful (Karberg *et al.,* 2008).

2.2. Role of Altitude in Litter Decomposition

Observing the varying decomposition rates, Pandey and Singh (1982) investigated leaf litter decomposition across altitudinal gradients. They chose one shrub species along with *Quercus leucotrichophora, Quercus floribunda, Ilex dipyrena, Cedrus deodara*, and *Aesculus indica* in the oak-conifer forest of Nainital. Their findings highlighted the influence of altitude on decomposition dynamics, with faster decomposition observed in *Daphne cannabin* at lower elevations and slower rates in *Cupressus torulosa* at higher

elevations. Building upon these initial observations, Majila *et al.,* (2005) further explored altitude's broader impacts on litter patterns, revealing seasonal variations in litterfall rates along altitude gradients of Binsar Wildlife Sanctuary, Central Himalaya. This underscored the complex interplay between altitude and ecological processes, shaping litter dynamics in mountain ecosystems.

Expanding on altitude's effects, Berger *et al.,* (2015) assessed climate influences on litter decay along altitudinal gradients of Northern Limestone Alps of Austria. Their study emphasized the intricate relationship between altitude, climate, and litter decomposition rates, with significant variations observed between beech and pine litter. Similarly, Bohara *et al.,* (2020) extended this research by conducting an in-depth elevation-based decomposition study in the central Himalayas of Nepal. Their findings highlighted the declining litter mass loss with increasing elevation, shedding light on species-specific decomposition dynamics and their interaction with altitude-dependent environmental factors. Zhao *et al.,* (2022) further reinforced these findings by demonstrating altitude-induced variations in litter decomposition rates across two contrasting forest communities in Beijing, North China. Their study underscored the importance of community traits and litter quality in shaping decomposition dynamics, highlighting altitude as a key determinant of ecosystem functioning.

Shifting the focus to species-specific decomposition patterns, Semwal *et al.,* (2003) examined chemical characteristics and decomposition trends of multipurpose trees in Central Himalaya, India. Their findings revealed species-specific variations in decomposition rates and nutrient release dynamics, emphasizing the role of species composition in influencing litter decomposition processes. Subedi *et al.,* (2010) built upon this understanding by investigating species-specific decomposition in Nepal, identifying key factors such as C:N ratio and moisture content influencing decomposition rates. This highlighted the variability among tree species and their contributions to litter decomposition dynamics in diverse ecological settings. Further supporting the pattern, Cornwell *et al.,* (2008) provided a global perspective on species-driven differences in litter decomposition rates across worldwide biomes, highlighting the ecological significance of species composition in shaping decomposition dynamics. This underscores the complex interplay between altitude, species composition, and environmental factors in influencing leaf litter decomposition processes across varied ecological settings.

Similarly, Hasanuzzaman and Hossain (2014) supported these findings by demonstrating variations in decomposition rates among different tree species in Bangladesh, emphasizing the significance of environmental elements and litter quality in mediating decomposition processes. Rawat *et al.,* (2020) also contributed to this understanding by comparing deciduous and evergreen species in Temperate Forest trees of Indian Himalayas, revealing faster decomposition rates in deciduous species. Their findings underscored the intricate relationship between green leaf and litter traits and their influence on decomposition dynamics.

2.3. Chemical Composition of Litter

Uncovering the profound impact of chemical quality on the monthly release rates of nitrogen, phosphorus, and potassium. Semwal *et al.,* (2003) conducted a detailed analysis of litter species in Central Himalaya, India. Their study revealed that polyphenol and nitrogen concentrations play critical roles in decomposition dynamics. Continuing this exploration, Mjofors *et al.,* (2007) investigated the chemical changes taking place during the decomposition of individual site litters in Forsmark and Oskarshamn, Sweden. They monitored the loss of water-soluble and ethanol-soluble substances, lignin decomposition patterns, and nitrogen and phosphorus mineralization. This study highlighted that different litter types exhibit diverse chemical dynamics throughout the decomposition process.

Furthermore, the study of leaf litter decomposition during the 10 months period to screen agroforestry in the farming areas of Chattishgarh, India, Singh *et al.,* (2007) discovered a substantial change in nutrients in residual litter over time. The concentration of potassium, phosphorus, and nitrogen changed in a manner that was roughly linear with mass loss. Up to the final month of sampling, every species exhibited a constant release of N, P, and K. *Leucaena leucocephala* and Gmelina arborea were found to exhibit immobilization of N, P, and K. *Leucaena leucocephala* > *Dendrocalamus strictus* > *Eucalyptus tereticornis* > *Dalbergia sissoo* > *Gmelina arborea* was the order in which the net release of N, P, and K among the species. Building on these findings, Cornwell *et al.,* (2008) examined the significant influence of plant physiological features on litter decay rates within worldwide biomes. Their research demonstrated a consistent correlation between a species' litter's decomposability and ecological strategy, providing valuable insights into global carbon cycling.

Expanding on this, Subedi *et al.,* (2010) underscored the roles of the C ratio, moisture, and species in influencing decomposition rates. Their findings indicated that higher decomposition rates were associated with a 20:1 C ratio and 75% moisture content, with notable variations in mineral-N release among different tree species of Nepal.

In a related context, Hasanuzzaman and Hossain (2014) focused on nutrient dynamics during leaf litter decomposition, revealing a consistent pattern of nutrient release (K > N > P) in agroforestry tree species of Bangladesh. Their research identified that *Zizipus jujuba* exhibited comparatively higher returns of nitrogen, phosphorus, and potassium. Further contributing to this discourse, Horodecki and Jagodziński, (2019) provided a unique comparison of leaf litter decomposition rates between degraded lands and adjacent natural forest areas of Central Poland. The study underscored differences in carbon and nitrogen release by species-specific litter, emphasizing the impact of soil conditions on litter mineralization and the critical importance of selecting appropriate tree species for reforestation in post-mining areas.

Advancing these understandings, Bohora *et al.,* (2020) presented findings indicating that nutrient release from litter throughout the annual decomposition process was not uniform in Central Himalaya, Nepal. The observations indicated that the release rate at the culmination of research period was in sequence P > K > C > N, suggesting a potential nitrogen sink due to its slow-release rate. These results highlighted the complexity of nutrient dynamics in central Himalayan Forest ecosystems, emphasizing the necessity for long-term research to establish a baseline for biodiversity preservation, ecosystem stability, and climate change mitigation. Additionally, Singh *et al.,* (2021) examined *Betula utilis* leaf litter decomposition in the timberline area of the Western Himalayas. They observed significant mass loss and decay rates for up to 34 weeks (19.03% and 0.35 per year, respectively), with variations in nutrient concentrations across spatially distant sites. Most recently, Zhao *et al.,* (2022) emphasized the role of litter quality in explaining variations in litter decomposition rates in two contrasting forest communities in Beijing, China. They identified crucial factors like the contents of the leaves, such as nitrogen, tannin, dry matter, and specific areas, contributing to a comprehensive understanding of the decomposition process.

2.4. Factors Affecting Litter Decomposition

Emphasizing the role of actual evapotranspiration (AET) as a crucial climatic index on five sites, Hardangervidda, Norway; Moorhouse, U.K.; H. J. Andrews Forest, Oregon; Coweeta, North Carolina; and Oak Ridge, Tennessee, Meentemeyer (1978) conducted a seminal study on regional variations in decay rates, This study proposed a general model incorporating AET, lignin concentration, and their interaction to predict decomposition rates. The findings suggested that climate, as indicated by AET, is a primary predictor of decay rates, surpassing the importance of litter quality. Building on these insights, Pandey and Singh (1982) investigated decomposition rates in an oak-conifer forest, Nainital, where 80% of the fluctuation in monthly weight loss could be explained by a linear combination of precipitation and temperature. Initial chemical composition, particularly nitrogen and lignin, significantly influenced decomposition rates over time.

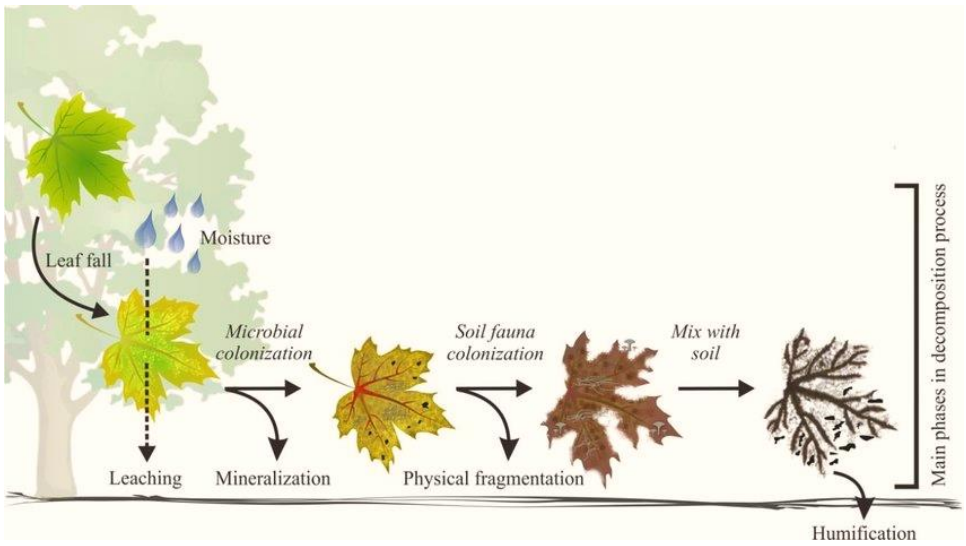

Figure 2. Major phases of leaf litter decomposition (Source: Tennakoon *et al.,* 2021)

Extending the exploration of climatic influences, Upadhyay *et al.,* (1989) examined litter decomposition in 10 sites of central Himalayan forests, revealing that monthly rainfall explained 25-89% of monthly weight loss. Additionally, annual temperature and altitude accounted for 48.7%, 53.6%, and 49.1% of the variability, respectively. Key factors such as nitrogen and lignin content were critical in predicting weight loss. Building on this foundation, Semwal *et al.,* (2003) examined how six multipurpose tree communities in the Central Himalayas, India were affected by species, incubation duration, and their interactions with monthly mass, nitrogen, phosphorus, and potassium release rates. Their

study highlighted the role of diverse multipurpose tree communities in stable nutrient cycling. With the aim to screen out agroforestry in the farming area of Chattishgarh, India, Singh *et al.,* (2007) spent ten months observing how the leaf litter of *Leucaena leucocephala, Eucalyptus tereticornis, Gmelina arborea, Dalbergia sissoo,* and *Dendrocalamus strictus* decayed. *Leucaena leucocephala* displayed a rapid weight loss, while *Dendrocalamus strictus* exhibited the slowest. The quantity of precipitation and humidity levels had an enormous effect on the rate of decomposition. The decomposition rate was high during the monsoon and minimal during summer.

Furthermore, Tyub and Reshi (2008) examined various biotic and abiotic factors influencing mixed litter decomposition in Kashmir Himalayan grasslands. They identified soil temperature and fungi as significant factors, showcasing the interplay between environmental factors and the decomposition process. Concurrently, Zhang *et al.,* (2008) constructed a comprehensive worldwide dataset on rates of litter decay, investigating the direct and indirect impacts of geography, climate, and litter quality variables on decomposition. Their findings emphasized the importance of litter quality, particularly the Carbon-Nitrogen ratio and overall nutrient value, as direct regulators of litter decomposition on a global scale. In addition to these climatic and chemical perspectives, Rawat *et al.,* (2010) observed discharge of nutrients and above-ground litter decay in the Indian Himalayan alpine ecosystem of the Gharwal Himalayas, India. Their study revealed monthly variations in above-ground litter crop, turnover rates, and nutrient content, with protected sites exhibiting higher turnover rates. This research underscored the effect of climatic factors on litter breakdown rates and highlighted the seasonal variations in decay processes.

In another context, Berger and Berger (2013) conducted research in six sites of two different bedrocks Flysch and Molasse in Austria, addressing the influence of mixed tree species within forest stands and within litter on mass loss and nutritional release. Their results suggested that adverse environmental conditions in spruce stands, rather than the inherent recalcitrance of needles, hindered decomposition. Moreover, Hasanuzzaman and Hossain (2014) identified factors affecting litter decomposition, including species-specific variations in mass loss, decomposition rates, and nutrient returns, while emphasizing the influence of climatic factors in agroforestry tree species of Bangladesh. Padalia *et al.,(* 2015) also investigated the influence of climate, including precipitation, temperature, and

relative humidity, on the decay rate in the two Oak forests, Nainital. Their study provided insights into decay rate coefficients and monthly relative decomposition rates for two Central Himalayan Oaks.

Exploring the impact of anthropogenic disturbances, Paudel *et al.,* (2015) examined the effects of deforestation and forest degradation on litter decomposition in a tropical disturbance gradient of Mengsong, Xishuangbanna, China. Their findings highlighted the significance of landscape-scale processes such as forest degradation in influencing decomposition rates. They observed variations in mass loss along the disturbance gradient, emphasizing the role of climatic conditions and decomposer functional diversity. Similarly, Horodecki and Jagodzinski (2019) compared litter decomposition rates in degraded lands and natural forest areas. They underscored the impact of stand conditions on litter mineralization and the need for selective tree species to accelerate soil development in post-mining areas in Central Poland.

In the context of high-altitude ecosystems, Bohora *et al.,* (2020) explored factors affecting litter decomposition in the central Himalaya, emphasizing the influence of tree species and elevation. Their study highlighted varying decomposition rates influenced by initial litter content and weather factors. Adding complexity to this understanding, Zohu *et al.,* (2020) highlighted the importance of litter identity and environmental context in determining the decomposition of litter mixtures across large spatial scales in temperate forests of Netherlands. Additionally, Ahirwal *et al.,* (2021) emphasized the role of environmental factors and forest types in shaping litterfall and decomposition patterns in Indian Himalayan Region, noting that distinct forest types exhibit unique characteristics influencing litterfall and decomposition responses.

Also, Tennakoon *et al.,* (2021) underscored the significance of fungal communities in nutrient recycling through the production of extracellular enzymes. They reviewed various studies on leaf litter decomposition, emphasizing fungal succession as a sequential and dynamic process, and advocated for integrating high-throughput methods for a comprehensive understanding of fungal succession. Finally, Zhao *et al.,* (2022) emphasized the importance of community-weighted mean traits and their interaction with litter quality as major factors affecting litter decomposition rates in Beijing, North China. This study called for future research focusing on the community-level effects of green leaf traits on litter decomposition. Collectively, these interconnected studies enhance our understanding

of the intricate processes governing litter decomposition, influenced by climatic conditions, litter quality, and species-specific characteristics. This comprehensive body of research underscores the wider involvement of global carbon cycling and climate change reduction.

2.5. Role of Litter in Nutrient Dynamics

Decades of ecological research have illuminated the crucial role of plant litter in nutrient dynamics within ecosystems. Early investigations by Pandey and Singh, (1982) laid the groundwork by demonstrating how litter decomposition contributes to soil fertility through the gradual release of nutrients, underlining its significance in sustaining plant growth. Subsequent studies, such as Mjofors *et al.,* (2007), delved deeper into the factors influencing litter decomposition, highlighting the importance of altitude and seasonal variations in affecting decomposition rates and subsequent nutrient cycling. Zhang *et al.,* (2008) further elucidated the role of environmental factors, emphasizing the impact of temperature and moisture on decomposition processes and subsequent nutrient release. Cornwell *et al.,* (2008) provided insights into the influence of litter quality and chemical composition on nutrient release rates, contributing to a more comprehensive understanding of litter-mediated nutrient dynamics. Rahman and Tsukamoto (2013) expanded the scope by examining the impacts of human activities on litter quality and decomposition in Japan, revealing how anthropogenic factors can alter nutrient dynamics in ecosystems.

Moreover, Berger *et al.,* (2015) highlighted microbial communities' role in decomposition and nutrient cycling, underscoring the intricate interactions between microorganisms and litter quality. Long-term studies by Bisht *et al.,* (2014) in subalpine forest communities of Northwest Himalayas and Bohora *et al.,* (2020) highlighted the cumulative effects of litter decomposition on soil fertility and organic matter accumulation over time. Rawat *et al.,* (2020) proposed an integrated approach combining green leaf and litter traits to enhance understanding of nutrient cycling processes, advocating for a holistic perspective in ecosystem studies. Recent advancements have seen the application of metagenomic techniques and global-scale comparisons to unravel further the complexities of litter decomposition and its pivotal role in ecosystem nutrient dynamics. Through this chronological progression of research, it becomes evident that plant litter serves as a fundamental component in nutrient cycling, influencing soil fertility and ecosystem productivity.

2.6. Litter Research in Himalayas

Early research by Garkoti and Singh (1995) on high elevation forests in the central Himalayas detailed the dynamics of forest floor biomass, litter fall patterns, and nutrient return. This study provided a foundational understanding of nutrient cycling and litter dynamics, highlighting significant annual nutrient return through litter fall and high nutrient use efficiency compared to other mid- and high-elevation forests. Building on this early work, Upadhyay *et al.,* (2014) investigated the decomposition of litter from ten Central Himalayan Forest species over two years. They highlighted the influence of climate and substrate quality on litter weight loss, showing that cell wall constituents like lignin were strong predictors of weight loss in warm temperate and subtropical climates. This research underscored the importance of annual temperature, actual evapotranspiration (AET), and altitude in controlling litter decomposition rates, thus extending the understanding of factors influencing litter decay established by earlier studies.

In a broader context, Sharma *et al.,* (2020) conducted research across various forest types and plantations in the Kumaun Himalaya, indicating significant variation in litterfall. Their findings showed litterfall ranging from low values in degraded Sal forests to high values in high-altitude oak forests and poplar plantations, with most forest types exhibiting maximum litterfall during the summer season. This research emphasized the importance of litterfall dynamics in determining carbon intake, carbon flow, and net primary production by reinforcing and expanding the earlier findings of Garkoti and Singh (1995). Further expanding on the role of specific tree species, Joshi and Garkoti (2020) examined the influence of Nepalese alder (*Alnus nepalensis*) on litter dynamics in white oak (*Quercus leucotrichophora*) forests. This study demonstrated that the presence of alder enhanced litter production, LAI, and forest floor respiration, leading to increased carbon flux, thereby building on previous insights into species-specific litter dynamics and nutrient cycling.

On the basis of these findings, Bohara *et al.,* (2020) carried out an in-situ litter decomposition experiment in central Nepal for a year, observing several tree species predominating in forests along an altitudinal gradient. This study provided a nuanced understanding of how elevation and species-specific traits affect litter dynamics, building on the foundational work of Garkoti and Singh (1995) and extending the climatic considerations explored by Upadhyay *et al.,* (2014). Moreover, Ahirwal *et al.,* (2021) synthesized data on litter production and decomposition across tropical, subtropical, and

temperate forests in the Indian Himalayan Region (IHR). This comprehensive analysis highlighted the significant influence of environmental factors such as moisture and precipitation on litterfall patterns and decomposition rates, echoing and further elaborating on the climatic influences noted by Upadhyay *et al.,* (2014). Field experiments on *Coriaria nepalensis*, a nitrogen-fixing shrub in degraded hills of Kumaun Himalaya, by (Awasthi *et al.,* 2022) showed rapid decomposition of leaves within six months and slower decomposition of lateral roots. The decomposition process was significantly affected by climatic factors, particularly rainfall, making leaves and reproductive parts important nutrient sources for ecosystem recovery in degraded lands. This study highlighted the role of specific species in nutrient cycling and ecosystem restoration, building on the insights provided by earlier studies on the importance of species-specific litter dynamics.

Despite the extensive ecological significance of the Himalayan region, research on litterfall and decomposition dynamics in this area remains limited. The few existing studies provide critical insights into the role of litter in nutrient cycling, carbon flux, and forest ecosystem functioning, yet they highlight a significant gap in our understanding. Given the region's diverse forest types and varying climatic conditions, comprehensive studies are essential to fully grasp how litterfall and decomposition processes contribute to ecosystem stability and resilience. Expanding this research is crucial for developing effective conservation and management strategies, especially in the face of global environmental changes.

2.7. Conservation Initiation in Gaurishankar Area

Recognizing the fact that Gaurishankar area supports a tremendous amount of biodiversity and this can benefit both local communities and the country as a whole from the vast floral, faunal and natural resources, the Government of Nepal decided to declare Gaurishankar area as a conservation area (2179 sq. Km) in 2010 by a historic cabinet meeting in Kalapathar, Everest Region. The objective of the declaration was to provide biological corridors between Everest National Park and Langtang National Park and to protect globally important species, its resources, conserve the local culture and tradition and promote nature-based tourism and livelihood support to the local communities. National Trust for Nature Conservation (NTNC) received the management responsibility for twenty years pursuant to the National Parks and Wildlife Conservation Act, 1973. NTNC prepared and implemented a five-year management plan (2013-2018) with a long-term vision of "**Conservation for Prosperity**" after receiving the management responsibility for 20 years.

The implemented plan was based on Integrated Conservation and Development Program Model (ICDP) similar to Annapurna Conservation Area (ACA) adapting to the needs and conservation necessities of the Gaurishankar Conservation Area.

At the time when GCA was started to work the region was hit hard by the earthquake and most of the infrastructures developed by GCAP were destroyed on 25 April 2015, adversely affecting the conservation initiatives. Even after that GCAP was successful in raising peoples' awareness on conservation, assisted them to undertake integrated conservation and development but also established 21 Conservation Area Management Committees (CAMCs) and the project handed over 37,323.1 ha forest area to 14,394 HHs through conservation forest management sub-committees (CFMSC). The second management plan has been implemented for 2023-2027 after thorough discussion with CAMC and key stakeholders based on the lessons from the past management efforts of the management authorities and CAMCs. The long-term vision of the recent management plan has remained the same as that of the earlier plan i.e., '**Conservation for Prosperity**' with some changes in management objectives, strategies and activities.

The recent plan has included five themes (species conservation, forest conservation, rangeland conservation, wetland conservation and conservation education) with four special programs (key species conservation, nature-based tourism, livelihoods diversification) and two related programs (adaptation to climate change and cultural heritage preservation) putting "Conservation" at the center. The plan has also prioritized the components to further strengthen the CAMCs giving priority towards strategies and actions in each of thematic programs. Considering the management plan priority toward the Integrated Conservation and Development it has also given space to harmonize with the programs of the local governments who are acknowledged with the roles and responsibilities delegated to them by the Constitution of Nepal.

CHAPTER 3. MATERIALS AND METHODS

3.1 Study Area

The Gaurishankar Conservation Area (GCA), established in 2010 A.D. (2066 B.S.), spans 2,179 km² between Langtang and Sagarmatha National Parks, serving as a vital link between these two protected areas in Nepal. Located within the districts of Sindhupalchok, Dolakha, and Ramechhap, it encompasses two municipalities and eight Rural Municipalities (RM), featuring an extensive altitudinal range from 968 m to 7,134 m across diverse climatic zones from Subtropical to Alpine. The area is rich in biodiversity, including important vegetation types such as *Juniperus, Pinus roxburghii, Schima-Castanopsis, Alnus nepalensis, Pinus wallichiana, Pinus patula, Rhododendron, Quercus lanata, Quercus semicarpifolia*, Lower Temperate Mixed Broad-Leaved, Abies, Upper Temperate Mixed (Birch-Rhododendron), Shrubland (Rhododendron-Anthopogon bushes), and Moist Alpine Scrubs. The conservation area comprises 47.5% forest, 22.6% grassland, 5.3% agricultural land, and 24.6% other land types. GCA is home to 18 forest types ranging from subtropical to alpine and hosts 722 species of wild flora. The National Trust for Nature Conservation (NTNC) was entrusted with its management for 20 years, implementing a five-year management plan (2013-2018) under the long-term vision of "Conservation for Prosperity" and continuing with a second five-year management term (2022-2027) (NTNC, 2022).

Bigu Rural Municipality, located in Dolakha District, is characterized by its predominantly agricultural economy, where the majority of the population engages in mixed farming and livestock rearing, supported by pastoralism and small-scale trade. The area's socio-economic development is constrained by limited access to modern infrastructure, yet the community remains largely self-sufficient through the exploitation of local resources, including agriculture and forest products. The municipality's diverse topography, ranging from river valleys to mountainous terrain, dictates varied land use patterns, with terraced agricultural fields supporting the cultivation of staple crops such as maize, millet, and potatoes. This diversity in land types is mirrored in the vegetation, which spans a broad spectrum from subtropical species like *Schima-Castanopsis* and *Pinus roxburghii* in the lower elevations to alpine species such as Juniperus and Rhododendron at higher altitudes. The forest types within Bigu Rural Municipality, ranging from subtropical to alpine, are rich in biodiversity and play a crucial role in sustaining local livelihoods by providing

essential resources like fuelwood, timber, and non-timber forest products. Additionally, these forests are vital for maintaining ecological functions, including climate regulation and water cycle stability. In this region, local agricultural practices are heavily integrated with forest management, as residents commonly collect forest litter, including leaves and branches, to use as organic mulch and compost for enhancing soil fertility in their terraced fields. This traditional practice not only supports sustainable agriculture but also reflects the community's reliance on and deep connection to their natural environment.

3.1.1 Local communities and livelihoods

GCA is not only rich in biodiversity but is also equally rich in ethnic groups and diverse culture practiced by them. It has been estimated that it has a total population of 67302 from different groups such as Tamang, Sherpa, Chhetri, Thami, Newar, Dalit, Magar, Gurung, Brahman, Sunuwar, and Surel (NTNC, 2022). The existing major economic activities are mixed farming practices, pastoralism, and quarrying for livelihoods. A very small population, in the remote area, is involved in tourism sector. But these trends are changing recently as a large youth population is out migrating, either in the larger cities or outside the country, in search of better livelihood options leaving the elderly people in the villages. This has adversely affected the agriculture production as more and more farmlands have remained abandoned for a long time.

Poverty is one of the most serious development challenges in GCA as there are very few livelihood options available in the rural mountain communities. A large population in the study area depend on subsistence agriculture for livelihoods. Local people practice a typical mountain farming in steep slopes by forming terraces to prevent soil loss. Use of chemical fertilizers and pesticides is very limited as it is unaffordable by the poor communities. The average farm size per household is less than 0.6 ha and is highly fragmented. Farming is predominantly subsistence and complex with a mutual interdependency of crops, livestock and forest resources. The main agriculture products are potato, wheat, barley, millet, buckwheat at the higher elevation whereas, rice is grown in the low land and is monsoon dependent. Agriculture production depends on livestock sustained by fodder and litter collection from the forests. Annually, litter is collected in large quantity from the forest and used for animal bedding which is later used for farm manuring. But this interdependency is being eroded due to labor shortage particularly because of decreasing interests of youths in agriculture and seasonal and permanent migration in search of employment. Pastoralism

was used to be one of the sources of livelihood for rural communities in the past but due to out migration of youth population has caused decline in Yaks and Chauri population (NTNC, 2022).

Dolakha is considered as a famous place for tourist attraction for its rich culture and religious sites, and famous trekking routes in Rolwaling Himal range. Unfortunately, a very small population is involved in tourism sector due to poor infrastructure facilities and lack of tourist development activities contributing limited opportunities to the mountain Sherpa communities.

3.1.2 Historical plantation and conservation by CAMCs

In the past, Swiss Development Corporation (SDC) has assisted His Majesty's Government of Nepal in the various development activities especially in the Central Hills of Nepal for about 30 years. One of the development activities were to provide assistance in the forestry sector through Integrated Hill Development Program (IHDP) between 1975 and 1990. This program was one of the integrated rural development programs that was implemented in Sindhupalchok district and later expanded into Dolakha district. The forestry sector within the integrated rural development approach had included activities as plantation of exotic Pine species on difficult, degraded sites and native *Alnus nepalensis* on damper sites to revive forest condition; technical forestry focus: nursery, plantations mainly of weeding, cleaning, etc.; local participation in plantation; educational campaign on the value of the forest and the need to conserve it; technical inputs mainly by expatriates; and technical training (technology transfer). The exotic *Pinus patula* and native *P. wallichiana* were planted under IHDP program have now dominated certain forest areas near the settlements in Bigu Rural Municipality. Large patches of *P. patula* and *P. wallichiana* are more than 30 years old but due to poor management practices they are not performing very well as they need immediate thinning. Even then both pine species have provided much needed timber for the reconstruction after 2015 earthquake that hardly hit Dolakha District.

There are 21 CAMC under GCAP having a total number of 13,030 household with a population of 56,521 individuals as users. These CAMCs work under GCAP for the conservation and management of forest based resources. Forest based resources were conserved and utilized by the local communities as Community Forest User's Group (CFUG) under the Community Forestry Program of GoN before the declaration of GCAP which were later reformed into CAMCs under the new conservation policies of GCAP.

Even after the declaration of GCAP for more than 15 years there are no successful stories in the conservation and management of forest based resources including biodiversity. In the past, the community forests that were conserved and managed by the local communities were the sources of forest products supporting the livelihoods of local communities. It has been reported that after the formation of CAMC the local communities have very limited access to the forest resources resulting lots of conflicts between the local communities and GCAP management affecting in achieving the objective of "Conservation for prosperity". Inefficiency and poor implementation in the conservation and management practices for forest based resources under GCAP management is blamed for the conflicts, by the locals.

3.1.3 Selection of study sites and tree species

The study was conducted in Ward Nos. 1 to 4 of Bigu Rural Municipality, within the Gaurishankar Conservation Area, Dolakha district. Six sites were selected across Singati, Laduk, Bulung, and Bulungkhani, covering elevations from 1010 m to 2500 m. These sites, represent diverse vegetation types and altitudinal gradients, offer insights into the relationships between vegetation, topography, and environmental factors.

Table 2. Studied tree species and their topographical location

Elevation	Location	Coordinates	Aspect	Tree Species	Types
1029	Singati	27°44′23″ N, 86°10′63″ E	130° SE	*Pinus roxburghii*	Evergreen
2050	Laduk	27°46′40″ N, 86°10′12″ E	98° E	*Pinus wallichiana*	Evergreen
2156	Bulung	27°46′19″ N, 86°10′40″ E	137° SE	*Myrica esculenta*	Deciduous
2189	Bulung	27°46′19″ N, 86°10′26″ E	100° E	*Rhododendron arboreum*	Evergreen
2243	Bulung	27°46′10″N, 86°10′23″ E	34° SE	*Pinus patula*	Evergreen
2310	Bulungkhani	27°47′15″N, 86°10′10″ E	144° SE	*Quercus lanata*	Evergreen

Site 1, located in Singati at an elevation of 1010m, is characterized by the dominance of *Pinus roxburghii* associated with *Schima wallichi* and *Englehartia spicata*, contributing to the site's unique ecosystem dynamics. Site 2, situated within 2050m, exhibits a contrasting vegetation profile with *Pinus wallichiana* as the primary forest constituent. This site also hosts *Pinus patula* and *Rhododendron arboreum* as associated species, highlighting the diversity within the forest community. Site 3 presents a distinct vegetation composition with *Myrica esculenta* as the dominant species, accompanied by *Pinus wallichiana*, *Rhododendron arboreum*, and *Alnus nepalensis*. This interplay of species reflects the

complex ecological interactions shaping the landscape. At Site 4, the landscape is dominated by *Rhododendron arboreum*, coexisting with *Schima wallichi* and *Pinus wallichiana*. This assemblage of species underscores the site's ecological significance and the need for comprehensive conservation efforts. Site 5 offers a glimpse into a *Pinus patula*-dominated forest ecosystem, complemented by the presence of *Quercus lanata* and *Rhododendron arboreum*. This site serves as a testament to the dynamic nature of forest communities, constantly evolving in response to environmental pressures. Finally, Site 6, located in Bulungkhani, presents a captivating vista characterized by the dominance of *Quercus lanata*. The presence of *Abies spectabilis*, *Alnus nepalensis*, and *Lyonia ovulifolia* further enriches the site's biodiversity, offering a sanctuary for diverse flora and fauna.

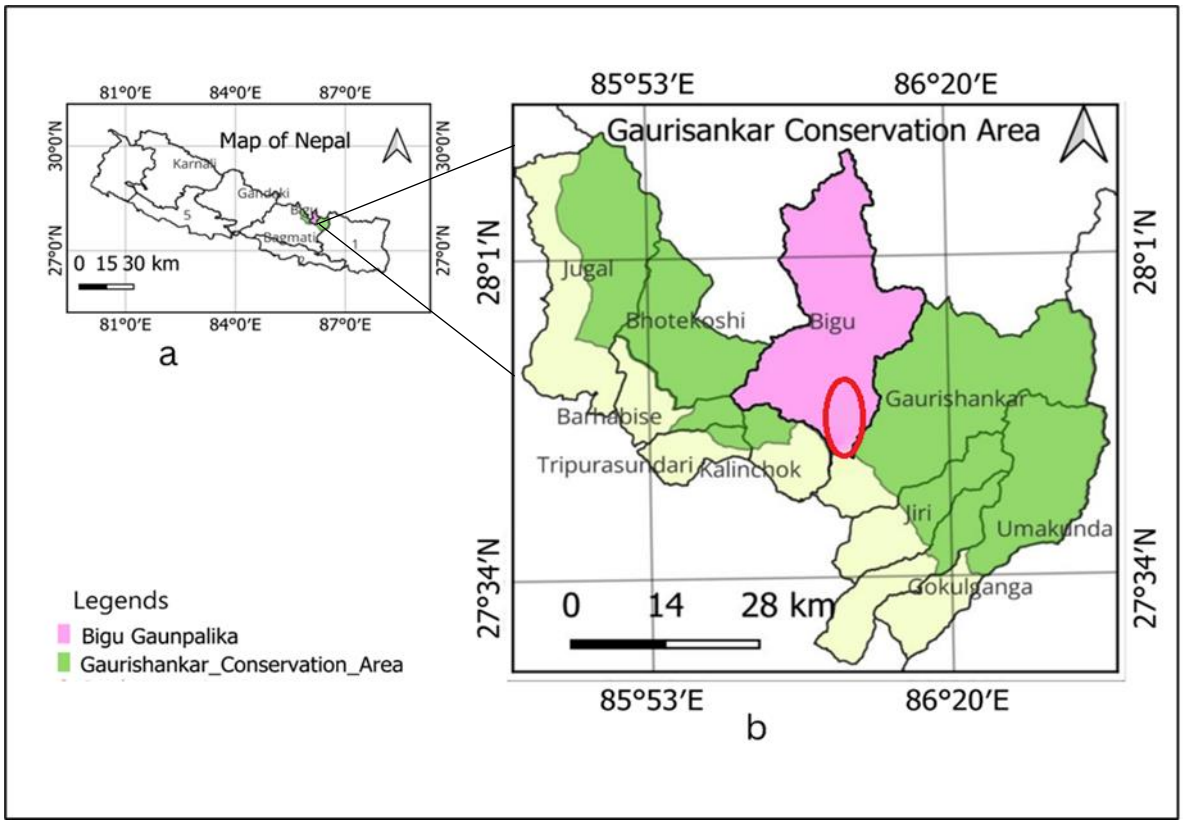

Figure 3. Location of study area in GCA. The sampling area is indicated by the circle. (Source: QGIS WGS84)

Figure 4. Location of tree species along the elevation gradient in the GCA. (Source: Google Earth, downloaded on October 6, 2023.)

(Site 1. *P. rocburghii*; Site 2. *P. wallichiana*; Site 3. *M. esculenta*; Site 4. *R. arboreum*; Site 5. *P. patula*; Site 6. *Q. lanata*)

3.1.4 Climate and Topography

There is great climatic variation in GCA region from sub-tropical to arctic climate. The altitude rises from less than 1,000 m to more than 7,000 m within a short span of 120 km. where the climate varies with altitude and aspect (NTNC, 2022). The average daily temperature decreases between December to February and reaches a maximum between May to July. Months from June to September represent a typical monsoon season. The elevation above 2500 m receives seasonal snowfall dropping the temperature below 0º C due to close proximity of Rolwaling Himalaya range (NTNC, 2022).

Temperature trends exhibit a gradual warming from January, with temperatures ranging from nearly 5° C to around 15° C, to a pinnacle in the mid-year months, where the maximum temperatures soar to approximately 25° C to 30° C. Subsequently, a cooling pattern is noticeable as the year progresses towards its later half, with minimum temperatures descending to the initial range by December. Precipitation, as indicated by the plotted data points, follows a monsoonal pattern, witnessing a substantial increase commencing from the month of June. The apex of precipitation occurs between July and August, where monthly totals escalate beyond 700 mm, indicating the presence of a pronounced wet season. Following the culmination of the monsoon, there is a steep decline in precipitation towards the end of the year, signifying a dry season starting from October to March.

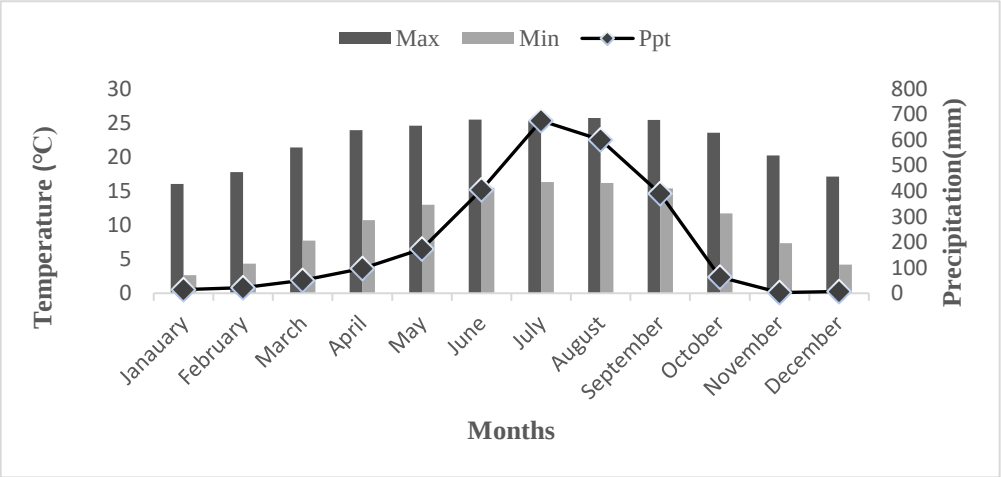

Figure 5. Ten years climatic data (2013-2023) indicating the mean monthly temperature and rainfall of Charikot, the nearest meteorological station from Bigu Rural Municipality. (Source: Department of Hydrology and Meteorology, Babarmahal, GoN).

3.2 Methods

The research focuses on the litter chemistry and decomposition rate, as well as nutrient release into the soil. Furthermore, litter and soil samples were collected, sorted and dried for laboratory analysis.

3.2.1 Field Sampling

The selected tree stands of *Pinus roxburghii*, *Myrica esculenta*, *Rhododendron arboreum*, *Pinus wallichiana*, *Pinus patula*, and *Quercus lanata* in various vegetation types were selected between Singati at 1000 m and Bulungkhani village at 2500 m within the Bigu Rural Municipality of GCA. The selection of six sites was based on the presence of common tree species across an altitudinal gradient, which allowed for a comprehensive study of ecological variations. Additionally, the considerable margin between the *Pinus roxburghii* and other species was taken into account, as the area between them is predominantly occupied by crop fields and settlements, creating a natural separation that emphasizes the gradient being studied.

Procedures for collecting litter, placing litter bags, and collecting soil samples were accomplished by following Berger *et al.,* (2015) and Bohara *et al.,* (2020).

3.2.2 Experimental Design

Freshly fallen litter samples from selected stands were collected manually from 1m2 plots from the forest floor and were dried separately at room temperature until the average weight of the litter samples were constant. The dried litter samples were placed in labelled zip-lock bags and stored at room temperature.

Following Berger *et al*., (2015), litter bags were prepared from Polyethylene nets with mesh size of 1mm. Strips of 20 cm x 10 cm of nets were folded to prepare 10 cm x 10 cm and were closed with clips. A total of 96 litter bags were prepared, in which 16 litter bags were used for each tree species (four replicates for four seasons). Three grams of dried litter was weighed using digital balance in the Botany Department of Amrit Campus, and the bags were secured using clips. Four litter bags were secured by stitching with nylon strings at a 20 cm distance from each other (Fig. 3.4) and were transported to the experimental sites in cardboard boxes. Sixteen litter bags for each tree species were secured at each site on top

of the soil after carefully removing the litter from the forest floor and all strings were firmly secured on the ground with the help of metal pegs. At the end litter bags were covered by the same amount of litter as it was before and no sign of disturbances were left to ensure to not to attract any wildlife or human being. The location of all sites were marked using colored spray paint on the surrounding trees or rocks, the GPS coordinates were noted down, and the photo records were taken. The litter bags were placed in the selected tree stands just before the monsoon 15 June 2022.

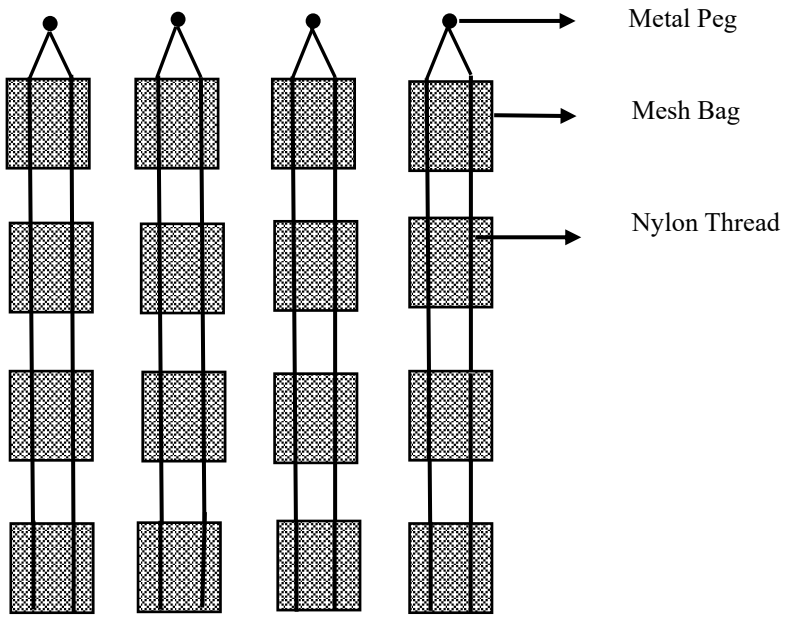

Figure 6. Process showing placement of litterbags

The litter bags were retrieved every three months subsequent to their initial deployment, specifically at the 3, 6, 9, and 12-month intervals. Following the collection, the bags were gently brushed to remove extraneous materials such as ingrown roots and soil with the help of a tooth brush. The litter was then dried under ambient room conditions and weighed using a precise weighing machine (Wensar, PGB220) until a constant weight was achieved. The residual litter mass present at the end of the sampling regimen represents the portion of litter that endured throughout the decomposition period. After weighing, the litter was then carefully replaced in properly labelled zip-lock bags and transported to the laboratory for the nutrient analysis.

The soil samples were collected from the O-horizon layer (10 cm below the top soil surface) from each respective forest stand during the final month of litter collection following

(Bohara *et al.,* 2020). Then, the litterbags were kept separately in labeled zip-lock bags and transported back to Kathmandu for lab analysis.

3.2.3 Laboratory Procedures

Chemical analysis of litter and soil was carried out in Agriculture Technology Center (ATC, agritechcenter.com.np), Kupandole, Kathmandu using the standard methods in a clean and contamination free environment.

Several methods were used for the chemical analysis of the litter samples. Litter N was determined using Kjeldahl Digestion-distillation method (Kjeldahl, 1883), wherein organic matter was digested with concentrated sulfuric acid, liberating ammonia, which after alkali treatment was quantified through titration. Phosphorus (presented as P_2O_5 percentage) was assessed by Vanadomolybdate method in conjunction with Spectrophotometry, where the developed yellow color intensity was measured at a wavelength of 400µ. Potassium (presented as K_2O percentage) levels were measured using the Flame Photometer method, a technique suitable for quantifying potassium content in the digested samples (Lundegardh, 1934). Organic Matter content was evaluated by two methods: The Walkley-Black method, which involves oxidation followed by back titration, assuming a 75% oxidation rate (Walkley and Black, 1934) ; and the Loss on Ignition method, where the sample was heated to between 550°C and 600°C with the loss of weight upon ignition equated to the organic matter content of the sample.

Similarly, various soil parameters were determined using different established methods. For the measurement of soil pH, the potentiometric 1:2.5 method was employed. Soil N by Kjeldahl method, incorporating modifications that include the addition of salicylic acid and sodium thiosulphate to address nitrate forms. The quantification of available Phosphorus was conducted by the modified Olsen's method for soils with a pH greater than 5.5, while for more acidic soils with a pH below 5.5, the Bray and Kurtz No. 1 method was used. The assessment of available potassium levels was performed using ammonium acetate as an extractant, and the levels were measured with flame photometry. Lastly, soil C was extracted by employing the Walkley-Black method. These methods were chosen for their suitability in accurately quantifying the soil characteristics.

3.2.4 Data Management and Analysis

To evaluate the Loss of Litter Mass Over Time (%), the protocols of Bragazza and Iacumin (2009) and the 'Decay Model' of Olson (1963), were followed.

$$K = -\ ln\ (X_t\ /X_0)/t$$

Where 'Xt' is the final weight of the litter following the collection and 'X0'is the known initial measured mass of the litter at the time of placement in the soil, respectively in gram(s), 'ln' is the base of the natural logarithm, 'K' is the 'Decay constant (Coefficient of decay rate)', and 't' is the 'time interval in year'.

Furthermore, the protocols of Guo and Sims (1999) were reviewed to calculate the 'Nutrient Release by Litter (%)'.

$$R = \{(X_0C_0 - X_tC_t)\ /X_0C_0\} \times 100$$

Where 'R' is the release of nutrients (%), 'C0' is the 'Initial Nutrient Concentration (mg/g)', and 'C_t' is the 'final concentration of nutrient' in the litter.

Data variations and correlations were thoroughly examined through various statistical methods. The difference in reduction of litter weight among different species and or along the altitudinal gradients were assessed using 'one-way analysis of variance (ANOVA).' Prior to conducting ANOVA, data normality was verified, and outliers were identified. After the ANOVA tests, 'post-hoc least significant difference (LSD)' tests were conducted to analyze the findings further. 'Pearson's correlation analysis' was used to quantify the relation among initial litter chemistry, nutrient dynamics, and litter mass reduction. The correctness and dependability of the study's findings were guaranteed by the statistical analyses that were conducted using 'IBM SPSS Statistics 23' and 'Microsoft Excel'. The data (coordinates) for the collection of soil and litter samples and the placement of litter bags were assessed using 'Google Earth Pro'. 'Geographical Information System (Q-GIS)' Software was used to project a study area map.

CHAPTER 4. RESULTS

4.1. Litter Decomposition in Different Forest Types

The litter mass loss exhibited a decreasing trend across all six species from the first quarter to the fourth quarter (Fig 4.1). The initial dry weight of the freshly fallen litter was 3 gm for all tree species. During the first quarter, the average dry weight reduced to 1.88 gm for *Pinus roxburghii*, 2.49 gm for *Pinus wallichiana*, 2.52 gm for *Pinus patula*, 2.31 gm for *Rhododendron arboreum*, 2.18 gm for *Myrica esculenta*, and 2.60 gm for *Quercus lanata*. By the fourth quarter, the gradual reduction in average dry weight resulted in 0.33 gm, 1.14 gm, 2.01 gm, 1.89 gm, 1.45 gm, and 1.63 gm for *P. roxburghii*, *P. wallichiana*, *P. patula*, *R. arboreum*, *M. esculenta*, and *Q. lanata*, respectively.

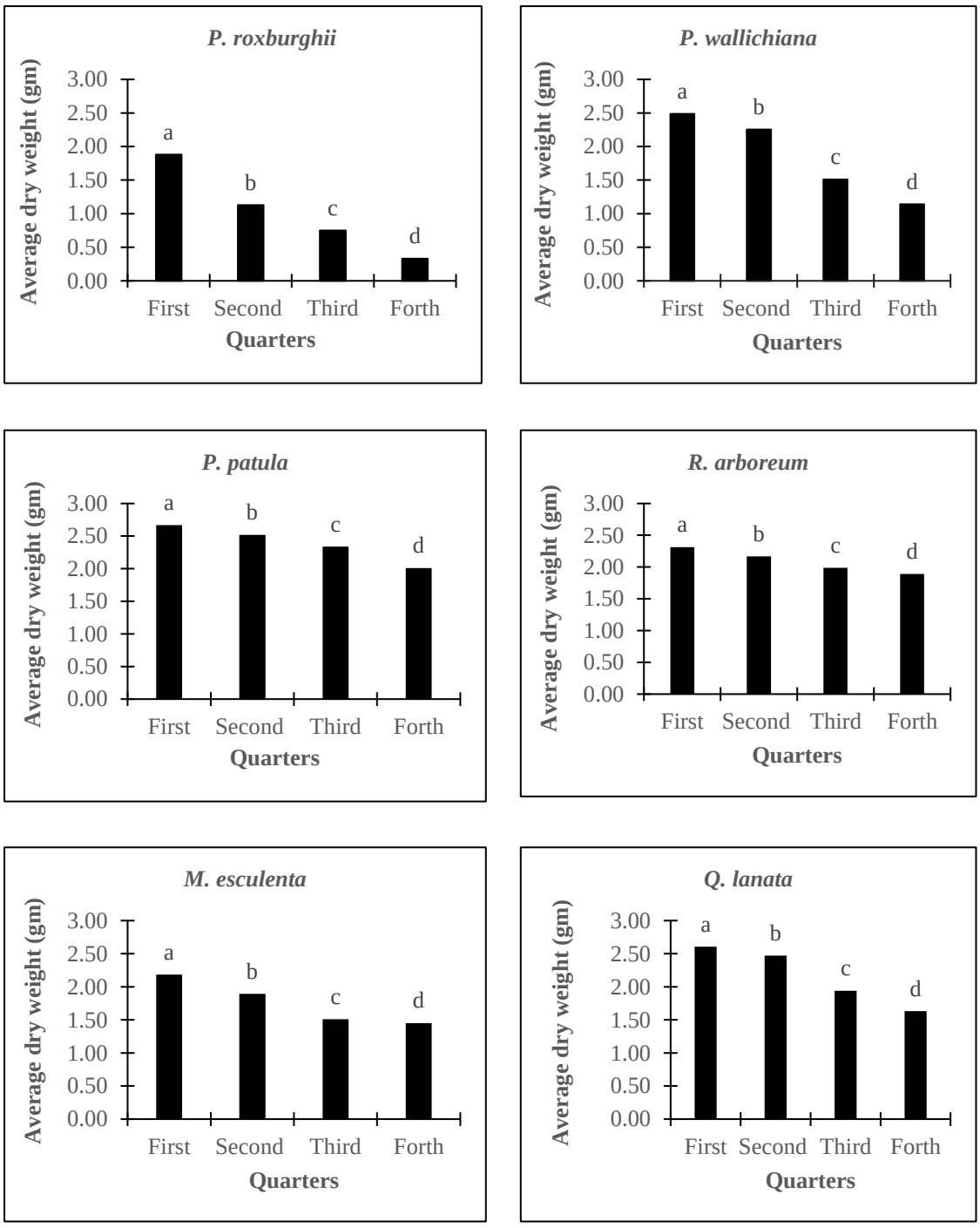

Figure 7. Average dry weight of litter mass loss during quarterly harvest. Different lowercase alphabets indicate the highly significant difference in decomposition rates (one-way ANOVA) from the first quarter to the fourth quarter.

The percentage reduction in average dry weight of litter was highest for *P. roxburghii* (89%) and lowest for *P. patula* (33%), with *P. wallichiana* (62%), *R. arboreum* (37%), *M. esculenta* (51.67%), and *Q. lanata* (45.67%) falling in between (Fig 4.2).

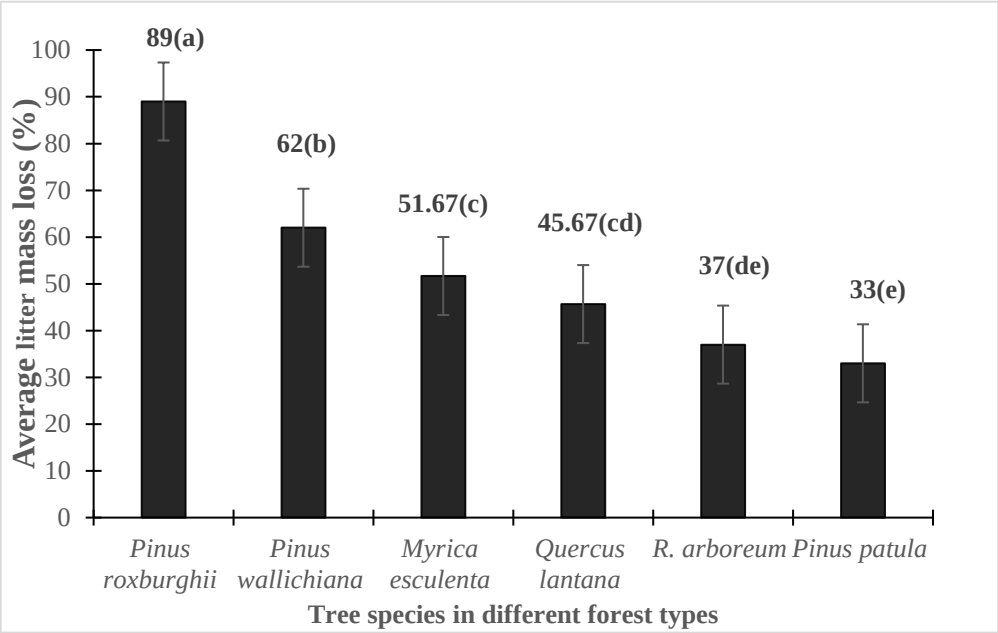

Figure 8. Average litter mass loss in percentage during 12 months period. Lowercase letters indicate significant variation in litter mass loss among tree species.

Consequently, *P. roxburghii* exhibited the highest decomposition rate, followed by *P. wallichiana*, *M. esculenta*, *Q. lanata*, *R. arboreum*, and *P. patula* during the fourth quarter. Significant difference was noticed in the decay constant of litter between the first and fourth quarters for all tree species (Fig 4.2).

P. roxburghii > *P. wallichiana* > *M. esculenta* > *Q. lanata* >*R. arboreum* > *P. patula*

The decomposition rates exhibited a considerable range among the studied species, varying from 0.40 for *P. patula* to 2.21 for *P. roxburghii* (Table 4.1). The results indicated that a period of 0.31 to 1.73 years was required for 50% litter decay, while 2.26 to 7.50 years were necessary for 95% litter decay across the species. Furthermore, litter mass loss displayed a notable pattern along the elevational gradient. The highest litter mass loss was observed at lower elevations, and it decreased with increasing elevation (Fig. 4.2). Significant variations in litter mass loss were evident among the species, as well as between the lower (1000 m) and higher (2310 m) elevational zones.

Table 3. Litter decay rate (K), half-life (t_{50}), and the time required for 95% decay (t_{95}) from the residual litter of different forest types.

Species	Decay constant (K)	t_{50} (year)	t_{95} (year)
P. roxburghii	2.21	0.31	2.26
P. wallichiana	0.97	0.71	5.15
P. patula	0.4	1.73	12.50
R. arboreum	0.46	1.51	10.87
M. esculenta	0.73	0.95	6.85
Q. lanata	0.61	1.14	8.20

4.2. Chemical composition of litter

The least N concentration was found for *P. roxburghii* at 1010 m and highest for *P. patula* at 2243 m (Table 4.2). Similarly, the lowest P concentration was found for *M. esculenta*, and the highest for *R. arboreum*. For K, the lowest concentration was found for *P. roxburghii* and the highest for *P. wallichiana*. The C concentration was highest for *P. roxburghii* and lowest for *Q. lanata*.

These differences in nutrient concentrations resulted in significant variations in nutrient ratios among the species. *P. roxburghii* had the highest C: N ratio while *M. esculenta* had the lowest. N:P was the high for *M. esculenta* and low for *R. arboreum*. Meanwhile, C:P and C: K were the highest in *M. esculenta* and *P. roxburghii* respectively but the lowest in *R. arboreum* and *P. wallichiana* respectively. *M. esculenta* and *R. arboreum* had the maximum N: K and P:K ratios respectively, whereas the minimum ratios of both were found in *P. wallichiana* (Table 4.2).

Table 4. Initial litter nutrient contents (mg/gm) and their ratios.

Species	C	N	P	K	C: N	C:P	C: K	N:P	N: K	P: K
P. roxburghii	584.6	6.9	0.9	2.3	84.72	649.56	254.17	7.67	3.00	0.39
P. wallichiana	569.2	10	1.6	15.3	56.92	355.75	37.20	6.25	0.65	0.10
P. patula	576.7	18.5	0.7	6.3	31.17	823.86	91.54	26.43	2.94	0.11
R. arboreum	562.6	11.9	2.3	3.7	47.28	244.61	152.05	5.17	3.22	0.62
M. esculenta	567.2	20	0.5	3.2	28.36	1134.40	177.25	40.00	6.25	0.16
Q. lanata	562.1	10	1.7	5.5	56.21	330.65	102.20	5.88	1.82	0.31

4.3. Litter Nutrient Dynamics

P. roxburghii consistently released the highest proportions of carbon and potassium across all time intervals, suggesting a relatively rapid decomposition rate for this species (Fig 4.3). Conversely, the release patterns for nitrogen and phosphorus varied among species and time points, with different species exhibiting maximum release rates at different intervals.

At the 3-month interval, *P. roxburghii* exhibited the high release of carbon (52.44%) and potassium (47.13%), while *P. wallichiana* had the highest nitrogen release (29.49%). *R. arboreum* displayed the highest phosphorus release (75.20%) during this initial stage. After 6 months, *P. roxburghii* continued to show the highest carbon (73.27%) and potassium (80.00%) release rates. *P. patula* had the maximum nitrogen release (50.45%), while *R. arboreum* maintained the highest phosphorus release (39.25%).

At the 9-month mark, *P. roxburghii* exhibited the high release of carbon (85.53%) and potassium (69.80%), followed by *Q. lanata* for nitrogen release (89.91%) and *P. patula* for phosphorus release (88.83%). Finally, in the 12-month period, *P. roxburghii* demonstrated the maximum release of carbon (96.81%) and potassium (95.69%), while *Q. lanata* had the highest nitrogen release (97.10%), and *P. patula* exhibited the highest phosphorus release (99.06%).

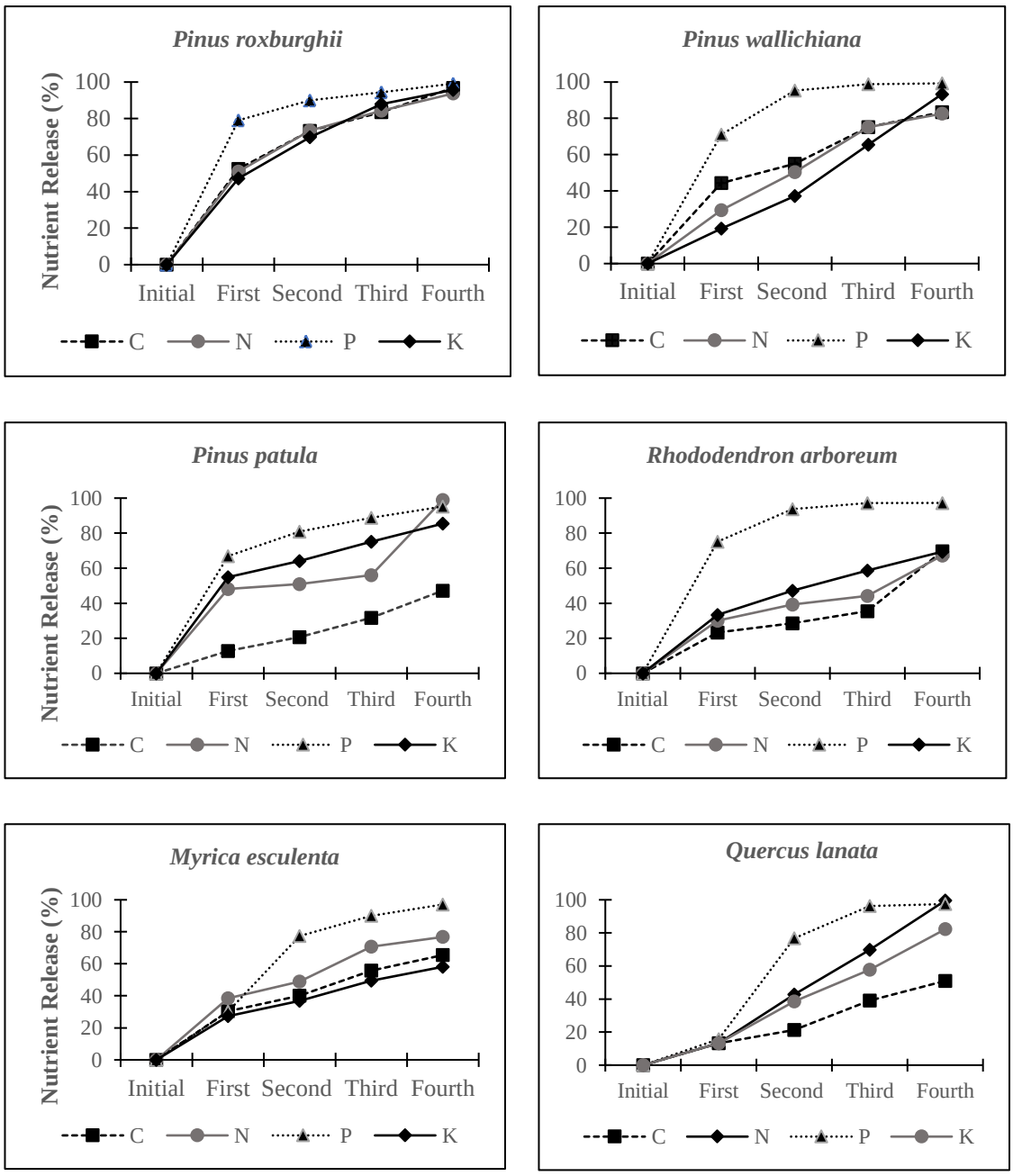

Figure 9. Nutrient release rates (expressed as percentages) from the residual litter of six different tree species from the initial to the fourth quarter of a year-long in-situ decomposition experiment. The nutrient release rates are provided for C, N, P, and K as carbon, nitrogen, phosphorus, and potassium respectively.

Additionally, the nutrient release patterns indicate significant variations among the tree species in terms of their ability to release specific nutrients from their decomposing litter over the course of a year (Fig 4.4). *P. roxburghii* exhibited a nutrient release pattern of P > C > K > N, indicating a highest release of phosphorus (99.14) followed by carbon (96.81),

potassium (95.69), and lastly nitrogen (93.71). *R. arboreum* also showed a P > C > K > N pattern, with values of phosphorus (97.27), carbon (69.72), potassium (69.43), and nitrogen (67.26). Similarly, *P. wallichiana* displayed a release pattern of P > K > C > N, with values of phosphorus (99.29), potassium (93.31), carbon (83.38), and nitrogen (82.55).

However, for *P. patula*, the release pattern was N > P > K > C, with values of nitrogen (99.06), phosphorus (95.22), potassium (85.46), and carbon (47.23). *M. esculenta* showed a release pattern of P > N > C > K, with values of phosphorus (97.10), nitrogen (76.79), carbon (65.46), and potassium (58.15). Lastly, *Q. lanata* exhibited a release pattern of N > P > K > C, with values of nitrogen (99.51), phosphorus (97.44), potassium (82.21), and carbon (50.96).

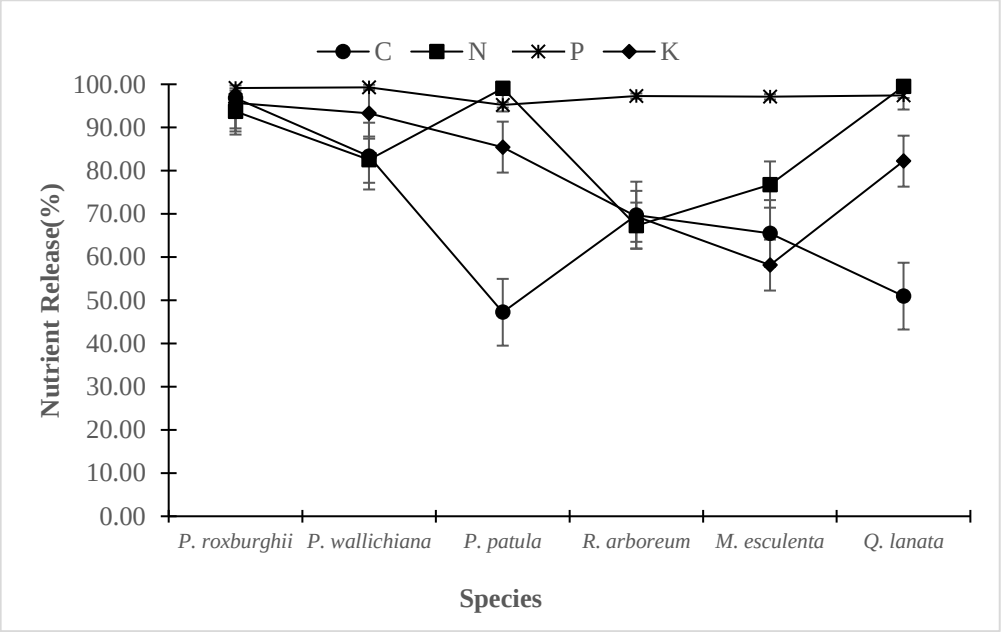

Figure 10. Nutrient release rate (%) from the remaining litter in the fourth quarter in different forest species.

The relationship between litter mass loss and nutrient release exhibited distinct patterns across the studied tree species (Table 4.3). For *P. roxburghii*, an almost perfect positive correlation was observed between litter mass loss and the release of carbon (0.999), nitrogen (0.998), and phosphorus (0.998), indicating that the loss of litter mass was closely associated with the release of these nutrients. A similarly robust positive correlation (0.992) was found for potassium release. *P. wallichiana* displayed a very high positive correlation between litter mass loss and carbon release (0.995), as well as a strong positive correlation

with nitrogen release (0.973). However, the correlation with phosphorus release (0.766) was relatively moderate, suggesting a weaker association between litter mass loss and phosphorus release for this species compared to *P. roxburghii*. Nonetheless, potassium release exhibited a very high positive correlation (0.990) with litter mass loss. *P. patula* exhibited an almost perfect positive correlation between litter mass loss and carbon release (0.998), along with strong positive correlations for nitrogen (0.937) and phosphorus (0.935) release. The correlation with potassium release (0.984) was also very high.

Among the broadleaf species, *R. arboreum* showed a high positive correlation between litter mass loss and carbon release (0.857), as well as strong positive correlations for nitrogen (0.914) and phosphorus (0.87) release. The correlation with potassium release (0.996) was remarkably high. *M. esculenta* demonstrated a very high positive correlation between litter mass loss and carbon release (0.98), and an extremely high positive correlation with nitrogen release (0.991). The correlations with phosphorus (0.941) and potassium (0.981) release were also strong and very high, respectively. *Q. lanata* exhibited an almost perfect positive correlation between litter mass loss and carbon release (0.997), a very high positive correlation with nitrogen release (0.975), and a high positive correlation with phosphorus release (0.806). The correlation with potassium release (0.967) was very high.

Table 5. Correlation between litter mass loss and litter nutrient contents. C, N, P, and K are carbon, nitrogen, phosphorus, and Potassium, respectively.

Species	**LitterC**	**LitterN**	**Litter P**	**Litter K**
P. roxburghii	0.999**	0.998**	0.998**	0.992**
P. wallichiana	0.995**	0.973*	0.766	0.990**
P. patula	0.998**	0.937*	0.935*	0.984**
R. arboreum	0.857	0.914*	0.87	0.996**
M. esculenta	0.98*	0.991**	0.941*	0.981**
Q. lanata	0.997**	0.975*	0.806	0.967*

4.4. Factors Affecting Litter Decomposition

The first quarter, from mid-June to mid-September, was distinguished by high temperatures, with an average maximum of 23.75°C and an average minimum of 16.75°C, along with high rainfall averaging 600 mm. During this period, decomposition was higher for *P. roxburghii, M. esculenta*, and *R. arboreum* (Table 4.4). Moreover, the second quarter,

spanning from mid-September to mid-December, experienced moderate temperatures, averaging high in 19°C and a low in 10.75°C, with moderate rainfall averaging 262.5 mm. During this time, decomposition was lower for most species, particularly for *P. wallichiana* and *R. arboreum*. The third quarter, from mid-December to mid-March, had low temperatures with a mean maximum of 14.75°C and mean minimum of 5.5°C, coupled with low rainfall averaging 150 mm. In this colder and drier period, decomposition was higher for *P. wallichiana* and *P. patula*, but lower for *P. roxburghii* and *R. arboreum*. The fourth quarter, from mid-March to mid-June, experienced increasing temperatures, averaging a maximum of 20.67°C and a minimum of 10.67°C, and increasing rainfall averaging 383.33 mm. During this period, decomposition was higher for *P. patula* and *R. arboreum*, but lower for *Q. lantana*.

Table 6. Litter decomposition (%) of each quarter in a year-long *in situ* litter decomposition process.

Quarters	*P. roxburghii*	*P. wallichiana*	*P. patula*	*R. arboreum*	*M. esculenta*	*Q. lanata*
First (June 15 – Sept 15)	37.33	17	16	23	27.33	13.33
Second (Sept 15 – Dec 15)	62.33	25	11	27.67	37	17.67
Third (Dec 15 – Mar 15)	75	49.67	22	33.67	49.67	35.33
Forth (Mar 15 – June 15)	89	62	33	37	51.67	45.67

In the context of litter decomposition dynamics across the studied environmental gradients, the correlation matrix reveals several relationships (Table 4.5). The mass loss of litter exhibits a highly significant negative correlation ($r = -0.911$, $p < 0.01$) with elevation. The aspect, representing the slope orientation, demonstrates a moderate positive correlation ($r = 0.484$, $p < 0.05$) with litter mass loss. This relationship implies that variations in aspect can influence the microclimate and other site-specific factors, consequently affecting the decomposition processes and the extent of litter breakdown.

Interestingly, C_0 exhibits a strong negative correlation ($r = -0.800$, $p < 0.01$) with elevation and a moderate positive correlation ($r = 0.631$, $p < 0.05$) with litter mass loss. Additionally, both N_0 and P_0 demonstrate moderate negative correlations ($r = -0.613$, $p < 0.05$, and $r = -0.230$, $p < 0.05$, respectively) with litter mass loss. These inverse relationships indicate that as the values of N_0 and P_0 increase, the decomposition rates of litter tend to decline.

Table 7. Correlation between mass loss, initial litter contents (C_0, N_0, P_0 and K_0) and environmental parameters.

	Massloss	Elevation	Aspect	C_0	N_0	P_0	K_0
Massloss	1						
Elevation	-.911**	1					
Aspect	.484	-.262	1				
Co	.631	-.800*	-.265	1			
No	-.613	.563	-.386	-.164	1		
Po	-.230	.247	.115	-.594	-.542	1	
Ko	-.023	.270	-.286	-.147	-.155	.229	1
**. Correlation is significant at the 0.01 level (1-tailed).							
*. Correlation is significant at the 0.05 level (1-tailed).							

These strong relationship between litter nutrient concentration with nutrient ratio and soil pH underscore the intricate relationships and interdependencies among each other (Table 4.6). Nitrogen content (N) exhibits a remarkably strong negative correlation with C/N ratio (-0.938), implying that higher nitrogen levels are firmly associated with lower C/N ratios within the studied ecosystem. Conversely, nitrogen content displays a robust positive correlation with nitrogen ratios (0.913), suggesting that elevated nitrogen content is strongly linked to higher nitrogen ratios. Phosphorus content (P) demonstrates a strikingly strong negative correlation with the C/N ratio (-0.934), indicating that increased phosphorus levels are strongly connected to lower C/N ratios in the soil. Additionally, phosphorus content exhibits a strong positive correlation with soil phosphorus (0.820), signifying that higher phosphorus content is strongly associated with greater phosphorus levels in the soil.

Furthermore, soil pH demonstrates a robust positive correlation with soil potassium (0.933), implying that higher soil pH is strongly linked to elevated potassium levels in the soil. Also, soil phosphorus exhibits a strong positive correlation with soil potassium (0.866), suggesting that increased soil phosphorus content is strongly associated with higher soil potassium levels.

Table 8. Correlation between initial litter nutrient contents, ratios and soil elements.

	C	N	P	K	C:N	C:P	C:K	N:P	N:K	P:K	Soil pH	Soil C	Soil N	Soil P	Soil K
C	1														
N	-.164	1													
P	-.605	-.535	1												
K	-.147	-.155	.232	1											
C:N	.450	-.938**	.233	-.013	1										
C:P	.378	.734*	-.934**	-.356	-.462	1									
C:K	.464	-.150	-.307	-.832*	.398	.347	1								
N:P	.080	.913**	-.790*	-.269	-.734*	.939**	.121	1							
N:K	.001	.672	-.542	-.692	-.484	.785*	.580	.803*	1						
P:K	-.205	-.450	.645	-.538	.367	-.520	.493	-.528	.044	1					
Soil pH	.871*	.010	-.664	-.500	.321	.585	.788*	.306	.443	.010	1				
Soil C	-.418	.204	.174	.251	-.275	.066	-.070	.197	.310	.031	-.161	1			
Soil N	-.136	.386	-.281	-.534	-.253	.546	.599	.554	.881*	.204	.349	.633	1		
Soil P	.611	-.381	-.180	-.489	.608	.158	.876*	-.108	.299	.452	.820*	.103	.454	1	
Soil K	.855*	-.274	-.559	-.366	.586	.415	.772*	.086	.248	.012	.933**	-.150	.274	.866*	1
*. Correlation is significant at the 0.05 level (1-tailed).															
**. Correlation is significant at the 0.01 level (1-tailed).															

CHAPTER 5: DISCUSSION

5.1. Rate of Litter Decomposition in Different Forest Types

The field experiments conducted across different forest types and elevational gradients in the Gaurishankar Conservation Area of Nepal provide valuable insights into the direct and site-specific factors influencing litter decomposition processes. This study represents the first comprehensive effort to elucidate these regional dynamics, contributing to a better understanding of nutrient cycling and ecosystem functioning in the Himalayan forest.

The present findings clearly demonstrated that litter from tree species thriving at lower elevations exhibited decomposition rates at quicker pace than those at elevated altitude. This finding is consistent with previous studies Xiao *et al.,* (2019), highlighting the strong influence of elevation on litter breakdown dynamics. The observed pattern can be attributed to the elevational variations in environmental factors such as temperature, precipitation, and microbial interaction, which collectively modulate the decomposition processes (Semwal *et al.,* 2003).

Interestingly, despite the general elevational trend, the decomposition rate of *P. patula* litter was slower than *Q. lanata* in the similar elevational pattern. This observation suggests that species-specific traits, such as litter chemistry and physical characteristics, can override the effect of elevation in certain cases, underscoring the importance of considering both abiotic and biotic components in understanding decay patterns. The observed faster decomposition of *Quercus lanata* litter aligns with the findings of Ghosh (2015), that Quercus litter decomposes at the fastest pace, with Pinus and Rhododendron litter following closely behind in Garhwal region of Central Himalaya. However, this result contrasts with the study Bohara *et al.,* (2020), potentially due to variations in soil physical characteristics and micro-environmental conditions (Ghosh, 2015). These inconsistencies underscore the context-specific nature of litter decomposition processes and the importance of considering local environmental factors.

Furthermore, the study displayed that decay rate was faster for the deciduous species *M. esculenta* compared to the evergreen *R. arboreum* at similar elevations. This finding aligns with the established understanding that decaying of litter is accelerated in woody deciduous species compared to woody evergreen species because of their shorter leaf life spans

compared to evergreen's longer-lived, resource-conserving foliage (Cornwell *et al.,* 2008; Rahman and Tsukamoto, 2013). Such variations in decomposition rates are closely linked to the adaptive strategies employed by plants, reflecting their resource allocation patterns and leaf traits.

Moreover, the research also found that the release of nutrients and their amounts in the litter (and the underlying soil) highly rely on the tree species along the altitudinal gradient. At the species level, the decomposition rate followed the order: *P. roxburghii* > *P. wallichiana* > *M. esculenta* > *Q. lanata* > *R. arboreum* > *P. patula*. This pattern emphasizes how different tree species control the quality of the substrate and the microenvironment beneath their canopies, including the temperature of the soil and the air, which in turn affects the decomposition dynamics (Eviner and Chapin, 2003).

The decomposition rates observed in this study, ranging from 0.40 to 2.21 yr^{-1} across an elevation gradient of 1029 m to 2310 m, are generally consistent with previous research conducted in similar ecosystems. Saha *et al.,* (2016) reported decomposition rates between 0.26 and 0.51 yr^{-1} for plant litter at elevations ranging from 2050 to 2300 m. While present study encompassed a broader elevation range, the lower end of the present study observed decomposition rates aligns well with the results of Saha *et al.,* (2016). Furthermore, Bohara *et al.,* (2020) found decay rates of 0.53–1.42 yr^{-1}, which overlap with the mid-range values in the present study. The higher maximum rate observed in our research (2.21 yr^{-1}) may be attributed to the inclusion of lower elevation sites (down to 1029 m), where warmer temperatures and potentially higher moisture availability could accelerate decomposition processes.

While elevation and tree species were the main focus of this study, other factors that were not examined, such as the interaction of the microbial community, may also be extremely important in explaining the dynamics of forest litter decomposition, especially in the early (Aerts, 1997; Berg *et al.,* 2014) and later (> 3 years; Berg *et al.,* 2010) stages. The knowledge of the processes involved in the breakdown of litter in these Himalayan forest ecosystems should be further refined by future study involving a thorough examination of biotic and abiotic components.

5.2. Chemical Composition of Litter

The pace at which litter breaks down in litter bags is influenced by the amounts of C, N, P, and K in the litter. High-quality litter (high N concentration, low C:N ratio) is found to degrade more quickly than low-quality litter (low N concentration, high C:N ratios) in prior research (Gao *et al.*, 2016; Zhang *et al.*, 2018; Xiao *et al.*, 2019). However, the present study found that *P. roxburghii* has the highest C content (584.6) but relatively low N (6.9) and P (0.9) contents, resulting in high C: N and C:P ratios which suggests the lower availability of N and P, that are essential for microbial activity.

In contrast, *P. patula* shows a significantly higher N content (18.5), the highest among the species listed, which leads to a much lower C:N ratio (31.17). The observation that litter decomposition was faster in *P. roxburghii* litter at lower elevations and slowest in *P. patula* litter at the highest elevation adds an interesting layer to the discussion. Despite *P. roxburghii* having a high C:N ratio, which typically suggests slower decomposition, other factors such as climate conditions, microorganism activity, and litter quality (Bhattarai and Bhatta, 2020) may have influenced the decomposition rate.

At lower elevations, the climate is generally warmer and more humid which can enhance microbial activity and speed up the decomposition process (Giweta, 2020). This could explain why *P. roxburghii* litter (closer to Tamakoshi river) decomposed faster in these conditions despite its nutrient content suggesting otherwise. Additionally, the presence of other nutrients or compounds in the litter not captured by the C: N and C:P ratios might also play a role in facilitating decomposition. On the other hand, the slower decomposition of *P. patula* litter at higher elevations could be attributed to the cooler and potentially drier conditions, which are less favorable for microbial activity (Veen *et al.*, 2015). Even though *P. patula* has a lower C:N ratio, which would typically be associated with faster decomposition, the environmental conditions at higher elevations seem to have a greater impact on slowing down the process. This is further supported by (Salah and Scholes, 2011) who found the increased decomposition rates in the increasing temperature in *P. patula* needle litter.

Additionally, the study also contradicts with the suggested findings that suggests, for organic N mineralization of litter in forests, the threshold C:N ratio typically lies between 20 and 30, beyond which microbial immobilization of mineral N takes place (Sharma and

Ambasht, 1987; Bohara *et al.,* 2019). The C:N ratio was found very high in almost all the species except *M. esculenta*. The species with high C:N ratio like *P. roxburghii* and *P. wallichiana* exhibits the fastest decomposition possibly due to the lignin degrading fungi (Rigobelo and Nahas, 2004) or the factors like temperature and humidity (Aber and Melillo, 1982). Nevertheless, C:N ratios are not always the best markers for modifications in breakdown processes (Ghosh, 2015; Vestgarden, 2001).

5.3. Litter Nutrient Dynamics

P. roxburghii exhibited a rapid and consistent release of all nutrients, indicating a high decomposition rate. Despite of the higher lignin content in the coniferous species like Pinus (Rahman and Tsukamoto, 2013), the presence of lignin degrading fungi in the soil might be the reason behind the faster decomposition (Rigobelo and Nahas, 2004) at the lower elevation. The substantial initial release of N and P is particularly notable, as it supports early plant growth and microbial activity (Gagnon and Zaidi, 2021).

Additionally, *P. wallichiana* and *M. esculenta* displayed a more gradual release pattern, with a slower initial release of K but achieving high levels of nutrient release by the end of the year. This finding contrasts with the findings of Han *et al.,* (2011) where K showed rapid release from initial phase of litter decomposition of *Malus domestica* till the end. The delayed release of K suggests the presence of more complex or tightly bound forms in the litter, requiring longer microbial processing (Laskowski *et al.,* 2011). Thus, *P. wallichiana* may contribute to a steadier nutrient supply, beneficial for maintaining ecosystem stability and long-term fertility as it is not immediately available for the uptake of the plants. (Laskowski *et al.,* 2011).

P. patula exhibited a unique pattern characterized by a slow C release but rapid release of N and P. This disparity indicates a high availability of N and P in the litter. While the slow C release may limit initial microbial growth, it ensures a long-term C input to the soil, thereby contributing to soil organic matter buildup, creating C- equilibrium (Jat *et al.,* 2022). *R. arboreum* demonstrated a rapid initial release of P supporting the study of Bisht *et al.,* (2014), in subalpine forests of Northwest Himalayas. The moderate release of other nutrients suggests a balanced litter composition, supporting sustained microbial activity and gradual nutrient availability (Dong *et al.,* 2022) whereas rapid P release during the initial phase supports early growth of seedlings and saplings (Quested *et al.,* 2007).

Moreover, rapid release of P in the early phase of litter decomposition in R. arboreum suggests that it can play a valuable role in improving P-deficient soils. *Q. lanata* displayed a slow initial nutrient release, suggesting the presence of recalcitrant litter components (Murphy *et al.,* 1998).

The predominant release of P from the leaf litter of most tree species supports the previous findings of Bohara *et al*., (2020) in the Central Himalayas of Nepal and Saha *et al*., (2016) in the Gharwal Himalayas of India. However, a notable exception was observed in *P. patula* and *Q. lanata*, which exhibited the highest release of N at the culmination of the decomposition period. This deviation could potentially be attributed to the inherently elevated initial N content within these species or the influence of soil microarthropods and other decomposer organisms, as suggested by Alfred and O'Sullivan (2001). Furthermore, the quick discharge of N in starting of decomposition for *P. patula* may be a consequence of this phenomenon. Moreover, the positive trend of litter N throughout the decay process and slow N release in the litter of most species aligns with the findings of (Bohara *et al.,* 2020) litter layer being the potential sink of N. However, variable nutrient values throughout breakdown process are also influenced by climatic changes related to the ecological and phenological characteristics of tree species and soil nutrients (Saha *et al.,* 2016). Thus, there was a notable variation of nutrients in the residual litter upon different time intervals which was also seen in the leaf litter decomposition experiment by Singh *et al.,* (2007) in Chattishgarh, India.

Litter decomposition among various trees in the studied ecosystem exhibits a perfect positive correlation between mass loss and the release of essential nutrients. The present findings are found to be contrasting with Bohara *et al.,* (2020) who reported perfect negative correlation with mass loss and nutrient release except for N. This is probably due to the variation in plant traits and other environmental factors such as climate, temperature, moisture, or microbial activities (Bhattarai and Bhatta, 2020; Du *et al.,* 2020)

5.4. Factors Affecting Litter Decomposition

During the first quarter, the decomposition process was highly influenced by environmental factors, particularly temperature and moisture availability. High temperatures and elevated rainfall levels promoted rapid decomposition rates during the first quarter (Archer, 2004; Li *et al.,* 2022), as displayed by the accelerated mass loss for species like *P. roxburghii* and

M. esculenta under such conditions. Conversely, moderate climatic conditions result in relatively lower decomposition rates, potentially attributable to the transition from high to low temperatures and reduced precipitation (Komar, 1998; Adair *et al.,* 2007) during the second quarter.

Low temperatures and limited rainfall during the third quarter may have suppressed microbial activity, leading to an overall deceleration of decomposition rates (Nedwell *et al.,* 1999; Zhuang and Tian, 2023). Interestingly, certain species, such as *P. wallichiana* and *P. patula*, exhibit relatively higher decomposition rates under these conditions, possibly due to specific litter properties or localized microclimatic factors favorably influencing the decomposition process (Archer, 2004). Notably, as temperatures and rainfall levels increase again, decomposition rates generally accelerate, particularly for species like *P. patula* and *R. arboreum*, which respond positively to the improved environmental conditions similar to Singh *et al.,* (2007) who found elevated decomposition rate in different tree species of Chattishgarh, India. This observation also aligns with the findings of Saha *et al*., (2016), who highlighted an acceleration of litter mass loss upon the arrival of monsoon, underscoring the importance of moisture availability in driving decomposition processes.

The high significant negative correlations between litter mass loss and elevation also supports the results of Bohara *et al.,* (2020), indicating that decomposition rates decline substantially as the elevation increases. This pattern suggests that the environmental conditions associated with higher elevations, such as lower temperatures, reduced moisture availability, or altered microbial communities, may impede the breakdown of detrital material (Bohara *et al.,* 2020). Additionally, the strong relation between the initial litter nutrient contents and the ratios of the major nutrients in the litter further suggests that the key nutrients interact to regulate nutrient mobility. This also supports the findings of Bohara *et al.,* (2020) throughout the decomposition process. The positive correlation between soil pH and litter carbon suggests that the litter releases basic alkaline compounds into the soil (Khotimah *et al.,* 2022). However, further study is necessary regarding the soil and nutrient relationship throughout the decomposition period. Additionally, significant correlation between the litter stoichiometry in the present study also aligns with their results. The stoichiometric ratios and nutrient chemistry of litter, in addition to its physical characteristics, have a significant impact on decomposer activity and its prevalence (Taylor

et al., 1989). This is also supported by the observed correlations between litter stoichiometry, litter breakdown, and nutrient composition over the decomposition period.

CHAPTER 6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The research has studied the litter decomposition rate and processes in different tree species in the Bigu Rural Municipality of GCA in Nepal along the elevation gradient. The findings emphasized the critical roles of abiotic components, like temperature and rainfall, along with biotic components like litter chemistry and species-specific traits, in controlling litter decomposition.

The results highlighted that litter from trees at lower altitude decomposes more quickly than the litter from higher elevations. This trend aligns with existing research, attributing the differences to variations in temperature, moisture availability, and microbial activity. However, some species, like *Pinus patula*, exhibited decomposition rates that did not follow the general elevational trend, indicating that intrinsic properties of the litter can sometimes have a stronger influence than environmental conditions. Moreover, the study revealed that deciduous species, such as *M. esculenta*, decomposes faster than evergreen species like *Quercus lanata*.

This supports the idea that leaf characteristics and lifespan have key role in decomposition dynamics. The observed nutrient release pattens were highly dependent on the species, highlighting the complexity of nutrient cycling in forest ecosystems. Significant variations were found in the decomposition rates among species and quarters. *Pinus roxburghii* showed the highest decomposition rate, while *Pinus patula* had the lowest. These findings are important for forest management and conservation strategies, as they provide insights into nutrient turnover and soil fertility in these forest systems. Additionally, it was found that the release and cycling of the major nutrients(C, N, P, K) are highly species-specific and influenced by the litter decomposition rate. Faster decay rates were related to higher nutrient release, which in turn affects soil fertility and forest productivity.

6.2. Recommendation

Based on the results of the present study, the following recommendations are proposed to enhance forest management and conservation practices in the Gaurishankar Conservation Area:

- Future priorities should be given to study species specific decomposition rates and nutrient release patterns of different tree species at the same elevation. This can provide better understanding of decomposition rate and nutrient release.
- Since decomposition rates vary with elevation, management practices should be tailored to the site conditions at each elevation zone to understand the nutrient cycle.
- Tree species with faster rate of litter decomposition like *Myrica esculenta* should be given priority for future plantation activities.
- Future studies should include detail analyses of soil fauna for better understanding their role in litter decomposition and nutrient cycling.
- Long-term monitoring of litter decomposition and nutrient dynamics should be established that can inform adaptive management strategies and policy-making.

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APPENDICES

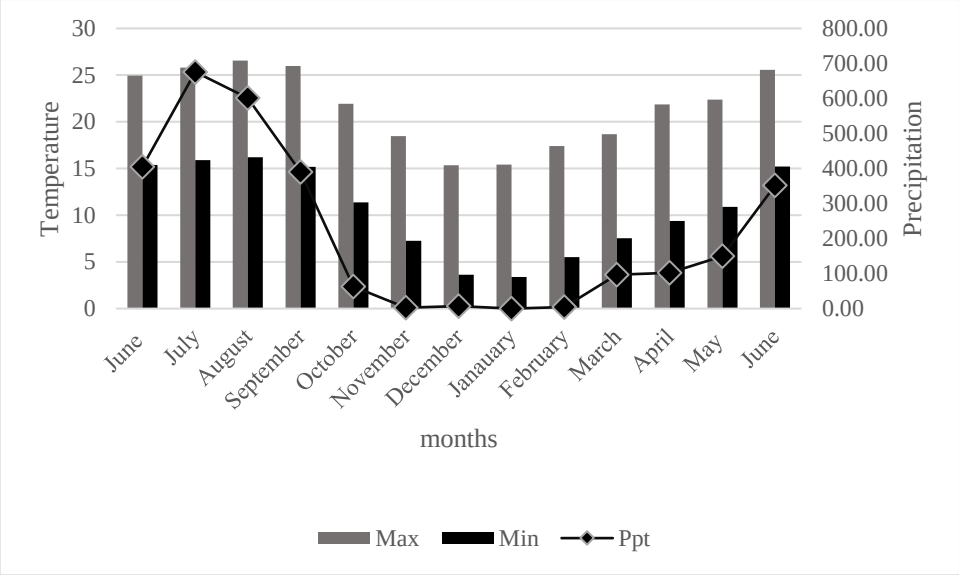

Fig. A1. Temperature and precipitation pattern of the nearest meteorological station (Charikot) for the period (15th June 2022 to 15th June 2023). (Source: Department of Hydrology and Meterology, Kathmandu, Nepal).

Table A1. Remaining litter mass in a year-long *in-situ* litter decomposition study. Values are mean ± standard deviation (n=4), and lowercase alphabets denote significant differences.

Quarters	First	Second	Third	Fourth
P. roxburghii	1.8825 ± 0.0597(a)	1.1250 ± 0.09183(a)	0.7525 ± 0.1508(a)	1.3300 ± 0.05456(a)
P. wallichiana	2.4875 ± 0.0050(c)	2.2525 ± 0.09535(c)	1.5050 ± 0.07506(b)	1.1375 ± 0.10012(b)
P. patula	2.6675 ± 0.01893(d)	2.5175 ± 0.01700(d)	2.3450 ± 0.07724(d)	2.0075 ± 0.14104(e)
R.arboreum	2.3100 ± 0.0946(b)	2.1700 ± 0.08287(c)	1.9900 ± 0.05657(c)	1.8800 ± 0.12124(de)
M. esculenta	2.1825 ± 0.0872(b)	1.8925 ± 0.1059(b)	1.5150 ± 0.1239(b)	1.4500 ± 0.1640(c)
Q. lanata	2.6205 ± 0.0723(cd)	2.4750 ± 0.0057(d)	1.9350 ± 0.07594(c)	1.6325 ± 0.13500(cd)
F	93.33	177.90	124.26	94.96
P- value	<0.001	<0.001	<0.001	<0.001

Table A2. Multiple comparison between the decomposition rate of during the first quarter.

First Quarter			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	*P. roxburghii*	*P. wallichiana*	-.60500*	.04300	.000	-.7417	-.4683
		P. patula	-.78500*	.04300	.000	-.9217	-.6483
		R. arboreum	-.42750*	.04300	.000	-.5642	-.2908
		M. esculenta	-.30000*	.04300	.000	-.4367	-.1633
		Q.lanata	-.72000*	.04300	.000	-.8567	-.5833
	P. wallichiana	*P. roxburghii*	.60500*	.04300	.000	.4683	.7417
		P. patula	-.18000*	.04300	.006	-.3167	-.0433
		R. arboreum	.17750*	.04300	.007	.0408	.3142
		M. esculenta	.30500*	.04300	.000	.1683	.4417
		Q.lanata	-.11500	.04300	.130	-.2517	.0217
	P. patula	*P. roxburghii*	.78500*	.04300	.000	.6483	.9217
		P. wallichiana	.18000*	.04300	.006	.0433	.3167
		R. arboreum	.35750*	.04300	.000	.2208	.4942
		M. esculenta	.48500*	.04300	.000	.3483	.6217
		Q.lanata	.06500	.04300	.662	-.0717	.2017
	R. arboreum	*P. roxburghii*	.42750*	.04300	.000	.2908	.5642
		P. wallichiana	-.17750*	.04300	.007	-.3142	-.0408
		P. patula	-.35750*	.04300	.000	-.4942	-.2208
		M. esculenta	.12750	.04300	.076	-.0092	.2642
		Q.lanata	-.29250*	.04300	.000	-.4292	-.1558
	M. esculenta	*P. roxburghii*	.30000*	.04300	.000	.1633	.4367
		P. wallichiana	-.30500*	.04300	.000	-.4417	-.1683
		P. patula	-.48500*	.04300	.000	-.6217	-.3483
		R. arboreum	-.12750	.04300	.076	-.2642	.0092
		Q.lanata	-.42000*	.04300	.000	-.5567	-.2833
	Q.lanata	*P. roxburghii*	.72000*	.04300	.000	.5833	.8567
		P. wallichiana	.11500	.04300	.130	-.0217	.2517
		P. patula	-.06500	.04300	.662	-.2017	.0717
		R. arboreum	.29250*	.04300	.000	.1558	.4292
		M. esculenta	.42000*	.04300	.000	.2833	.5567

Table A3. Multiple comparisons between the decay rate during the second quarter.

Second Quarter			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	*P. roxburghii*	*P. wallichiana*	-1.12750*	.05473	.000	-1.3014	-.9536
		P. patula	-1.39250*	.05473	.000	-1.5664	-1.2186
		R. arboreum	-1.04500*	.05473	.000	-1.2189	-.8711
		M. esculenta	-.76750*	.05473	.000	-.9414	-.5936
		Q.lanata	-1.35000*	.05473	.000	-1.5239	-1.1761
	P. wallichiana	*P. roxburghii*	1.12750*	.05473	.000	.9536	1.3014
		P. patula	-.26500*	.05473	.002	-.4389	-.0911
		R. arboreum	.08250	.05473	.664	-.0914	.2564
		M. esculenta	.36000*	.05473	.000	.1861	.5339
		Q.lanata	-.22250*	.05473	.008	-.3964	-.0486
	P. patula	*P. roxburghii*	1.39250*	.05473	.000	1.2186	1.5664
		P. wallichiana	.26500*	.05473	.002	.0911	.4389
		R. arboreum	.34750*	.05473	.000	.1736	.5214
		M. esculenta	.62500*	.05473	.000	.4511	.7989
		Q.lanata	.04250	.05473	.968	-.1314	.2164
	R. arboreum	*P. roxburghii*	1.04500*	.05473	.000	.8711	1.2189
		P. wallichiana	-.08250	.05473	.664	-.2564	.0914
		P. patula	-.34750*	.05473	.000	-.5214	-.1736
		M. esculenta	.27750*	.05473	.001	.1036	.4514
		Q.lanata	-.30500*	.05473	.000	-.4789	-.1311
	M. esculenta	*P. roxburghii*	.76750*	.05473	.000	.5936	.9414
		P. wallichiana	-.36000*	.05473	.000	-.5339	-.1861
		P. patula	-.62500*	.05473	.000	-.7989	-.4511
		R. arboreum	-.27750*	.05473	.001	-.4514	-.1036
		Q.lanata	-.58250*	.05473	.000	-.7564	-.4086
	Q.lanata	*P. roxburghii*	1.35000*	.05473	.000	1.1761	1.5239
		P. wallichiana	.22250*	.05473	.008	.0486	.3964
		P. patula	-.04250	.05473	.968	-.2164	.1314
		R. arboreum	.30500*	.05473	.000	.1311	.4789
		M. esculenta	.58250*	.05473	.000	.4086	.7564

Table A4. Multiple comparisons between the decay rate during the third quarter.

Third Quarter			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	*P. roxburghii*	*P. wallichiana*	-.75250*	.06998	.000	-.9749	-.5301
		P. patula	-1.59250*	.06998	.000	-1.8149	-1.3701
		R. arboreum	-1.23750*	.06998	.000	-1.4599	-1.0151
		M. esculenta	-.76250*	.06998	.000	-.9849	-.5401
		Q.lanata	-1.18250*	.06998	.000	-1.4049	-.9601
	P. wallichiana	*P. roxburghii*	.75250*	.06998	.000	.5301	.9749
		P. patula	-.84000*	.06998	.000	-1.0624	-.6176
		R. arboreum	-.48500*	.06998	.000	-.7074	-.2626
		M. esculenta	-.01000	.06998	1.000	-.2324	.2124
		Q.lanata	-.43000*	.06998	.000	-.6524	-.2076
	P. patula	*P. roxburghii*	1.59250*	.06998	.000	1.3701	1.8149
		P. wallichiana	.84000*	.06998	.000	.6176	1.0624
		R. arboreum	.35500*	.06998	.001	.1326	.5774
		M. esculenta	.83000*	.06998	.000	.6076	1.0524
		Q.lanata	.41000*	.06998	.000	.1876	.6324
	R. arboreum	*P. roxburghii*	1.23750*	.06998	.000	1.0151	1.4599
		P. wallichiana	.48500*	.06998	.000	.2626	.7074
		P. patula	-.35500*	.06998	.001	-.5774	-.1326
		M. esculenta	.47500*	.06998	.000	.2526	.6974
		Q.lanata	.05500	.06998	.966	-.1674	.2774
	M. esculenta	*P. roxburghii*	.76250*	.06998	.000	.5401	.9849
		P. wallichiana	.01000	.06998	1.000	-.2124	.2324
		P. patula	-.83000*	.06998	.000	-1.0524	-.6076
		R. arboreum	-.47500*	.06998	.000	-.6974	-.2526
		Q.lanata	-.42000*	.06998	.000	-.6424	-.1976
	Q.lanata	*P. roxburghii*	1.18250*	.06998	.000	.9601	1.4049
		P. wallichiana	.43000*	.06998	.000	.2076	.6524
		P. patula	-.41000*	.06998	.000	-.6324	-.1876
		R. arboreum	-.05500	.06998	.966	-.2774	.1674
		M. esculenta	.42000*	.06998	.000	.1976	.6424

Table A5. Multiple comparisons between the decay rate during the fourth quarter.

Fourth Quarter			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	*P. roxburghii*	*P. wallichiana*	-.80750*	.08748	.000	-1.0855	-.5295
		P. patula	-1.67750*	.08748	.000	-1.9555	-1.3995
		R. arboreum	-1.55500*	.08748	.000	-1.8330	-1.2770
		M. esculenta	-1.12000*	.08748	.000	-1.3980	-.8420
		Q.lanata	-1.30250*	.08748	.000	-1.5805	-1.0245
	P. wallichiana	*P. roxburghii*	.80750*	.08748	.000	.5295	1.0855
		P. patula	-.87000*	.08748	.000	-1.1480	-.5920
		R. arboreum	-.74750*	.08748	.000	-1.0255	-.4695
		M. esculenta	-.31250*	.08748	.023	-.5905	-.0345
		Q.lanata	-.49500*	.08748	.000	-.7730	-.2170
	P. patula	*P. roxburghii*	1.67750*	.08748	.000	1.3995	1.9555
		P. wallichiana	.87000*	.08748	.000	.5920	1.1480
		R. arboreum	.12250	.08748	.726	-.1555	.4005
		M. esculenta	.55750*	.08748	.000	.2795	.8355
		Q.lanata	.37500*	.08748	.005	.0970	.6530
	R. arboreum	*P. roxburghii*	1.55500*	.08748	.000	1.2770	1.8330
		P. wallichiana	.74750*	.08748	.000	.4695	1.0255
		P. patula	-.12250	.08748	.726	-.4005	.1555
		M. esculenta	.43500*	.08748	.001	.1570	.7130
		Q.lanata	.25250	.08748	.088	-.0255	.5305
	M. esculenta	*P. roxburghii*	1.12000*	.08748	.000	.8420	1.3980
		P. wallichiana	.31250*	.08748	.023	.0345	.5905
		P. patula	-.55750*	.08748	.000	-.8355	-.2795
		R. arboreum	-.43500*	.08748	.001	-.7130	-.1570
		Q.lanata	-.18250	.08748	.337	-.4605	.0955
	Q.lanata	*P. roxburghii*	1.30250*	.08748	.000	1.0245	1.5805
		P. wallichiana	.49500*	.08748	.000	.2170	.7730
		P. patula	-.37500*	.08748	.005	-.6530	-.0970
		R. arboreum	-.25250	.08748	.088	-.5305	.0255
		M. esculenta	.18250	.08748	.337	-.0955	.4605

PHOTOPLATES

Photo plate 1.

Photo 1. Experimental site of *Pinus wallichiana*

Photo 2. Extracting litter bags in the experimental site of *Pinus roxburghii*

Photo plate 2.

Photo 3. Freshly fallen litter of *Rhododendron arboreum*

Photo 4. Drying of litter in shade

Photo plate 3

Photo 5. Laying of litter bags

Photo 6. Extracting litter bags

Photo plate 4

Photo 7. Preparing litter bags

Photo 8. Drying soil samples in room temperature

Photo plate 5

Photo 9. Working in the lab

Photo 10. Kjeldahl apparatus for nitrogen estimation