Forest Structure, Carbon Stock and Plant Invasion in Sal and Riverine Forest of Dhangadhi, Western Nepal

A thesis submitted for the Partial Fulfillment of the Requirements for the Master's Degree in Botany

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DECLARATION

I declare that this Dissertation entitled **"Forest Structure, Carbon Stock and Plant Invasion in Sal and Riverine Forest of Dhangadhi, Western Nepal"** which is being submitted to the Department of Botany, Amrit Campus, Institute of Science and Technology, Tribhuvan University, Nepal for the partial fulfillment of the requirement for the Master's degree in Botany is original.

This research work is carried out under the supervision of Mr. Krishna Prasad Sharma, Assistant Professor Department of Botany, Tri-Chandra Multiple Campus. This research is original and has not been published or submitted elsewhere, in whole or in part, for any other degree or professional qualification. Any literature, data, or works created by others and cited in this thesis have been properly acknowledged and listed in the reference section.

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RECOMMENDATION

This is to recommend that the Master's thesis entitled **"Forest Structure, Carbon Stock and Plant Invasion in Sal and Riverine Forest of Dhangadhi, Western Nepal"** is carried out by **"Pooja Bhatta"** 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 fulfillment of Master Degree in Botany.

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LETTER OF APPROVAL

The thesis work entitled **"Forest Structure, Carbon Stock and Plant Invasion in Sal and Riverine Forest of Dhangadhi, Western Nepal"** submitted to Department of Botany, Amrit Campus, Tribhuvan University by **Ms. Pooja Bhatta,** 5-2-554-105-2014 has been accepted for the partial fulfillment of M.Sc. in Botany.

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ABSTRACT

In this study we evaluated the diversity of tree species, regeneration, carbon stock and impact of IAPS in Sal and Riverine forests in Far western Nepal. A total of 40 plots (20 plots in each forest type) of size 20 m x 20 m were laid using systematic sampling method. Transects were drawn perpendicular to the river at a distance of 200 m each. At least four quadrats were placed in each transect. All the plot and vegetation characters were recorded from the sample plots. Tree species richness of riverine forest (25) was significantly higher than that of (16) Sal Forest (p= 0.01152). The regeneration in Sal Forest was better than riverine forest with reverse J shaped d-d curve. Tree carbon stock was also significantly higher (250.40t ha^{-1}) in Sal Forest than Riverine Forest (126.55 t ha^{-1}) (p=0.002957). The invasion of invasive plant was high in Riverine Forest with IAPS richness (7) than in Sal Forest (3). Our study suggests that Sal Forest with high canopy cover has less IAPS richness than Riverine Forest. This suggests that maintaining canopy cover could be the effective strategy to limit the IAPS invasion in forests ecosystem.

Keywords: Carbon stock, Community Forest, IAPS, Regeneration, Tree diversity

शोधसार

यस अध्ययनमा हामीले सुदूरपश्चिम नेपालको साल र नदी तटीय वनमा रूख प्रजातिको विविधता, पुनर्जन्म, कार्बन स्टक र मिचाह प्रजातिको प्रभावको मूल्याङ्कन गर्‍यौं। कूल ४० प्लटहरू (प्रत्येक वनमा २० प्लटहरू) २० मिटर × २० मिटर आकारको व्यवस्थित नमूना विधि प्रयोग गरी राखिएको थियो। प्रत्येक २०० मिटरको दूरीमा नदीको लम्बाइमा ट्रान्जेक्टहरू कोरिएको थियो। प्रत्येक ट्रान्जेक्टमा कम्तिमा चार प्लटहरू राखिएको थियो। नमूना प्लटहरूबाट सबै प्लट र वनस्पतिको विशेषताहरू रेकर्ड गरिएको थियो । नदी तटीय वन (२५) को रूख प्रजातिहरूको विविधता (१६) साल वन (.p= ०.०११५२) भन्दा उल्लेखनीय रूपमा बढी थियो। उल्टो आकारको d-d curve भएको नदी तटीय वन भन्दा साल वनमा पुनर्जन्म राम्रो थियो। रूखको कार्बन स्टक पनि सालजङ्गलमा २५०.४० टन प्रति हेक्टर धेरै बढी थियो र नदी तटीय वन (१२६.५५ टन प्रति हेक्टर ,(p= ०.०००२९५७) कम थियो । मिचाह प्रजातिको सङ्क्रमण साल वनमा भन्दा नदी तटीय वनमा बढी थियो । हाम्रो अध्ययनको सुझाव अनुसार उच्च वन छत्रछायाँ भएको साल जंगलमा नदी तटीय वन भन्दा कम मिचाह प्रजातिको विविधता छ । तसर्थ यो अनुसन्धान को निष्कर्ष वन छत्रछायाँ कायम राख्ने वन पर्यावरणमा मिचाह प्रजातिका सङ्क्रमणलाई सीमित गर्न प्रभावकारी रणनीति हुन सक्छ ।

ACRONYMS AND ABBREVIATION

AGB	Above Ground Biomass
AGC	Above Ground Carbon
Asl	Above Sea Level
BA	Basal Area
BGB	Below Ground Biomass
BGC	Below Ground Carbon
CBFM	Community Based Forest Management
CFs	Community Forests
C-stock	Carbon Stock
DBH	Diameter at Brest Height
d-d	Density-diameter
DFRS	Department of Forest Research and Survey
DHM	Department of Hydrology and Metrology
et al	And others
GIS	Geographic Information System
GPS	Global Positioning System
ha	Hectare
IAPS	Invasive Alien Plant Species
IUCN	International Union for Conservation of Nature
IVI	Importance Value Index
Lm	Linear model
Max	Maximum
Min	Minimum
MPFS	Ministry of Forest and Soil Conservation
ppt	Precipitation
RBA	Relative Basal Area
RD	Relative Density
RF	Relative Frequency
Sp	Species
sq.km	Kilometer Square
T per ha	Tons per hectare

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CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 Forest structure and regeneration

Forests are important reservoirs of terrestrial biodiversity. They have a significant impact on the socioeconomic and cultural characteristics of human communities, as well as the livelihood activities of traditional societies that dwell in these location (Herman, 2006; Baboo *et al.,* 2017). A comprehensive understanding of the diversity, composition, and structure of plant species forms the cornerstone of sustainable management approaches in various forest ecosystems (Gutierrez & Huth, 2012). The plant component more than any other living component of the system determines the structure and function of the forest ecosystem (Richards, 1996). Diversity in plant life is determined by a range of biotic and abiotic parameters (Palit & Chanda, 2012) patterns of species distribution and abundance impact plant diversity at any given site (Rannie, 1986; Huston, 1994). The vegetation diversity of the forest ecosystem is influenced by a region's topography, soil, climate, and geographic position (Ram *et al.*, 2004). It was discovered that tree species have received more attention in plant diversity inventories in tropical forests than many types of life (Mani & Parthasarathy, 2006). The origin of trees is estimated to have occurred more than 300 million years ago, at the time when woodiness started to emerge in many plant families across the taxonomic spectrum (Kenrick & Crane, 1997; Fitzjohn *et al.*, 2014). Assessing tree communities is necessary to determine the condition of tree diversity and the general well-being of forest communities, taking into account variables like distribution, abundance, dominance, and composition (Longman & Jenik, 1987; Puhlick *et al.*, 2012; Sarkar &Devi, 2014). Noticeably, plant as opposed to other living things in the environment, primarily influence the composition and structure of a forest ecosystem (Sarkar & Devi, 2014).

The ecological features of the sites, species diversity, and species regeneration status all have a significant influence on the nature of forest communities (Khumbongmayum *et al.,* 2006). Species diversity is key aspects of forest ecosystem because it acts as a fundamental indicator of the general health of the forest and offers valuable information for the protection of tree species, their habitats and other organisms found therein (Roy *et al.*, 2004, Sharma & Kant 2014). Species diversity is significant metrics for assessing the sustainability and stability of forest communities. For a forest to be managed wisely in terms of its economic value and capacity for regeneration, information on its species composition is crucial (Wyatt-Smith, 1987). In the end, this information may help to preserve biological diversity (Verma *et al.*, 1999). Individual trees play a crucial role in their ecosystems since they serve as the base of the food chain and a foundation for several other species (Beech *et al.*, 2017). Tree diversity is the number and diversity of tree species found in a specific geographic region. Ecologists have created numerous species diversity indices, the two most well-known of which is Simpson's Index (Simpson, 1949) and Shannon-Wiener Index (Shannon & Weaver, 1949).

Forest regeneration is the process of re-growth or reproduction of plants through their juvenile stages. It is crucial for reproduction as well as for guaranteeing repopulation of any community member who pass away after reaching the end of their life cycle (Fatubarin, 1987). A species population structure in a forest can reveal information about its reproductive strategy and regeneration behavior (Singh & Singh,1992).The presence of a sufficient number of seedlings, saplings, and young trees in a given population is indicative of a successful regeneration (Pokhriyal *et al.*, 2010) and the number of seedlings in any species can be regarded as that species capability for regeneration (Negi & Nautiyal, 2005).The methods for analyzing regeneration include counting seedlings and saplings and analyzing size class distribution (Vetaas, 2000; Koirala, 2004).The size class distribution in undisturbed old growth forests with sustainable regeneration is shown to be reversely J-shaped (West *et al.*, 1981; Parker & Peet, 1984). It has been suggested that damaged forests with inconsistent and hindered regeneration exhibit a bell-shaped size class distribution (Parker & Peet, 1984; Saxena *et al.,* 1984).

The most important step towards achieving the long-term sustainability of forest is probably successful regeneration (Saikia & Khan, 2013). The key factors influencing a plant ability to regenerate include its average seed output, seed viability, seed dormancy, seed dissemination, seedling growth, vegetative growth, and reproductive growth. The best conditions for a healthy regeneration are more seedlings and their adequate establishment (Napit, 2015). The biotic and abiotic elements of the forest ecosystem interact to influence the regeneration of a tree species as well as the survival and growth of its seedlings (Khan *et al.*, 1986). Low and unpredictable seed establishment and availability frequently restrict the recruitment of tree seedlings. It is further restricted by the absence of appropriate microsites and factors that influence the growth and mortality of young seedlings (Clark *et al.*, 1999). The micro environmental elements that influence the growth stage of trees and sustain population structure fluctuate with seasonal variation (Rahman *et al.*, 2011).

1.1.2 Forest carbon stock

The amount of carbon dioxide that has been taken up from the atmosphere and is presently stored in a forest environment is referred to as the carbon stock. Less carbon is present in decomposing wood and organic debris on the forest floor, but the majority of this carbon is preserved in soil and living flora (Keith *et al.*, 2009). Presently, the carbon stored in the world's forests and forest soil exceeds one trillion tones, which is double the amount of carbon found in the atmosphere (ISFR, 2015; Mohanta *et al.*, 2020). Forests are acknowledged worldwide as the primary repository for carbon, holding 80% of the carbon that is found on land above ground and 40% of the carbon that is found below ground (Ranabhat *et al.*, 2008). Climate, tree species, and forest management all have an impact on a forest's carbon pool (Aryal *et al.*, 2013).

Forests are thought to be the repository for terrestrial carbon, hence determining their carbon stock is crucial to comprehending their capacity to mitigate climate change (Ghimire *et al.*, 2018). Since forests store 20–100 times more carbon per unit area than croplands, they play a major role in reducing the amount of carbon dioxide in the atmosphere (Brown *et al.*, 1994). There are multiple elements that impact the quantity of carbon sequestered in forests and their capacity to take in carbon dioxide. These factors include the kind of forest, its age, the size and density of its trees, the rate at which organic matter decomposes, climate, topography, health of the forest, previous disturbances and land management practices (Dixon *et al.*, 1994; Zhang *et al.*, 2011; Vayreda *et al.*, 2012). Sal trees offer as an essential ecological advantage by slowing down global warming and climate change by sequestering atmospheric carbon dioxide, in addition to its increased economic worth (Shrestha, 2008). Forests that are productive and well-managed have the capacity to store significant amounts of carbon (Pokharel *et al.*, 2007). A forest's C-stock and biomass often rise as the forest ages (Baker *et al.*, 2004). Numerous studies also demonstrated that as forests aged, their C-stock increased and that they were a significant source of C storage for CFs (Baral *et al.,* 2009; Bhattarai *et al.,* 2012; Pandey *et al.,* 2014; Thapa-Magar & Shrestha, 2015; Mandal *et al.,* 2016; Behera *et al.,* 2017; Dangal *et al.,* 2017).

1.1.3 Plant Invasion

Exotic species that pose a hazard to native species, ecosystems, or habitats are referred to as invasive plants (CBD, 2008). Species with these features typically have vigorous vegetative development, can thrive in harsh environments and generate numerous long-lived seeds (Lee *et al.,* 2018; Mathakutha *et al.*, 2019). The IAPS has the potential to have detrimental effects on a variety of fields, including agriculture, aquaculture, human health and livelihood, biodiversity, ecosystems, and economic losses (Rai & Singh, 2020). Invasive alien plant species (IAPS) can displace native species, decrease biodiversity, alter species composition, and hinder tree regeneration in forests (Belnap *et al.,* 2005; Baret *et al.*, 2008; Minden *et al.*, 2010).

IAPS are more common near road and human disturbances (Kohil *et al.*, 2009). Increases in atmospheric temperature and CO_2 concentrations are anticipated to exacerbate plant invasion because of their versatility and ability to disrupt a wide range of biogeography conditions and ecosystems (Mooney & Hobbs, 2000). IAPS put the economy, the environment, and human wellbeing at risk, according to (Lodge *et al.*, 2006). Additionally, they alter the dynamics of the prevailing vegetation and nutrient cycling, decrease or completely replace native species, and require more funding for agricultural and silviculture operations (Richardson & Higgins, 1998). By releasing nutrients, altering natural disturbance regimes, and increasing susceptibility to invasion, human activity frequently contributes to the disturbance of ecosystems (Davis *et al.*, 2000).

IUCN Nepal designated 21 flowering plant species with self-sustaining populations as invasive in Nepal during initial evaluation of invasive alien plant species (IAPS) in 2002–2003 (Tiwari *et al.*, 2005).26 out of 179 naturalized plant species have been classified as invasive, indicating that the problem of plant invasions in Nepal is getting worse (Shrestha, 2019). Notably, species that disturb Nepal's forests and shrublands include *Ageratina adenophora, Chromolaena odorata, Mikania micrantha, Lantana camara, and Hyptis suaveolens* (Tiwari *et al.,* 2005*). L. camara, M. micrantha, C. odorata, and Eichhornia crassipes* are among the most harmful invasive plants globally. Western Nepal has less invasive alien plant species than central and eastern Nepal (Shrestha *et al.*, 2017).

The diverse range of climates in Nepal, spanning from tropical to alpine, makes it easier for introduced plant species from different bioclimatic zones to adapt (Shrestha *et al.,* 2019).

In this study we compare Forest structure, carbon stock and plant invasion in Sal and Riverine Forest of Dhangadhi, Western Nepal.

1.2 Justification

Community forests in Nepal are currently essential to manage and safeguard natural resources (Thapa-Magar & Shrestha, 2015). The protection of forest diversity, the storage of carbon, and the lessening of the effects of climate change have all been significantly aided by these community forests in Nepal. In addition for having a favourable impact on carbon stocks and carbon sequestration in the forest, CBFM has shown dramatic slow down the rates of deforestation and forest degradation (Nagendra *et al.,*2008). The consequences of climate change may therefore be lessened by reducing the rates of deforestation and forest degradation through community forest management.

According to Sapkota *et al.*, (2009) & Khumbongmayum *et al.,* (2006), there is a low regeneration state of Sal in Nepal as a result of a number of reasons, including logging, burning of grasses, animal grazing, lopping, and forest fires. The community forest user group has an obligation to improve the forest's sustainability and quality ever since the forest was turned over to them. Invasive plant species are a major cause of biodiversity loss. They contribute to the extinction of native species and pose a significant threat to their diversity and prevalence. Prior to managing and controlling invasive species, it is critical to understand their occurrence and dispersion. In Nepal, most IAPS are prominent in the tropical and subtropical regions (Shrestha, 2019). Numerous studies have been conducted in various parts of Nepal on the influence of plant variety, carbon stock, regeneration and impact of IAPS in CFs. However, little studies have been conducted on the influence of plant diversity, carbon stock, regeneration and impact of IAPS on Sal and Riverine forests. Consequently, the community-managed Sal Forest could be crucial to the preservation of biodiversity, improvement of sustainability and quality, and increase of the forest's carbon store. So this study was carried out in two community forests of Dhangadhi with distinct forest types to examine their tree diversity, carbon stock, regeneration status and impact of IAPS. The research's findings will be useful in planning and implementing forest management and conservation efforts.

1.3 Research Questions

i) What is the vascular plant diversity in the Riverine and Sal Forests ?

ii) What is the population structure and regeneration status of tree species in these Forests?

iii) What is the status of carbon stock in these Forests?

iv) What are the impacts of IAPS on tree diversity and regeneration in these Forests?

1.4 Objectives

The general objective of this study was to assess the diversity of plants, the carbon stock and plant invasion in Riverine and Sal forests of Dhangadhi, Western Nepal and the specific objectives were:

i) To determine the tree diversity indices and IVI of two community forest.

ii) To compare the population structure and regeneration status of trees on two community forests.

iii) To compare the carbon stock of two community forests.

iv) To compare the impact of IAPS on plant diversity and regeneration on different forests.

v) To analyze the soil characteristics and compare its role on different forest types.

1.5 Limitations of the Study

i) Only 20 plots in each type of forest were sampled regardless of the size of forest.

ii) Canopy cover was estimated by using visual method.

iii) Important value Index, Diversity Indices and carbon stock were calculated only for tree species.

iv) Only soil pH, moisture and temperature were measuresd.

CHAPTER 2: LITERATURE REVIEW

2.1 Forest Structure and Diversity

The nature of forests can be understood by examining their composition, function, and structure. Forests are dynamic ecosystems that change over time and location (Franklin *et al.*, 1981). According to Myers *et al.*, (2000), it is acknowledged as the biggest terrestrial ecosystem and is distinguished from other ecosystems by its exceptional biodiversity. Ecological systems depend heavily on the diversity patterns, composition, and community structure of a forest (Gairola *et al.*, 2008; Ahmad *et al.,* 2010). The variety of tree species in the forest assumes paramount importance because it provides almost all of the forest's resources and habitat for almost all living things in the forest (Jimoh & Lawal, 2016).

In the Western Tarai of Nepal, Timilsina *et al.,* (2007) found 131 plant species, including 28 trees, 10 shrubs, 6 climbers, and 87 herbs. Of these, *Shorea robusta* was the most dominant tree species. Acharya (2011) found 125 plant species from 55 families, including 36 tree species, 50 shrub species, and 39 herb species from the SE and SW slope, during a study in the Parroha community forest in the Rupandehi District. *S. robusta* was the most densely populated tree at both SE and SW slope followed by *Terminalia alata*. Based on IVI *S. robusta* (127.20) was the most dominant tree species in SW slope while *T. alata* (93.12) in SE slope. Similarly, Gachhadar (2023) carried out an investigation along elevation gradients in the Morang district, Eastern Nepal finding 315 plant species in five forests (Bhaunne, Raja-Rani, Murchungi, Sagma & Adheri) representing 82 families and 255 genera, with *S. robusta* being the dominant tree having highest importance value index (134.78) in Adheri community forest.

Giri *et al.*, (2001) conducted a study in the Western sector of the Royal Bardia National Park, where they identified a total of 27 tree species in the deciduous riverine forest. Among these species, *Senegalia catechu* was found to be the most dominant, with an IVI of 118.24 followed by *Dalbergia sissoo* with an IVI 46.30. This high IVI value indicates that *S. catechu* plays a significant ecological role in the structure and function of these forests. The dominance of *S. catechu* is attributed to its adaptation to seasonal flooding and its ability to thrive in well-drained, alluvial soils.

Sanyam and Vipasha (2018) conducted research on subtropical zone of Himanchal pradesh and revealed that *S.robusta* was the dominant tree species in Dry Shiwalik Sal forest while in Northern Dry mixed Deciduous forest, Dry Deciduous Scrub forest and Dry riverine forest the dominant tree species was *S. catechu* with the IVI values 26.09, 40.40 and 45.70 respectively.

2.2 Forest Regeneration

For a species to persist in a community under a variety of environmental circumstances, regeneration is an essential process. Regeneration is an essential component of forest management, as it keeps the intended species composition and stocking in place following a variety of disturbances (Khumbongmayum *et al.*, 2005). *Shorea robusta* has a large population of seedlings in natural forests, but they do not mature in sufficient numbers to reach the juvenile and young stage (Shankar, 2001).

Regeneration status is an essential indicator in forest ecology since it describes the future composition of a community and is heavily influenced by factors such as grazing, disturbances, soil (edaphic), seed, and biotic condition (Mishra *et al.*, 2021). However, the majority of these features remain more or less consistent within a narrow area of a forest (Tyagi *et al.*, 2011).

In the Tarai Sal Forest of Bardiya National Park, (Giri *et al.,* 1999) found that the Sal plant had a greater seedling density of 11185 pl ha^{-1} and a sapling density of 321 pl ha^{-1} than other related species. Bashyal (2005) recorded 1375 pl ha^{-1}seedling and 562.5 pl ha^{-1} sapling for 209.37 pl ha^{-1} *S. robusta* trees within the tropical forest of the Palpa district. Kandel (2007) also observed a similar tendency towards higher Sal density in the community-managed Inner Terai woods, which are dominated by Sal trees in central Nepal. The density of Sal seedlings was found at 43000 pl ha^{-1} and the density of saplings at 2974 pl ha^{-1}.

In the Ganesh and Ramnagar CFs, there are an estimated 8591 ± 288 and 25000 ± 1663 seedlings per acre, respectively, according to (Joshi *et al.*, 2021). A similar finding revealed that Ramnagar CF had an overall higher number of saplings than Ganesh CF, accounting for 92841 saplings and 38111 in ha^{-1}, which included 15 seedlings and 17 saplings from the community-managed Sal Forest of Kanchanpur's district. As to the findings of (Sharma *et al.,* 2020) investigation on the regeneration state of a community-managed hill Sal Forest in

Baglung district, Sal was the predominant species, and Dipterocarpaceae was the dominant family.

Numerous studies carried out in Nepal have revealed that Sal has a better rate of regeneration in Sal forests than other similar species (Bhatta, 2016). Research in the Hollongapar Gibbon Wildlife Sanctuary in Assam, northeast India, by Sarkar and Devi (2014) revealed that 24% of species had a "good" regeneration quality and 36% had a "fair" regeneration condition, with a reverse J-shaped pattern. This offers important information for forest management and species protection efforts in the sanctuary, as well as pointing to a robust and sustainable future community.

2.3 Forest Carbon Stock

In the previous studies, (Dixon *et al.,* 1994; Pan *et al.,* 2011) found that the transfer of carbon from the ground to the atmosphere and retain 60% of the terrestrial carbon in the world's soil and floras, Sedjo (2001) and Luyssaert *et al.*, (2008) stated that forests get older, have more trees per unit area, and a higher biomass and carbon store. Carbon sequestration occured more quickly in young, regenerative forests, although carbon was stored higher in older, mature forests Luyssaert *et al.*, (2008). The composition of the carbon stock in forests was influenced by a number of variables, such as the kind of forest, age of the stand, degree of disturbance, and plant species(Brown *et al.,* 1989 ; Dixon *et al.*, 1994). According to Kaul *et al.*, (2010) forest's carbon storage varied regularly due to plant growth, ageing, and decomposition. This research had reported differing levels of carbon store in different Sal forests in Nepal, which are managed by different populations for different objectives.

Bhatta & Devkota (2020) evaluated the carbon stock in Dadeldhura district who separated the forests into two groups according to the duration of management (11 to 20 years). The living biomass of the studied forests had an average carbon stock ranging from 148 to 202 t ha^{-1}. The forests that had been maintained for about 20 years had a higher carbon stock than the forests that had been managed for approximately 11 years (199 t ha^{-1}). They found that community forests under longer-term management have higher carbon reserves than those under shorter-term management.

The total carbon stock was measured at 479.29 t ha^{-1} and 234.54 t ha^{-1}, respectively, in two community Sal forests in Chitwan (tarai) and Gorkha (Hills). It was found that the biomass carbon stock density in the Tarai region was greater (384.20 t ha^{-1}) compared to that of the Hills region (123.15 t ha^{-1}) (Pandey & Bhusal, 2016).

Gairhe (2015) examined the tree carbon stock of two Sal forests under community management in the Tanahun District of central Nepal. He discovered that the tree carbon stock of Taldanda CF was 109.82 t ha^{-1}, while the tree carbon stock of Fulbari CF was just 71.11 t ha^{-1}. According to his findings, disturbance levels had minimal effect on total tree carbon and tree diversity, but carbon retention increases biodiversity. The possibility for storing carbon was examined by Joshi *et al.,* (2021) in the tropical Sal (forest located in the Kanchanpur district of Nepal. A larger carbon stock existed in Ramnagar CF than in Ganesh CF because of the presence of huge trees with greater biomass values. In Ramnagar CF*, S. robusta* supplied the most to the carbon stock, with contributions of 143.10 t ha^{-1} (87.73%) and 38.45 t ha^{-1} (50.17%), respectively.

Joshi (2020) conducted research in two community forests in Dhangadhi, Nepal discovered that moist woods had higher carbon stocks than dry forests. Research on the biomass and carbon stock of the Hill Sal Forest, which has been managed for more than 20 years, was done by Thapa Magar & Shrestha (2015) were notably greater than in the woods under management for less than 20 years. They proposed that community forests have been functioning as a sink of atmospheric CO_2 because local management has a favourable impact on the woods' carbon pool (Gaudel *et al.,* 2016) in Parsa Wildlife Reserve Found that above ground tree biomass (AGTB) was found higher in low invasion area (192.22±48.18 t ha^{-1}) followed by medium severity (161.21±32.15 t ha^{-1}) and low (85.35±15.33 t ha^{-1}) in higher severity area.

2.4 Biological Invasion in Nepal

Nepal has a diverse geography and climate, which contributes to its abundant biodiversity. The diverse environmental circumstances, from tropical to alpine, support the growth of introduced plant species from various bioclimatic areas (Shrestha *et al.*, 2018). Conversely, Nepal has at least 219 alien flowering plant species (Tiwari *et al.,* 2005; Siwakoti, 2016) and 64 animal species that have naturalized (Budha, 2015).

In 2002-2003, the IUCN undertook the first assessment of invasive alien plant species (IAPS) in Nepal, categorizing 21 naturally occurring flowering plant species as invasive (Tiwari *et al.*, 2005). Later, more species were discovered, bringing the total to 27 problematic invasive alien plant species in Nepal (Shrestha *et al.*, 2022). Nepal's flora contains 0.5% species from 14 families and 24 genera, with Asteraceae being the most varied family. This scenario confirms that the invasion of IAPS in Nepal has been increased in recent years.

Plant invasions are becoming more prevalent in Nepal, with 26 of 179 naturalized plant species categorized as invasive (Shrestha *et al.*, 2017). Certain IAPS, such as *A.adenophora, C.odorata, M. micrantha, L. camara,* and *Hyptis suaveolens,* are highly damaging to forests and shrublands (Tiwari *et al.*, 2005). Four of the 27 invasive species - *L. camara*, *Eichhornia crassipes*, *M.micrantha and C. odorata* are among the top 100 worst invasive species in the world (Shrestha *et al.*, 2022). These IAPS offer serious dangers because of their fast expansion, competitiveness, and capacity to colonise new areas quickly. Nepal's native biodiversity has been threatened by increasing population demand, over-reliance on natural resources, uncontrolled or unplanned urbanisation, and land use practices (Singh & Sharma, 2014).

The existence of IAPS poses a significant threat to Nepal's protected regions, particularly in the lowlands. *C. odorata, M. micrantha, L. camara, Ipomoea carnea* and *Parthenium hysterophorus* are among the most abundant and problematic species found in national parks and wildlife reserves. These invasive plants disturb a variety of habitats, including the Sal Forest in the Terai region (Bhuju *et al.*, 2013).

Chaudhary *et al.*, (2020) recorded 14 IAPS in the Parsa National Park. Pathak *et al.*, (2021) recorded 20 IAPS from Pokhara valley, i.e. 77% of the total number of IAPS reported from Nepal. Singh & Sharma (2014) collected fifty-five species which are invasive and alien. A total of 190 invasive alien species under 112 genera, belonging to 47 families have been recorded (Sekar, 2012). A total number of 125 invasive alien species under 83 genera, belonging to 39 families have been recorded based on field observations, herbarium and literature consultation (Sekar *et al.*, 2015).

Based on the aforesaid literature analysis, various studies on regeneration and plant invasion have been conducted in the Sal Forest and National Park areas. There has been no research into this issue in riverine forests. Furthermore, a comparative research of forest structure, regeneration, and plant invasion between two forest types has not been conducted. This study will be a comparative analysis of the Sal and Riverine forests. This will help to determine the forest's current ecological health, which is critical for biodiversity protection.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location and Geomorphology

The study area is situated in Dhangadhi sub metropolitan city Sudurpashchim province, Far Western Nepal. The Dhangadhi covers an area of 261.75 square km and expands between 28° 68' 52" N latitude and 80° 62' 16" E longitude. It is placed at an altitude of 180m above sea level and climatic zone is tropic.

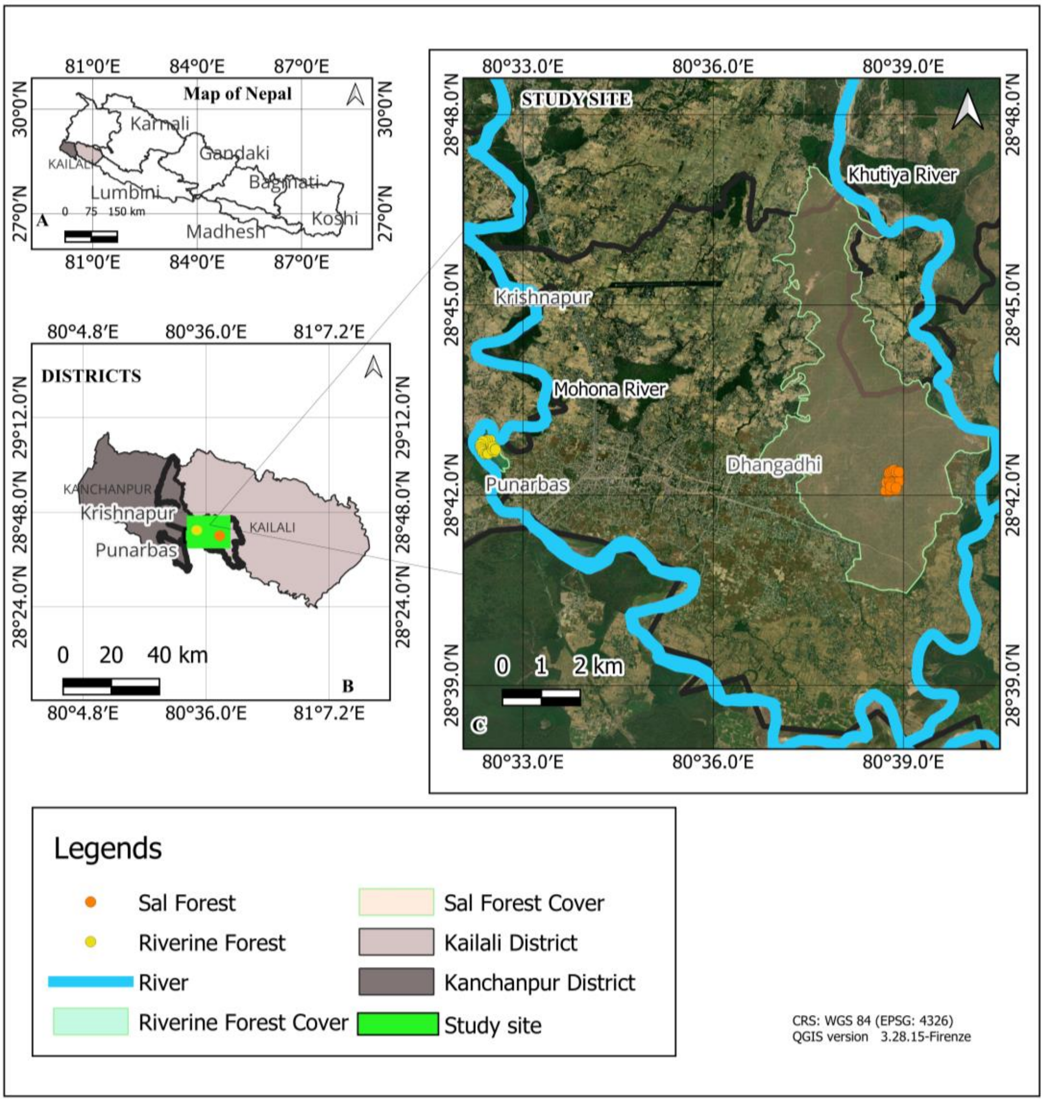
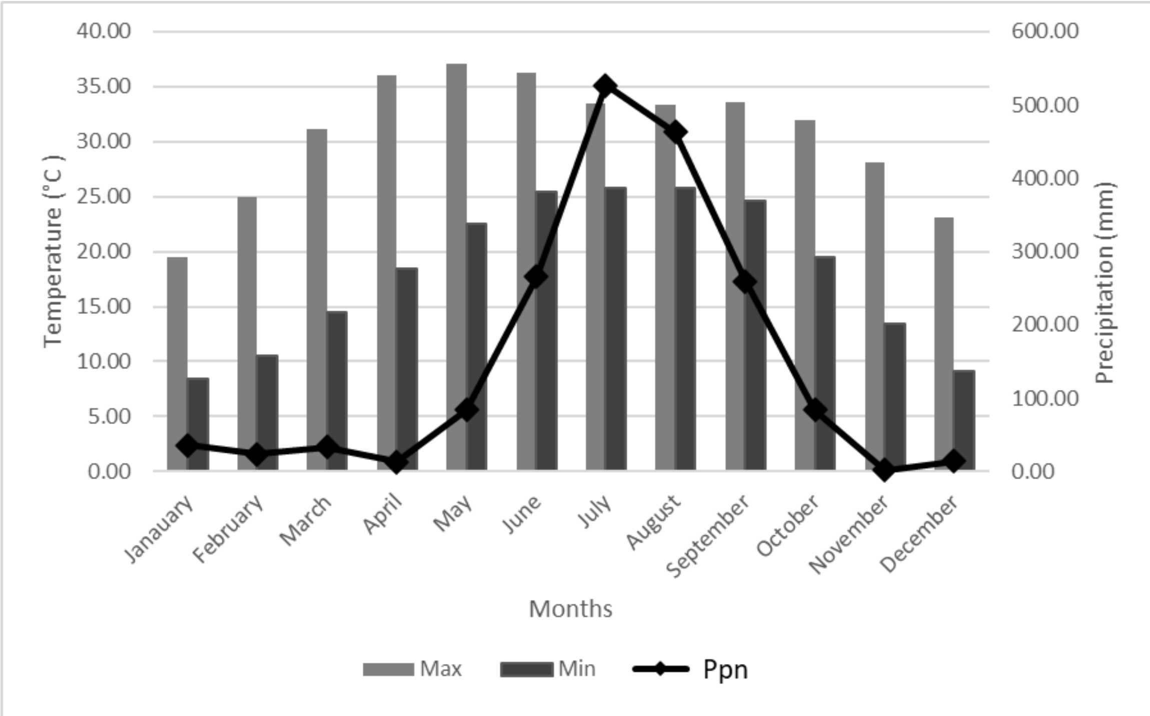


Figure 1: Map of study area showing, (A. Map of Nepal, B. Kailali District, C.Adarsh Community Forest, Deoria Community Forest

There are 316 community forest within the division forest office of Dhangadhi, Kailali that were manually managed and hand over to the community (DFO, 2021/2022). The study was conducted in Deoria community forest and Adarsh community forest. The Deoria community forest was hand over to the community in 2003 A.D. Deoria community forest is divided into 7 block to prevent forest from fire during summer season. It covers a total area of 256.52 ha. The study was carried out in Block 4 which covers an area of 44.77 ha and 936 people take membership of this community forest. Similarly, Adarsh community forest was hand over to the community forest in 2002 A.D. It covers an area of 43.8 ha.

3.2 Climate

The study area is located in the western region of the tarai, within the tropical climatic zone. The climate is very warm in summer and very cold in winter whereas rainfall is high in summer and very low in winter. Temperature and precipitation data for the study area's nearest station, Attariya, were collected from the Department of Hydrology and Metrology in Kathmandu, Nepal, for an 11-year period (2013-2023).The collected data was used to calculate the monthly average maximum temperature, minimum temperature, and precipitation. The results showed that the average maximum temperature reached 36.03°C in April while the average minimum temperature was 8.37°C in January. The highest average monthly rainfall occurred in July, with 526.88mm. In November, however, the average monthly rainfall was only 5.61mm (Figure 2).



(Source: Department of Hydrology and Meteorology, Government of Nepal, 2024)

Figure 2: Eleven-year (2013-2023) average monthly maximum (Tmax) and minimum (Tmin) temperature and precipitation recorded at Attariya station

3.3 Vegetation

Tropical vegetation predominants in the study area with *Shorea robusta* in Deoria community forest. Other common associated species were *Terminalia alata, Semecarpus anacardium, Holarrhena pubescens, Syzgium cumini, Garuga pinnata, Careya arborea, Aegle marmelos, Lagerstroemia parviflora*. In Adarsh Community Forest (Riverine Forest) *Senegalia catechu* is the dominant tree. Other common associated species were *Adina cordifolia, Dalbergia sissoo*, *Bombax cebia, Melia azedarach, Mallotus philippensis, Trewia nudiflora, Albizia lebbeck, Syzgium cumini, Tectona grandis, Dalbergia latifolia, Phyllanthus emblica, Syzgium nervosum.*

3.4 Vegetation Sampling

In October 2023 vegetation sampling was done by using systematic sampling method. In five transects at least 4 plots in both riverine and Sal Forest were laid. There were 20 plots in each forest types totaling 40 sample plots of size 20m × 20m. Quadrats measuring 5m × 5m were employed for the shrubs and saplings inside the main plot. Furthermore two, 1m × 1m subplot were set up within each main plot for seedlings and herbaceous plants. Individuals belonging to different kinds of trees were categorized into three growth stages: trees (> 5 cm DBH), saplings (1–5 cm DBH and > 1 m height) and seedlings (< 1 m height) (Timilsina *et al.*, 2007). The geographic coordinates and altitude of the study region were measured using a GPS tracker device. A clinometer was used to assess the angle between the top of the tree and the head of a person holding a clinometer, which was then used to compute the height of the tree using the trigonometry tangent formula. To measure diameter of trees the measurement were taken at 1.37 cm above the ground. During the analysis, Quadrats with invasive alien plant species (IAPS) coverage greater than 10% were classed as invaded indicating a higher occurrence of non-native plant species. Quadrats having less than 10% IAPS coverage were classified as non-invaded quadrats, indicating a reduced predominance of non-native plants. The total number of IAPS, as well as their1 number and coverage in each quadrat, were recorded.

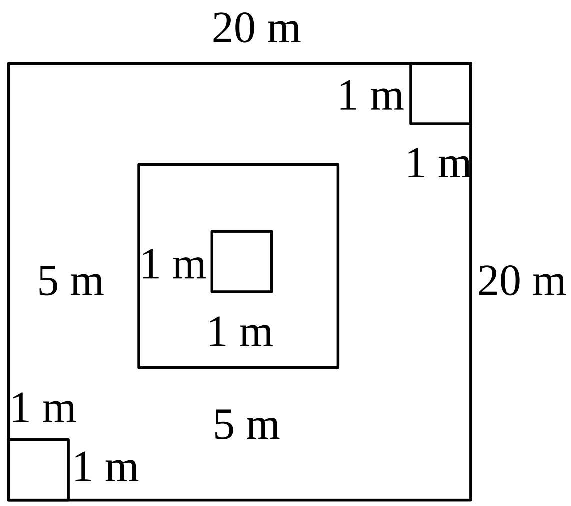


Figure: 3: Outline of vegetation sample plot

3.5 Forest Community Structure

To know the community structure, community characters including density, frequency, relative density, relative frequency, Importance value Index (IVI) were computed in accordance with Zobel *et al.*, (1987).

Frequency: Frequency is the degree to which a species is dispersed within a community. It is the proportion of sample units that are found in a particular area and are home to a particular species. It was computed by using following formula.

$$\textbf{Frequency (F\%)} = \frac{\text{No.of quadrat in which species occured}}{\text{Total no of quadrat studied}} \times 100$$

Relative frequency: The degree of dispersion of a specific species in a given region relative to the total number of species present is known as relative frequency, and it was calculated using the following formula

$$\textbf{Relative frequency (RF\%)} = \frac{\text{Frequency of individual species}}{\text{Total frequency of all species}} \times 100$$

Density is defined as the number of individuals per unit area. It displays the species dominance in terms of numbers within the community. Density was calculated using the following formula:

$$\textbf{Density (D pl ha}^{-1}\textbf{)} = \frac{\text{Total number of individual of a species in all plots}}{\text{Total number of plot studied} \times \text{size of plot} (m^2)} \times 1000$$

Relative density is the study of a species population size in relation to the total number of individuals in all species. It was calculated as:

$$\textbf{Relative density (RD\%)} = \frac{\text{Density of individual species}}{\text{Total density of all species}} \times 100$$

Coverage= Visual estimation

Relative coverage is the cover of particular species or life forms as a percentage of total plant cover. It was calculated as:

$$\textbf{Relative coverage (RC \%)} = \frac{\text{Coverage of individual species}}{\text{Total coverage of all species}} \times 100$$

The basal area of a species in each sample plot was determined by adding the BAs of all the individuals in that species. The formula for converting BA to a percentage was as follows:

$$\textbf{Basal area (BA)} = \pi \times \frac{d^2}{4}$$

Where,

d = DBH (diameter at breast height)

$\pi = 3.1416$

$$\textbf{Basal area of a species (m}^2\textbf{ /ha)} = \frac{\text{Total basal area of a species}}{\text{size of plot} (m^2)} \times 1000$$

The basal area of a certain tree species multiplied by the total basal area of all tree species yields the relative basal area.

$$\textbf{Relative basal area (RBA \%)} = \frac{\text{Basal area of individual species}}{\text{Total basal area of all species}} \times 100$$

The important value index (IVI) is used to assess each species' overall significance within the community structure. The formula below was used to determine IVI.

Important value index (IVI) = RD + RF + RBA

Species Diversity Index (H')

Measures of species diversity are commonly determined using the Shannon index. A formula used to calculate it.

$H' = -\Sigma$ Pi ln Pi

Where,

H' = Species Diversity Index

Pi = Proportion of the species

Pi = ni / N

N = Total number of species

ni = Number of individual of each species

Index of Dominance

The dominance index is calculated using Simpson's index of dominance, a metric that evaluates variances in diversity. Put more simply, it aids in determining the degree to which a certain species is distinct from or dominating in a specific habitat.

Simpson's Index of dominance (D) = $1 - [\Sigma n\,(n-1)/N(N-1)]$

Where,

n =No. of individual of a species

N= Total no. of individual of all species

3.6 Estimation of Biomass and Carbon Stock of a Trees

Estimation of above and Below Ground Biomass

In order to determine the above-ground biomass and carbon stock of the forest, one of the key values needed was the measurement of DBH in the field. The global wood density database was used to calculate the wood density of the trees that were sampled (Zanne *et al.*, 2009). Aboveground biomass (AGB) comprised the biomass of the individual plant's bole, branches, and leaves. The above ground tree biomass was estimated using the formula for damp forest stands established by Chave *et al.,* (2005).

The equation was:

$$AGTB = 0.0509 \times \varrho D^2 H$$

Where,

AGTB = above ground tree biomass (kg)

ϱ = specific wood density (g/cm^3)

D = tree diameter at breast height (cm)

H = height of tree (m)

$$AGC = AGB \times 0.47$$

Where 47% carbon is assumed to be stocked in the above ground parts of the trees (Chave *et al.,* 2005).

Estimation of below ground biomass

All biomass found in subterranean portions is included in the below-ground biomass. The biomass of bole was multiplied by the default factor of 0.15 to determine the below-ground biomass (Tamrakar, 2000).

Mathematically,

$$BGC = AGC \times 0.2$$

Where 20% of carbon is assumed to be allocated in the below ground parts of the trees (Chave *et al.,* 2005).

The Total carbon stock of the forest was determined by summing of the below ground carbon stock and the above ground carbon stock.

3.7 Soil Sampling and Analysis

About 500 g soil was taken from each quadrat from the depth up to 15 cm and placed in zip-lock polythene bags after being thoroughly mixed. After air drying, the soil was brought to the laboratory for further examination. Soil pH were measured using digital pH meter. As instructed by Soil Survey personnel (2014), the pH of the soil was determined using a pH meter. To get consistent readings, 10g of air-dried soil and 10 ml of distilled water (1:1) were combined. Three replicates of each sample were used to record the pH. Moisture content of the soil was also calculated. In order to determine the moisture content of the soil, the soil was first oven dried for 48 hours, followed by 24 hours for the second and third phases to obtain a consistent weight. Using a alcohol thermometer, the temperature of the soil was measured in the field.

Calculation,

Initial wt. of the soil (W_i) = Moist soil weight

Final wt. of soil (W_f) = Dry soil weight

$$\text{Soil water content } (W_s) = \frac{\text{Initial wt.of soil } (W_i) - \text{Final wt.of soil } (W_f)}{\text{Final wt of soil } (W_f)} \times 100\%$$

$$\text{Soil moisture } (\%) = \frac{\text{Sum of soil moisture of each plot}}{\text{Total number of plot studied}}$$

3.8 Regeneration Analysis

Regeneration status of species was determined based on population size of seedlings and saplings (Khan *et al.*, 1987).

i) Good regeneration if seedlings > saplings >adults;

ii) Fair regeneration if seedlings > or < saplings < adults;.

iii) Poor regeneration if the species survives only in sapling stage, but no seedlings (saplings) may be <,> or = adults).

iv) No regeneration if a species is present only in adult form.

v) New regeneration if species has no adults but only in seedlings or saplings.

3.9 Plant Identification

During field sampling, the most of the plants were identified using their local names with the assistance of local specialists and field members of certain CFs. Unidentified species were collected, tagged and pressed with the help of newspaper and herbarium presser in the field. These species were then identified by consulting with teachers and with the aid of the book "Plant Resources of Kailali, West Nepal" (DPR, 2016). Herbarium specimens were kept in ASCOL herbarium, Kathmandu, Nepal. For author citation, Plants of Nepal (Gymnosperms & Angiosperms) was used (Shrestha *et al.*, 2022).

3.10 Statistical Analysis

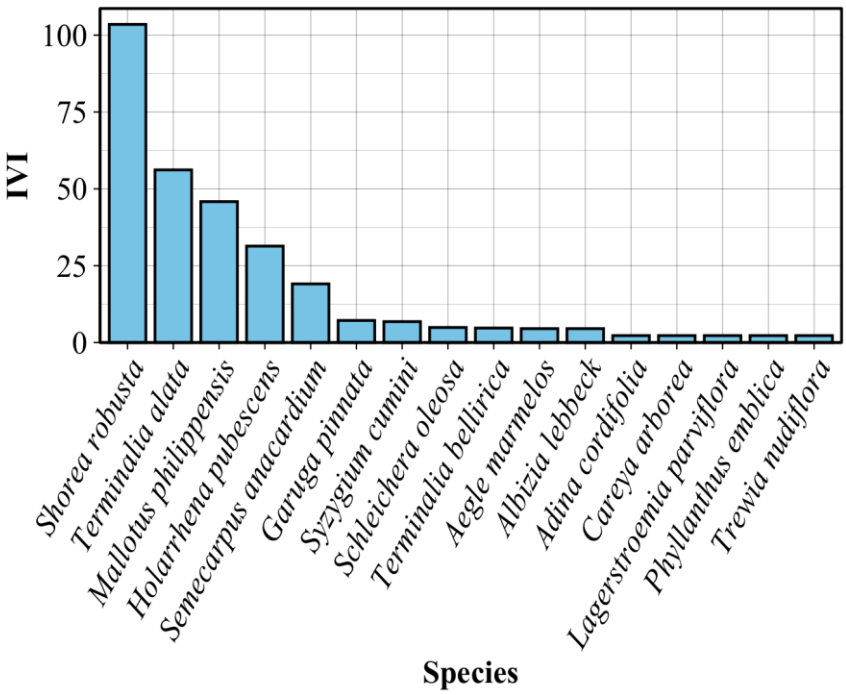
Species richness, population proportion of distinct life forms (seedling, sapling, and tree) and soil variables (moisture, temperature, and pH) were compared across two forest types using an independent sample t-test (student t-test). Before analysis, the data were tested for normality. The normality of residuals was assessed to ensure the validity of linear regression assumptions. Residuals were extracted from the fitted linear regression models using the residuals () function in R studio. The Shapiro-Wilk test was conducted to statistically evaluate the normality of residuals, with p-value greater than 0.05 indicating no significant depature from normality. Additionally, Q-Q plots qqnorm() and qqline() were generated to visually inspect the alignment of residuals with the theoretical normal distribution, and histograms of residuals were plotted to detect any apparent deviations. Linear regression analysis was used to determine whether seedling and sapling density were related to tree basal area. Similarly, linear regression was used to investigate the association between invasive species density, seedling, sapling, ground vegetation, and soil pH. To determine the significance level, a t-test was performed between seedling and sapling density and tree basal area, as well as between invasive species density, coverage with seedling, sapling, ground vegetation, and soil pH. The Pearson correlation coefficient was used to demonstrate the relationship between various parameters in the forest. All data obtained were maintained in Microsoft Excel 2013. In this study, R Studio (version 2023.12.1 + 402) was used to perform data analysis, including linear regression, correlation, bar graph, t-tests, scatter plots and a correlation matrix. Linear regression was conducted using the lm () function, while the Pearson correlation and correlation were computed with cor () and visualized using the corr plot package. Bar graphs and scatter plots were created with the ggplot2 package using geom_bar () and geom _ point respectively. T-tests were performed with the t test () function from base R.

CHAPTER 4: RESULTS

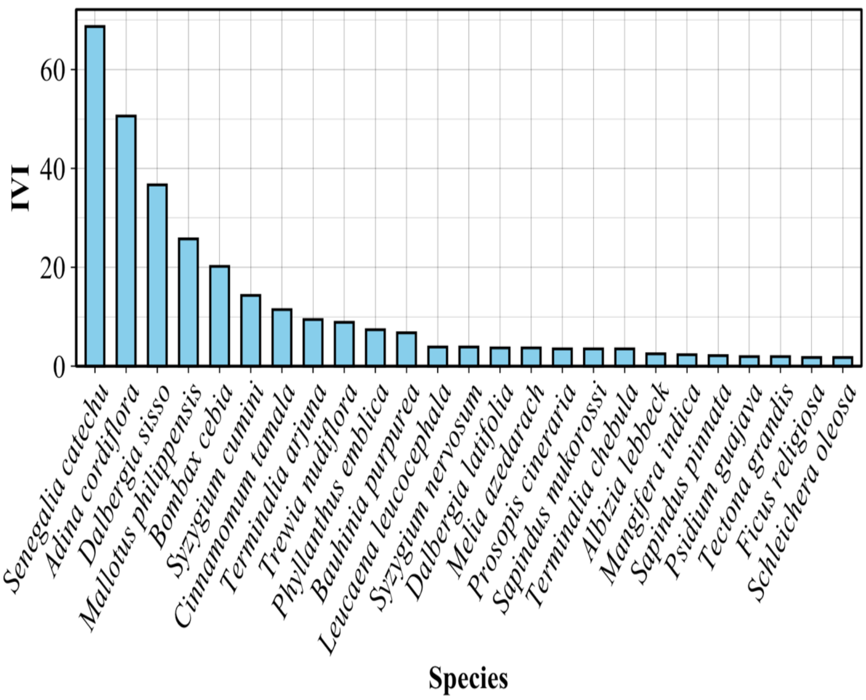
4.1 Forest Compositions and Diversity

Altogether 81 Species (25 herbs, 13 Shrubs, 35 trees, 4 climbers, 4 ferns) of vascular plants were reported from the study forests. In Riverine Forest 25 species of trees belonging to 13 families were found. Based on IVI the most dominant species was *Senegalia catechu* (68.70) followed by *Adina cordifolia (50.59)* and *Dalbergia sissoo* (36.67). Similarly, the least dominant species was *Tectona grandis* and *Pisidium guajava (*1.93) followed by *Ficus religiosa* and *Schleichera oleosa* (1.74) (Figure 4, Appendix V).

In case of Sal Forest 16 species of trees belonging to 13 families were reported. The most dominant species was *Shorea robusta* (103.49) based on IVI followed by *Terminalia alata* (56.15) and *Mallotus philippensis* (45.84). Likewise, the least dominant species was *Aegle marmelos* and *Albizia leebeck* (4.53) followed by *Phyllanthus emblica, Trewia nudiflora* (2.26). (Figure 4, Appendix, V).



(a)



(b)

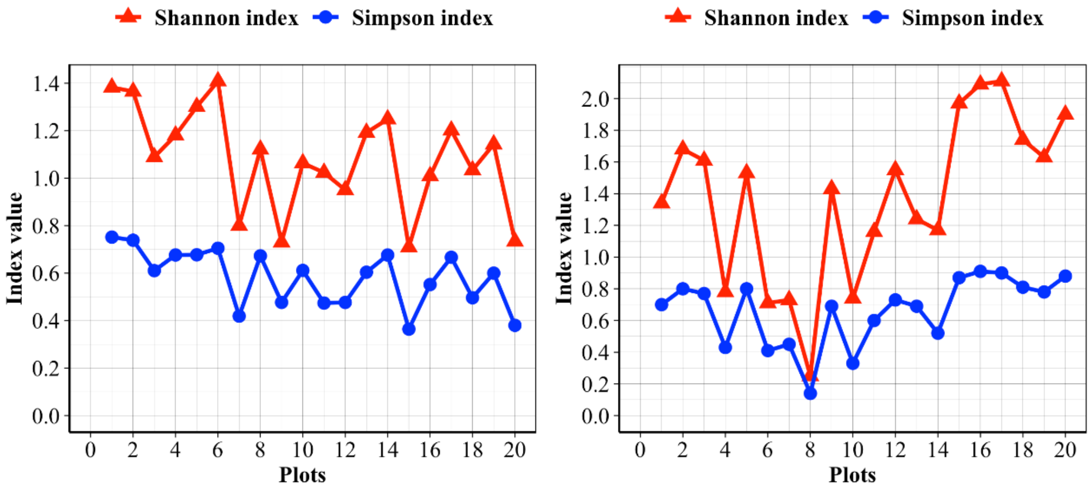
Figure 4: Importance value Index of tree species in (a) Sal Forest (b) Riverine Forest

Shannon's index was determined to be 2.21 in the Sal Forest, with a species richness of 16 and a Simpson's index of dominance 0.86. Simpson's diversity index was found to be highest in plot numbers 1 and 2 with a value of 0.75 and 0.73 whereas lowest in plot numbers 15 and 20 with values of 0.36 and 0.38 respectively. Likewise, Shannon's diversity index was found to be highest in plot number 6 and 1 with the values 1.40 and 1.38 respectively and recorded lowest in plot number 15 and 9 with the values 0.70 and 0.72 (Figure 5, Appendix VII).

In case of riverine forest Shannon's index was determined to be 2.71 with a species richness of 25 and Simpson's index of dominance 0.91. Simpson's index of diversity was recorded highest in plot number 16 and 17 with the values 0.91 and 0.90. Similarly, Shannon's index of diversity was determined to be highest in plot number 17 and 16 with the values 2.11 and 2.09 respectively and determined lowest in plot number 1 and 8 with the values 0.11 and 0.24. When comparing the two forest types, it was found that the riverine forest had higher Shannon's and Simpson's index (Figure 5, Appendix VII).

Table 1: Shannon's and Simpson's Index of diversity of tree species in Sal and Riverine Forest

Diversity Indices	**Sal Forest**	**Riverine Forest**
Shannon's index (H')	2.21	2.71
Simpson's index (D)	0.86	0.91



(a) (b)

Figure: 5: Plot wise Shannon's and Simpson's Index of diversity of (a) Sal Forest (b) Riverine Forest

4.2 Population structure and regeneration

The population structure of the Sal Forest reveals that the forest comprises 75% seedling, 6% of saplings, and 19% of tree species. In a riverine forest, similar proportions were observed: 34% consisted of seedlings, 8% of seedlings, and 58% of mature tree species (Table 3).

Table 2: Population proportion of different life forms of tree in Sal and Riverine Forest.

Life Stage	**Population(Stem /ha)**	
	Sal forest	**Riverine forest**
Seedling	2681 (75%)±2073[a]	398 (34%)±268[b]
Sapling	201 (6%) ±130[a]	88 (8%)±123[b]
Tree	676 (19%) ± 250[a]	680 (58%)±219[a]

Note: Value sharing different letters along the row of individual category are significance at P<0.05 in student t-test

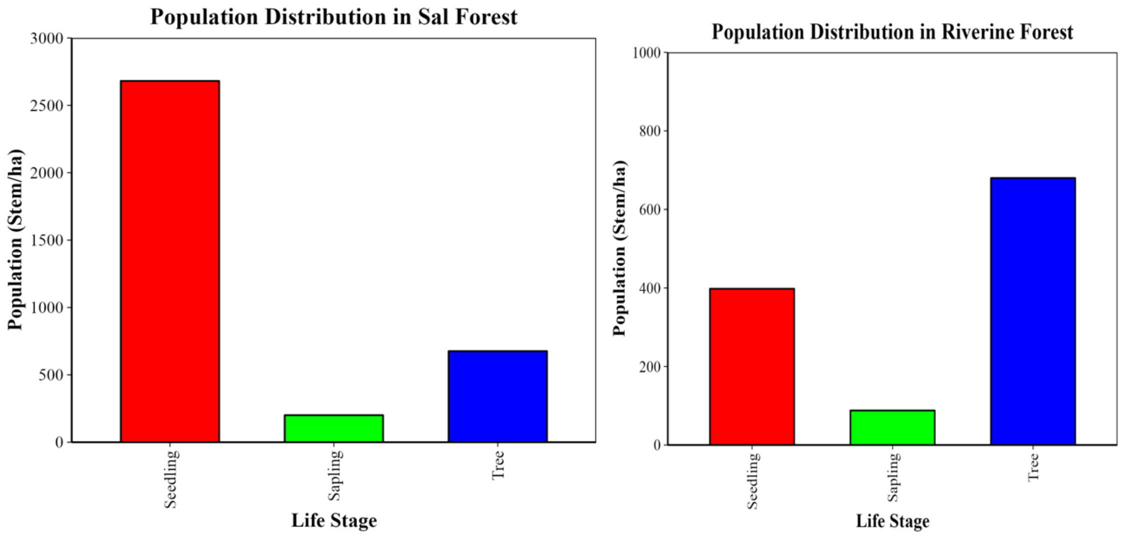
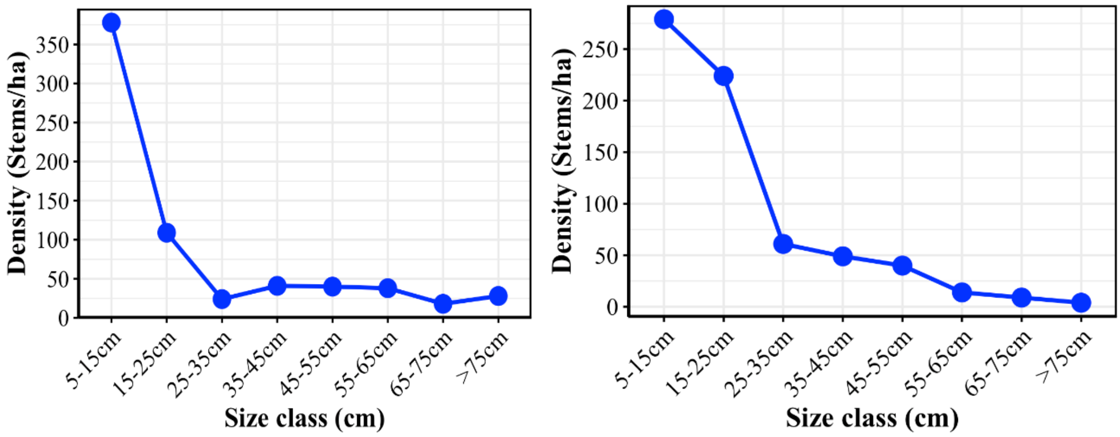


Figure 6: Population proportion of different life forms of tree

A density-diameter curve is a plot showing the relationship between the number of trees (or individuals) per unit area and the diameter class of those trees, which can be used to assess stand dynamics, competition, and growth trends within a forest ecosystem. This curve helps in evaluating stand density and can inform management decisions aimed at achieving desired forest conditions (Smith *et al.*, 1997).

The adult density diameter curves of the Sal and riverine forest exhibit a reverse J-shaped curve, with a greater proportion of young trees than adult trees (Figure 7).



(a) (b)

Figure 7: Density diameter (d-d) curve of tree species in a) Sal Forest b) Riverine Forest

By constructing a d-d curve, the regeneration status of several species in each of the forests was also examined. *S. robusta* in the Sal Forest exhibits a reverse J-shaped curve, indicating high regeneration status, and a slight deviation in the DBH class of 5–15 cm. Likewise, *T. alata* displays a reverse J-shaped curve in the DBH class of 5–15 cm, with a small deviation. A sigsnificant number of tree species were found in this DBH class. No trees were observed above the 65 cm DBH class. *M. philippensis* similarly exhibits a reverse J-shaped curve with a slight divergence in the DBH class of 15–25 cm. Within this DBH class, a considerable number of tree species were observed. Following that, the DBH class drops sharply from 15 to 25 cm to 45 to 55 cm, and no trees were seen above the 55 cm DBH class. A reverse J-shaped curve with a little divergence in the DBH class of 5–15 cm is also seen in *H. pubescens*. A significant number of trees were found belong to this DBH class. There are no trees observed above the 45 cm DBH class, and the DBH class drops off drastically beyond that. In contrast to other species it was found that *S. robust*a had relatively strong regeneration rate (Figure 8).

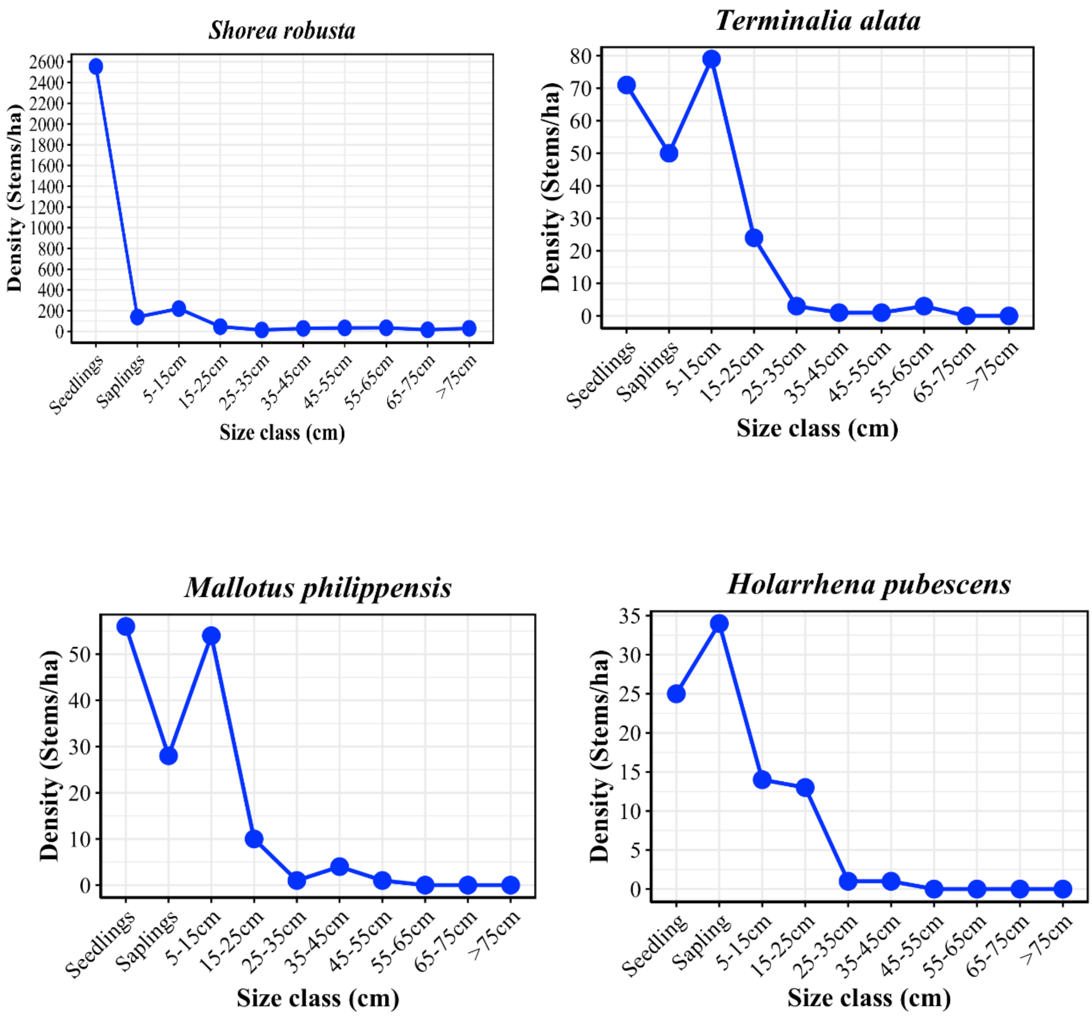


Figure 8: Density diameter (d-d) curve of dominant tree species of Sal Forest

Within the riverine woodland, *S. catechu* was found to exhibit a reverse J-shaped curve with a minor variation between the DBH class of 15–25 cm. Between DBH class 15- 25 cm, a high number of trees were detected. *A. cordifolia* also deviates from the reverse J-shaped curve, with a greater number of individuals detected in the 15–25 cm DBH interval, followed by a sharp decline and the absence of trees above the 45 cm DBH class. Likewise, *D. sissoo* exhibits a bell-shaped curve. No seedlings or saplings were seen in the *D. sissoo* instance. In DBH class 15–25 cm the greatest number of trees were observed. In addition, *M.philippensis* has a reverse J-shaped curve, with a higher proportion of individuals observed between DBH classes 5 - 15 cm and no trees observed in DBH classes 25 - 35 cm and above DBH class 55cm. *D. sissoo* exhibits low regeneration in comparison to other species (Figure 9).

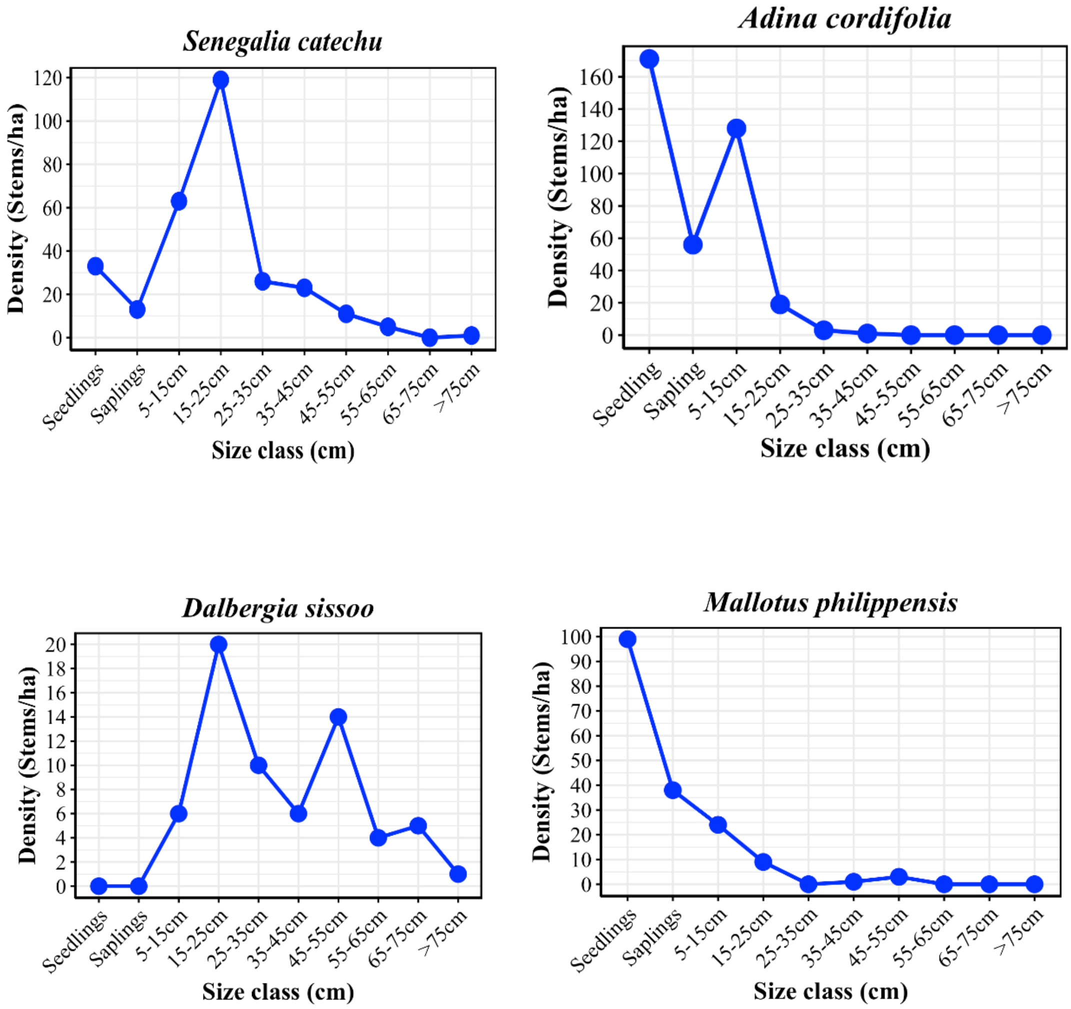
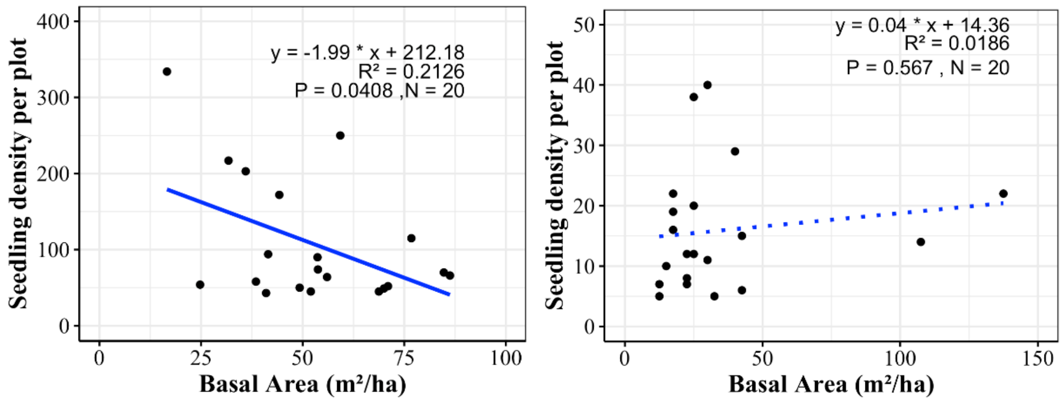


Figure 9: Density diameter (d-d) curve of dominant tree species of Riverine Forest

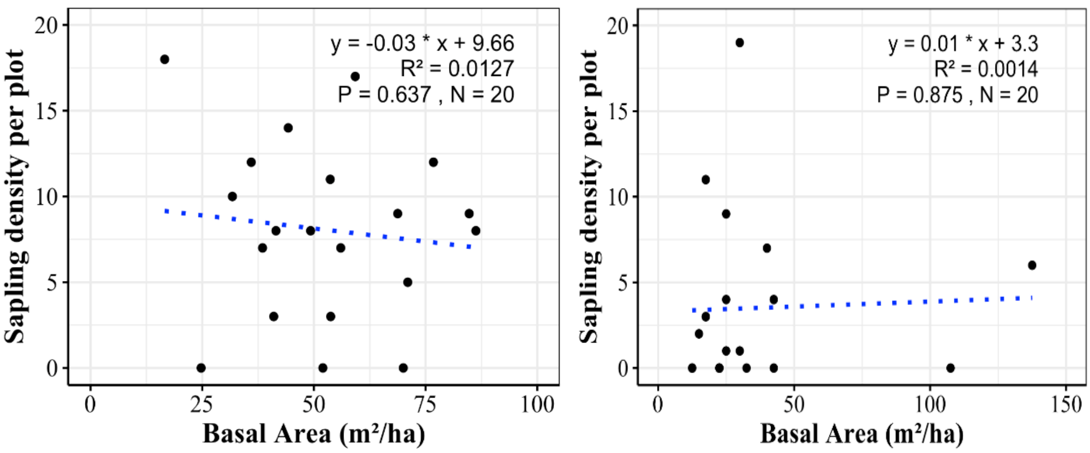
Regression analysis showed that there was a significant (p=0.04) negative relationship between basal area and seedling density in Sal Forest while insignificant relationship between basal area and seedling density in Riverine Forest. The trend line showed an increasing seedling density with basal area the density of seedling decreases in case of Sal Forest .



(a) (b)

Figure 10: Regression between tree basal area and seedling density of a) Sal Forest b) Riverine Forest

Regression analysis between sapling density and basal area showed an insignificant negative relationship in both forest types.

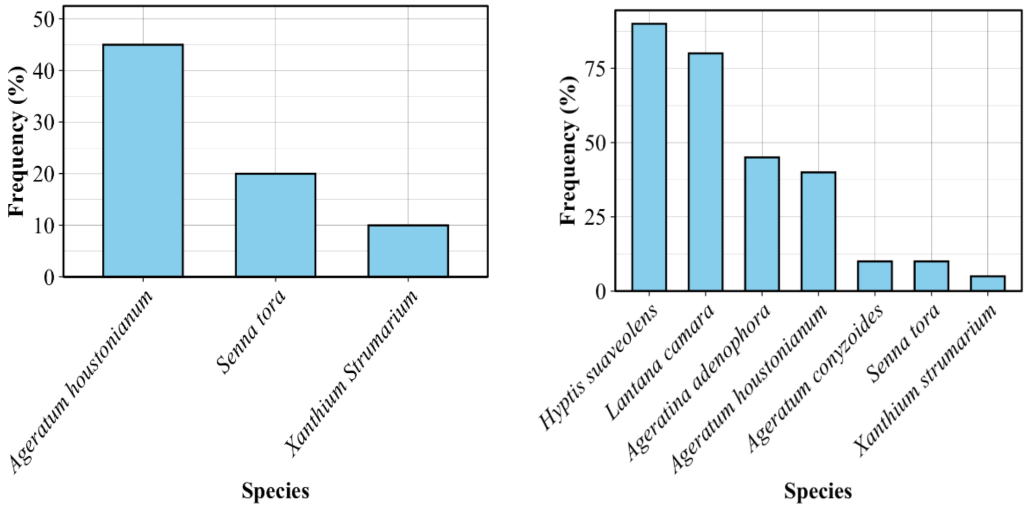


(a) (b)

Figure 11: Regression between tree basal area and sapling density of (a) Sal Forest (b) Riverine Forest

4.3 Plant Invasion

In Sal Forest only 3 invasive species were reported among which *Ageratum houstonianum* has the highest frequency (45%) followed by *Senna tora* (20%), *Xanthium strumarium* (10%) whereas in Riverine Forest 7 invasive species were reported among which *Hyptis suaveolens* has the highest frequency (90%), followed by *Lantana camara* (80%), *Ageratina adenophora*(45%), and *Ageratum houstonianum* (40%) (Figure 12).



(a) (b)

Figure 12: Frequency of Invasive Alien Plant species in a) Sal Forest b) Riverine Forest

Regression analysis revealed insignificant relationship between Tree canopy cover and Invasive cover (p>0.05) (Figure 13).

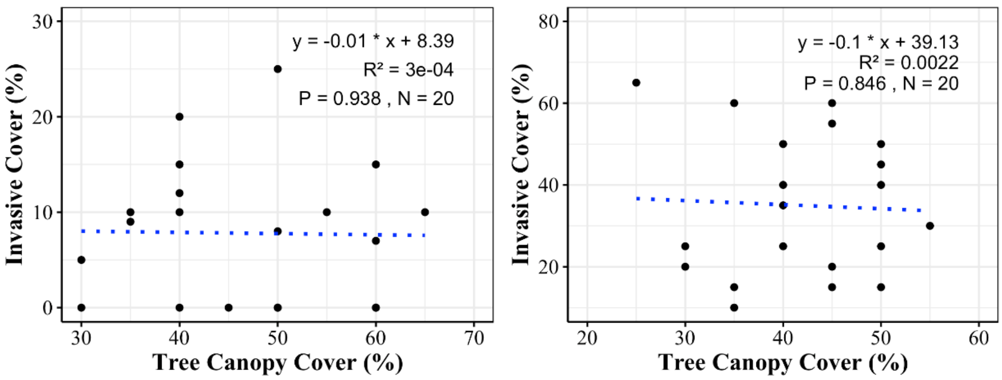
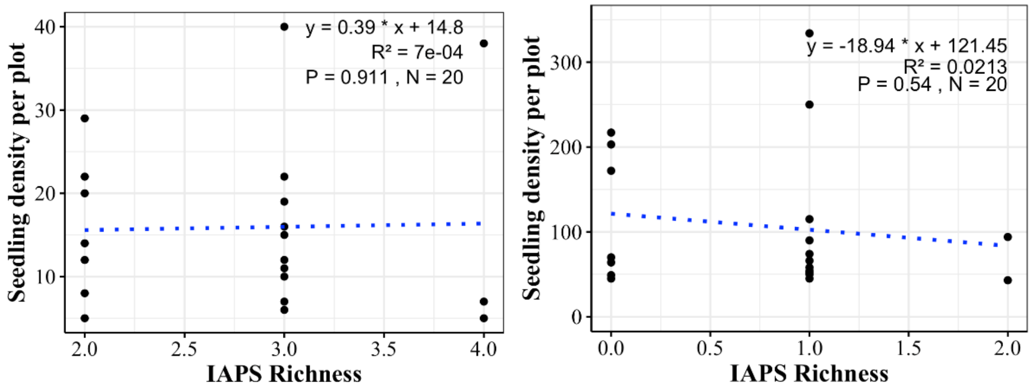


Figure 13: Regression between Tree Canopy Cover and Invasive Cover a) Sal Forest b) Riverine Forest

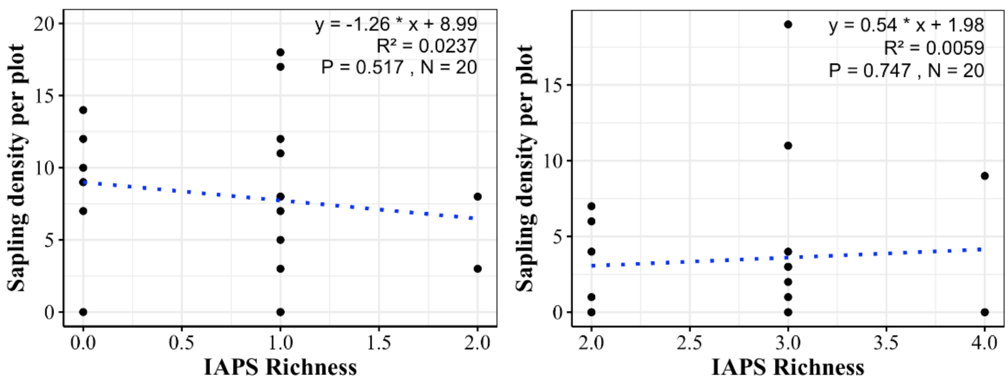
A regression analysis indicates insignificant negative relationship between IAPS richness and the density of seedlings (p>0.05) in Sal Forest while insignificant positive relationship between IAPS richness and density of seedling (p>0.05) in riverine forest (Figure 14).



(a) (b)

Figure 14: Regression between IAPS richness and tree seedling density of a) Sal Forest b) Riverine Forest

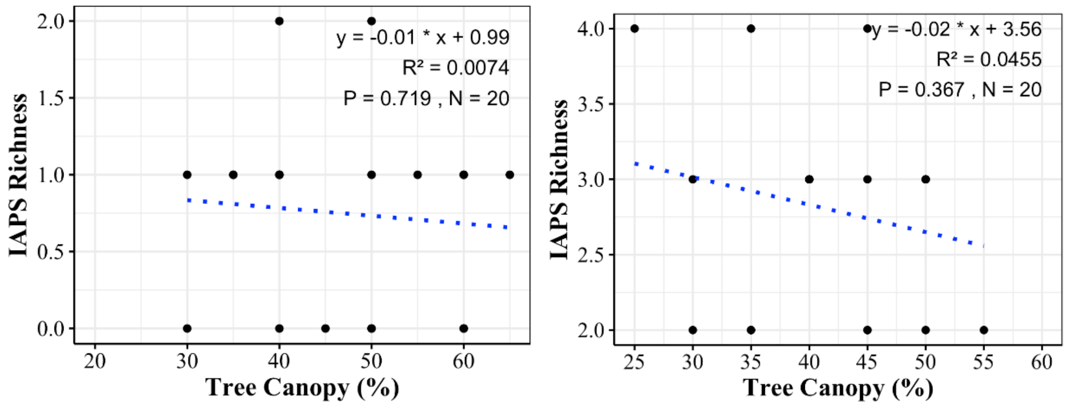
A regression analysis reveals that there is an insignificant negative association (p>0.05) between IAPS richness and sapling density in Sal Forest, but insignificant positive link (p>0.05) between IAPS richness and sapling density in riverine forest (Figure 15).



(a) (b)

Figure 15: Regression between IAPS richness and tree sapling density of a) Sal Forest b) Riverine Forest

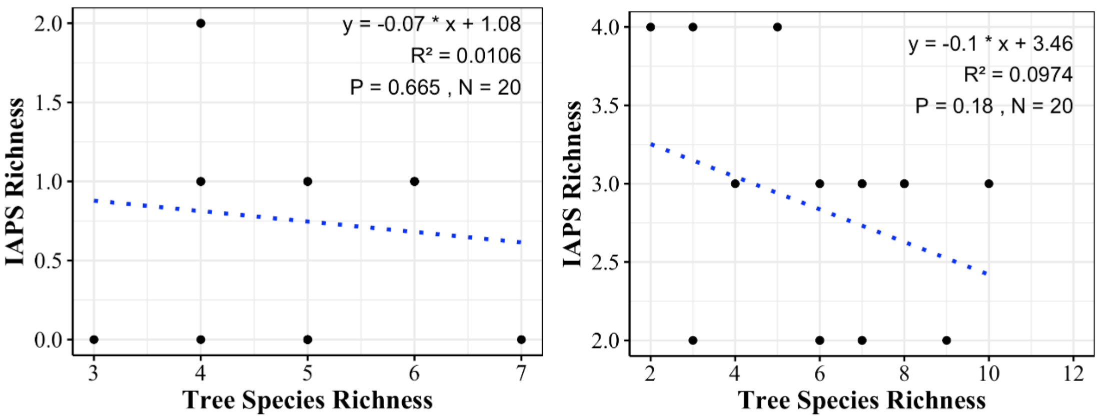
Similarly, regression analysis demonstrates an insignificant negative association between IAPS richness and tree canopy cover (p>0.05) in Sal Forest, whereas in riverine forest regression analysis shows a substantial negative relationship between IAPS richness and tree canopy cover. In riverine forests, the relationship between IAPS and canopy cover displays a decreasing trend, indicating that increasing canopy cover reduces IAPS richness (p<0.05) (Figure 16).



(a) (b)

Figure 16: Regression between IAPS richness with tree canopy cover of a) Sal Forest b) Riverine Forest

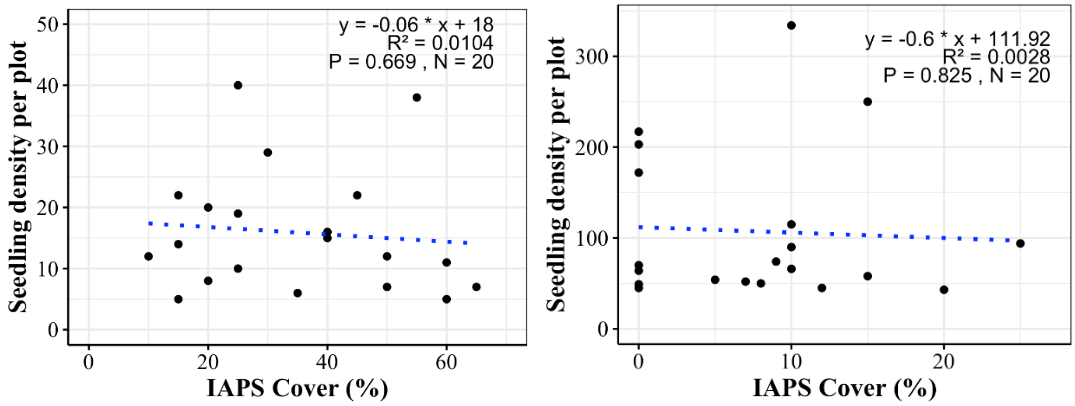
Likewise, regression analysis reveals a insignificant negative link between IAPS richness and tree species richness (p>0.05) in Sal forest, but a substantial negative relationship between IAPS richness and tree species richness (p<0.05) in riverine forest. The relationship between IAPS and tree species richness reveals a declining tendency in riverine forest. This suggests that as IAPS richness increases, tree species richness decreases (Figure 17).



(a) (b)

Figure 17: Regression between IAPS richness with tree species richness of a) Sal Forest b) Riverine Forest

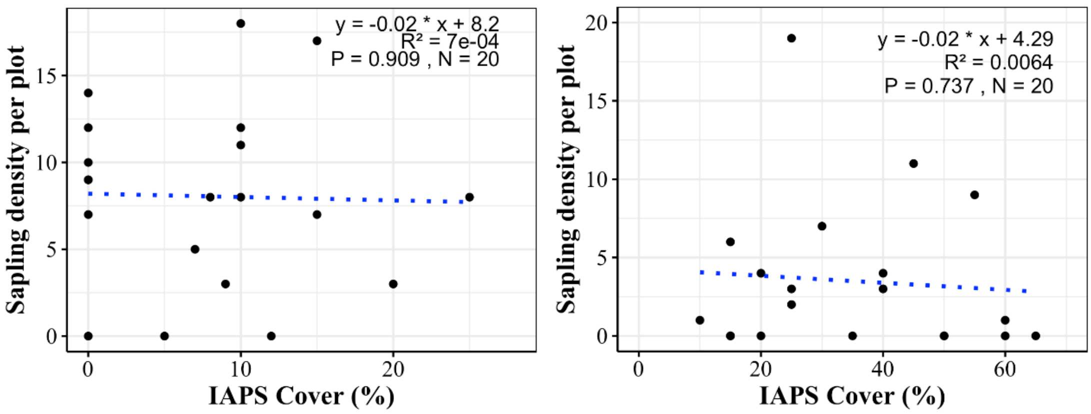
Furthermore, the regression analysis comparing the density of tree seedling to the IAPS cover (p>0.05) shows insignificant negative relationship in both forest types (Figure 18).



(a) (b)

Figure 18: Regression between IAPS cover with density of seedling of a) Sal Forest b) Riverine Forest

Additionally, the regression analysis comparing the density of sapling to IAPS cover ($p>0.05$) demonstrates an insignificant negative relationship in both forest types (Figure 19).

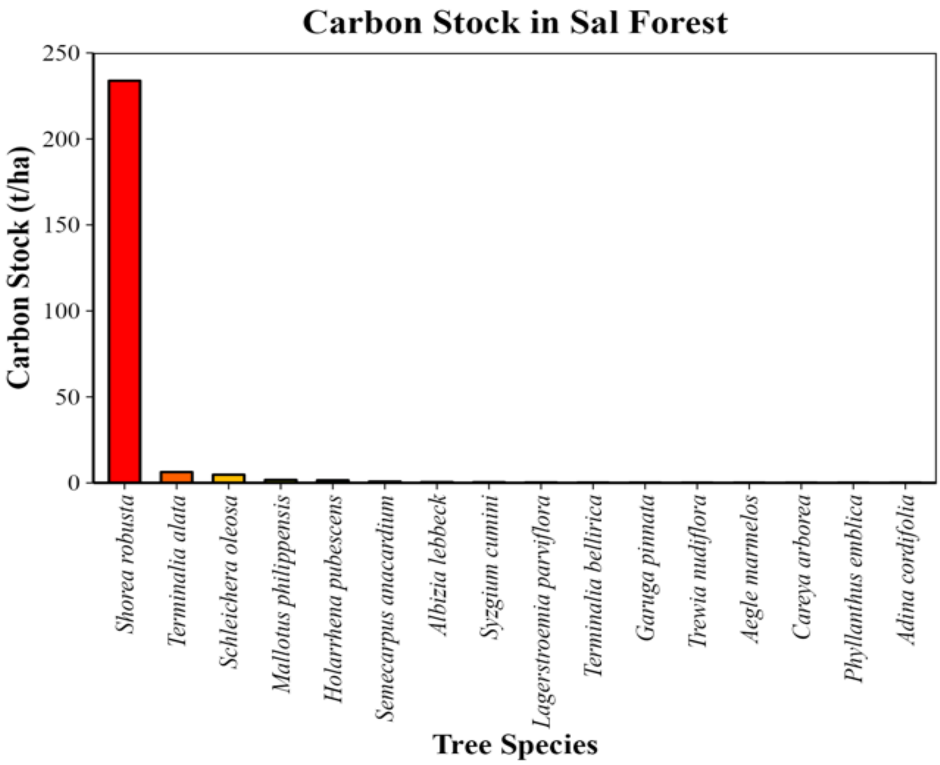


(a) (b)

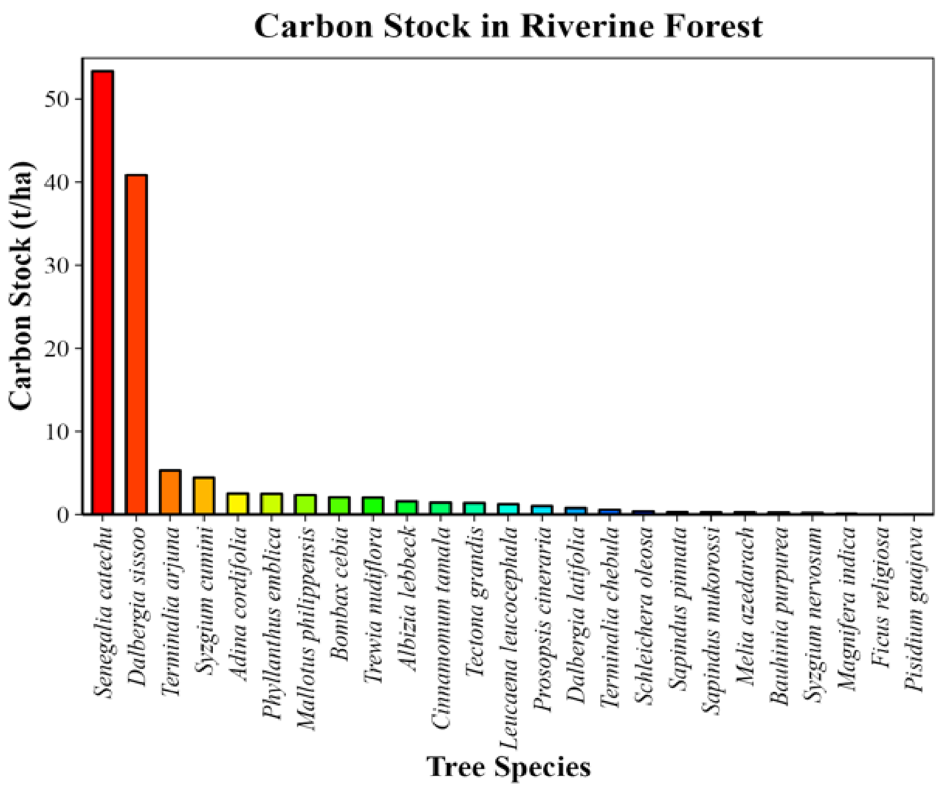
Figure 19: Regression between IAPS cover with density of sapling of a) Sal Forest b) Riverine Forest

4.4 Carbon Stock

Tree carbon stock was significantly higher in Sal Forest (250.40 t ha^{-1}) than in Riverine Forest (126.55t ha^{-1}). The comparison of species-wise carbon stocks in Sal and Riverine Forest indicated considerable differences in carbon accumulation between tree species. In Sal Forest *S.robusta* (233.83 t ha^{-1}) had the highest carbon stock followed by *T.alata* (6.29 t ha^{-1}) and *S. oleosa* (4.77 t ha^{-1}) while in riverine forest *S.catechu* (53.34 t ha^{-1}) had the highest carbon stock followed by *D.sissoo* (40.85 t ha^{-1}) and *Terminalia arjuna* (5.30 t ha^{-1}) (Figure 20, Appendix VI).



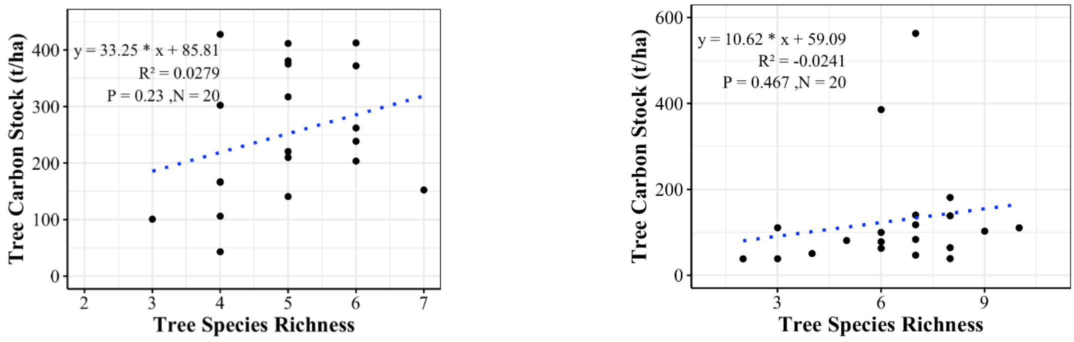
(a)



(b)

Figure 20: Carbon stock of tree species a) Sal Forest b) Riverine Forest

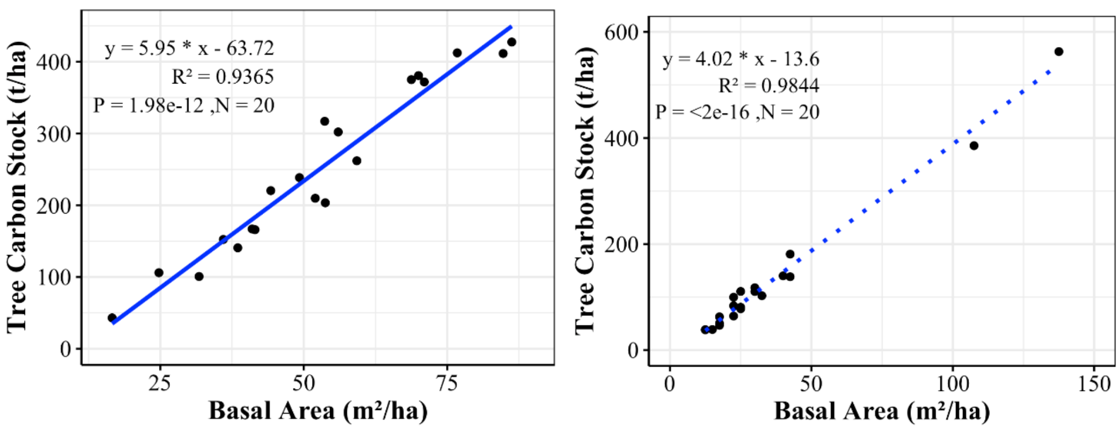
The regression analysis shows that there was a strosng insignificant relationship between carbon stock and species richness with p value (P>0.05) (Figure 21).



(a) (b)

Figure 21: Regression between tree species richness and carbon stock a) Sal Forest b) Riverine Forest

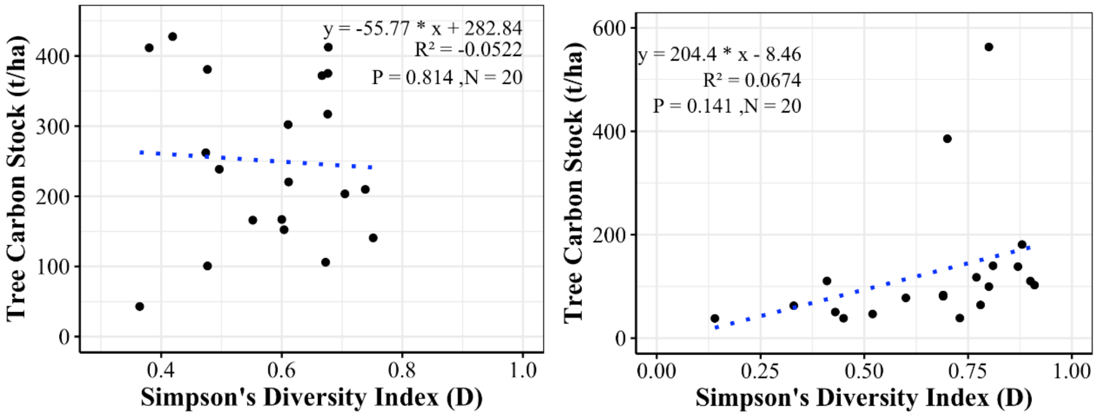
Likewise, the regression analysis shows that there was significant positive relationship between carbon stock and basal area in both forest types (P<0.05). This indicates that as the basal area of trees increases, the amount of carbon stored in the forest also increases. Larger trees, which contribute to higher basal area, typically have more biomass and thus sequester more carbon (Figure 22).



(a) (b)

Figure 22: Regression between Basal area and tree carbon stock a) Sal Forest b) Riverine Forest

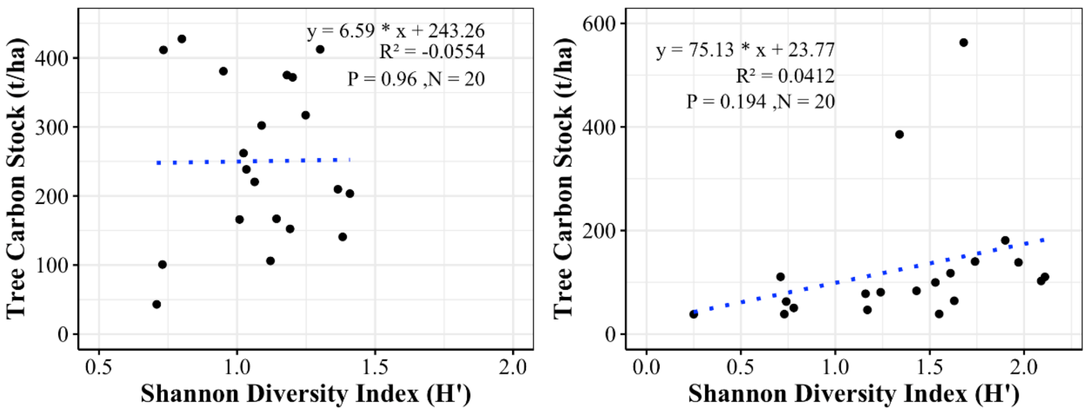
Additionally, the regression analysis comparing the Simpson's and tree carbon stock is insignificant in both forest types (p>0.05) (Figure 23).



(a) (b)

Figure 23: Regression between Simpson's diversity index and tree carbon stock a) Sal Forest b) Riverine Forest

Furthermore, the regression analysis shows insignificant relationship between Shannon's diversity index and tree carbon stock ($p>0.05$) (Figure 24).



(a) (b)

Figure 24: Regression between Shannon's diversity index and tree carbon stock a) Sal Forest b) Riverine Forest

The relationship between height and tree carbon stock also indicates significant positive relationship ($p<0.05$). The trendline shows with the increase in height tree carbon stock increases. Taller trees tend to have more biomass and therefore store more carbon (Figure 25).

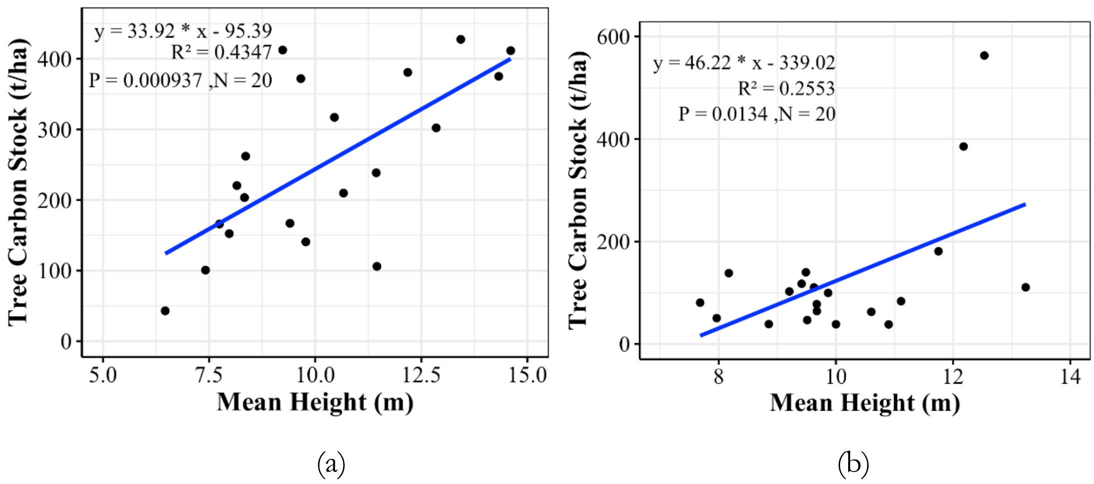


Figure 25: Regression between mean height and tree carbon stock a) Sal Forest b) Riverine Forest

4.5 Soil characteristics

The average soil moisture content in Sal Forest was found to be 20.67. Soil moisture content has a value between 20.33 -20.95. The soil has a temperature range of 20–24°C. The recorded average temperature was 21.95°C. The average soil pH value in the study area was 6.34, indicating the presence of acidic soil.

Additionally, average soil moisture content of the Riverine Forest was found to be 20.94 %. Soil moisture content has a value between 20.37-22.22 %. The soil has a temperature range of 21–24°C. It was noted that the average temperature was 22. 65°C.The average soil pH was recorded 8.06 which signify the presence of alkaline soil in the study area.

Table 3: Different Soil Characteristics in Sal and Riverine Forest

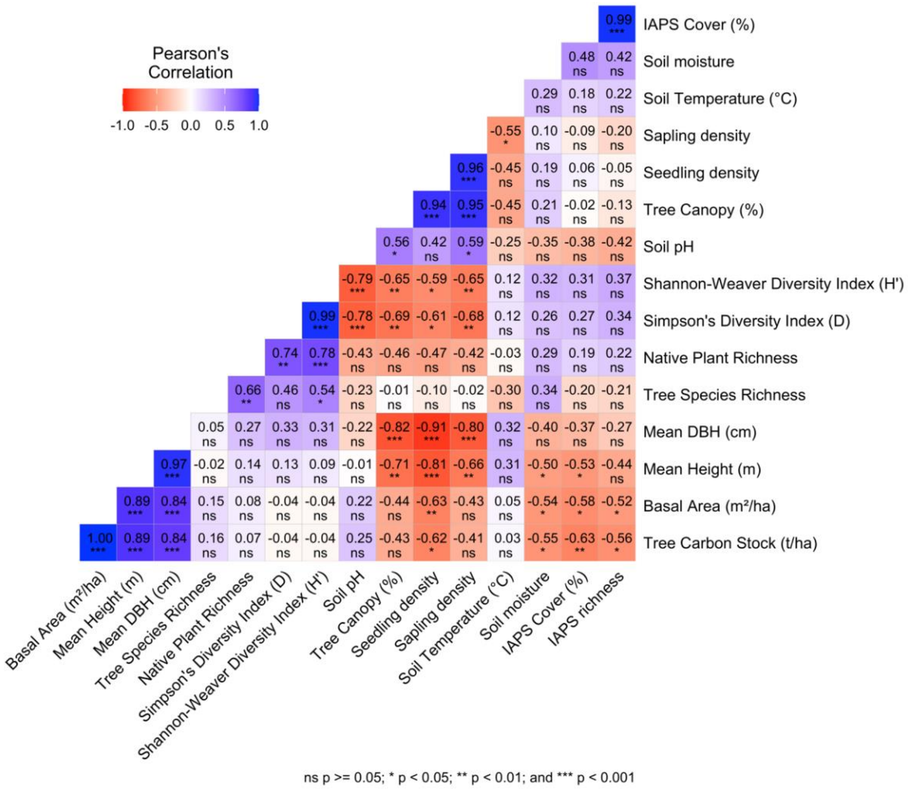
Soil characteristics	**Sal forest**	**Riverine forest**
Moisture content (%)	20.67[a]	20.94[b]
Temperature (°C)	21.95[a]	22.65[a]
pH	6.34[a]	8.06[b]

Note: Value sharing different letters along the row of individual category are significance in student t-test ($p<0.05$).

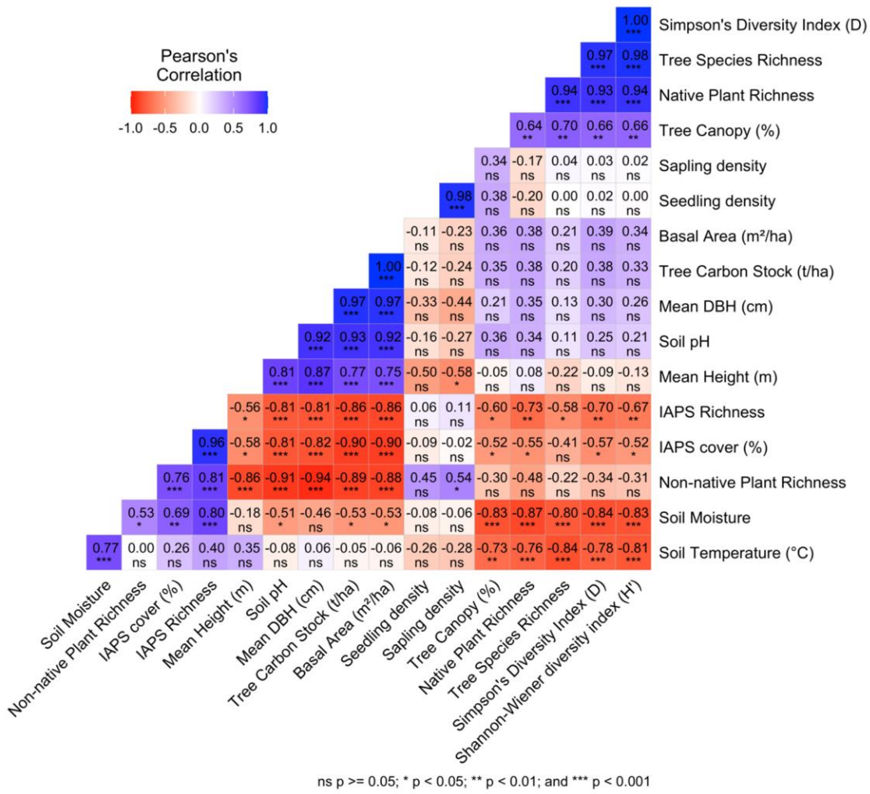
4.6 Correlation between the parameters in Sal and Riverine Forest

The data indicates notable correlations between various ecological factors in the Sal Forest. For instance, there is a strong positive correlation (0.68) between mean height and mean tree carbon stock suggesting that taller trees are associated with higher tree carbon stock while a robust positive correlation (0.97) is observed between tree carbon stock and basal area indicating that higher tree carbon stock is associated with a larger basal area. Moreover, a substantial positive correlation (0.64) exists between basal area and mean height indicating that taller trees are associated with larger basal area. Additionally, there is a strong positive correlation (0.94) between IAPS cover and IAPS richness indicating that higher IAPS cover is associated with higher IAPS richness and there is moderate negative correlation between number of seedling and Shannon -Weaver Diversity (-0.43) suggesting that areas with more seedling have lower Shannon -Weaver diversity. Conversely, a moderate negative correlation (-0.46) is observed between number of seedling and Simpson's Diversity suggesting that areas with more seedling tend to have lower Simpson's Diversity. Similarly, a strong positive correlation (0.69) exists between number of seedling and tree canopy and between number of sapling and tree canopy (0.64). There is also a notable strong negative correlation (-0.67) between number of seedling and mean height. Additionally, positive correlations are observed between number of saplings and the number of seedlings (0.79), and very strong positive correlation between Simpson's Diversity and Shannon -Weaver diversity (0.93) (Figure 26a).

In case of Riverine Forest the data indicates notable correlations between various ecological factors. For instance, there is a very strong positive correlation (0.99) between tree carbon stock and mean DBH, while a robust positive correlation (0.98) is observed between Simpson's Diversity Index (D) and tree species richness. Moreover, a substantial positive correlation (0.95) exists between tree carbon stock and basal area, and between Simpson's Diversity Index (D) and native plant richness (0.84). Additionally, there is a strong positive correlation (0.93) between tree carbon stock and basal area, and between mean height and soil temperature (0.89). Conversely, a strong negative correlation (-0.53) is observed between IAPS richness and native plant richness, and a significant negative correlation (-0.48) exists between IAPS cover and native plant richness. There is also a notable negative correlation (-0.47) between IAPS cover and tree species richness, and a negative correlation (-0.44) between IAPS cover and Simpson's Diversity Index (D). Slight negative correlations are observed between IAPS cover and the number of seedlings (-0.34), and between IAPS cover and the number of saplings (-0.40). A slight positive correlation is observed between soil moisture and soil temperature (0.31), and between soil pH and mean height (0.30) (Figure 26b).



(a)



(b)

Figure 26: Correlation between various vegetation parameters in a) Sal Forest b) Riverine Forest

CHAPTER 5: DISCUSSION

5.1 Forest Composition and Diversity

The greatest *S. robusta* Importance Value Index (IVI) is found in all community managed forests. Comparable results have been noted in mid-hill Sal forests (Shrestha, 2005) and inner Terai Sal forests (Acharya *et al.*, 2006; Kandel, 2007). *S. robusta* typically predominates among other tree species in the forest in which it grows (Tripathi & Shankar, 2014). The results of Acharya *et al.,* (2011) in the Parroha Community Forest of the Rupandehi district are consistent with the existence of *S. robusta* dominance. In a case study from Lumbini Collaborative Forest, Rupandehi, (Awasti *et al.*, 2015) discover the same outcome. Similar outcomes were obtained by DFRS (2014), conducted in Terai Forest Inventory and found that *S. robusta* had the greatest IVI, followed by *T. alata*. In the Charpala Community Forest Rupandehi district, Chalise and Paneru (2022) found 69 families of distinct plant species, indicating a somewhat similar sort of varied forest. They also discovered *S. robusta* to be the dominant tree in their study. Ayer *et al.*, (2024) conducted study in the community forest of Udaypur district and identified 17 tree species from 11 families. *S. robusta* was dominate tree species, exhibited the highest IVI (176.15) which is comparable to the current study.

In riverine forest *S.catechu* (250 pl ha^{-1}) is the most dominant species followed by *A cordifolia* and *D. sissoo* with the IVI 68.70, 50.59, 36.67 respectively. This demonstrates how *S.catechu* influences the structure and dynamics of riverine forests. The findings of Giri *et al.*, (1999) in the deciduous riverine forest of Royal Bardiya National Park support the presence of *S. catechu* dominance.

According to Awasthi *et al.*, (2015), an assessment of the evenness and species richness of a region is Species diversity. Quantitative assessments of species diversity and evenness within each forest type were provided by diversity indices, such as Shannon's and Simpson's indices. When compared to riverine forests, Sal forests showed lower diversity indices, suggesting a less varied plant community and possible dominance of a few species. This may be because *S. robusta* is so prevalent in Sal forests. In contrast, riverine forests displayed higher diversity indices, which were indicative of a more uniform distribution of species and a higher level of species richness. Variations in species distribution between different plots within Sal and riverine forests were revealed by a spatial analysis of diversity indicators. Higher diversity indices were found in certain plots than in others; this could be because localized variations in environmental factors or management techniques affect composition of plant communities.

5.2 Plant Invasion

The invasion rate is higher in riverine forest than in Sal Forest, as the riverine forest was nearer to human settlement, the invasion might have occurred due to anthropogenic activity (Larson *et al.*, 2001). Riverine forest is close to the roadside as well as the local community, and the residents of this community rely heavily on the riverine forest site for timber and fodder plant collection, therefore it is extensively disturbed, which may be the reason of the high invasive species diversity. Furthermore, the high abundance of IAPS in riverine forest may be favored by flooding, which aids in seed dissemination of this species.

In the Sal Forest, *A.houstonianum* emerges as the dominating invasive species, which aligns with the study of (Khaniya & Shrestha, 2020). This could be because invasive species prefer disturbed ecosystems (Meyer *et al.*, 2021). Invasive alien plant species were found mostly in open canopy, degraded forest and open land where light penetration is high (Ghimire *et al.*, 2020). Forest area having closed canopy cover act as the physical barriers to the dispersal pathways and prevailing light and moisture condition act as environmental barriers for the establishment of alien plant species (Mavimbela *et al.*, 2018). Open canopy reduces the barriers of seed dispersal and growth of the early successional species due to high penetration of light under forest. (Lawes *et al.,* 2004). This shift in light availability encourages the development of opportunistic invasive species like *A.houstonianum*, which may quickly colonize disturbed areas due to their high growth rate and robust reproductive potential (Khaniya & Shrestha, 2020).

Floristic research in western Chitwan indicated the presence of *H.suaveolens* in riverine forests, along with a diverse range of other plant species which supports the idea of our study. These study focus on the ecological dynamics of riverine forests and the challenges posed by invasive species such as *H.suaveolens* (Dangol, 2001).

H.suaveolens thrives in high-light conditions, where it can dominate forest understory. Its propensity to grow in disturbed regions (e.g., logging, grazing) enables it to outcompete native vegetation for resources. The presence of light, which is frequently augmented by anthropogenic activity, promotes its growth and spread in riverine habitats. (Kumar, 2020).*H.suaveolens* is highly adaptable to a variety of environmental circumstances, increasing its invasive potential. It flourishes in a broad variety of climates, including tropical and semi-arid regions. This versatility enables it to colonies disturbed regions like riverbanks and floodplains, where it can thrive (David, 2020).

The influence of IAPS on forest ecosystems, as demonstrated by regression analysis, supports various findings. There is a continuous and insignificant negative relationship between IAPS richness and several forest health indicators in both Sal and riverine forest types. The insignificant negative relationship between IAPS covers with sapling density contrasts with Chaudhary *et al.,* (2020), who reported a strong negative relationship between IAPS cover and sapling density. This could be due to fewer aggressive invaders or a more resilient local population Chaudhary *et al.*, (2020) Moreover, the insignificant negative relationship between IAPS richness and tree canopy cover is in contrast to Khaniya *et al.*, (2020), who found a strong negative relationship between IAPS richness and canopy cover. This could be due to differences in the ecological circumstances between the research areas. Khaniya *et al.*, (2020). may have conducted their research in areas where dense tree canopy cover greatly reduces light availability, thereby limiting IAPS growth. Soil type, moisture, and other environmental conditions can all affect how IAPS interact with local flora. The negative and substantial connection between IAPS richness and canopy cover in riverine forest suggests that invasive plants may out compete native vegetation for sunlight, resulting in a decline in forest canopy density. The connection between IAPS richness and seedling density differs from the sapling density reported by Khaniya *et al.*, (2020). The data imply that increasing tree canopy cover generally correlates to decreased IAPS richness, especially in distinct microhabitats such as canopy gaps and edges, where growth reduces the richness and abundance of invasive alien plant species. The connection between IAPS richness and tree species richness differs from that reported by Khaniya *et al.,* (2020). In Sal forests, higher tree canopy cover and basal area resulted in significantly lower IAPS richness and cover. It implies that denser forest stands are more resistant to invasions, which could explain the lack of relationship between IAPS and tree species richness in Sal Forest.

5.3 Population Structure and Regeneration

Forest regeneration refers to a species innate tendency to flourish and thrive. The existence of a ample number of young trees, seedlings, and saplings in the forest periphery suggests that specific species have the ability for regeneration (Hammond *et al.,* 2021).The frequency of seedlings fluctuates according to numerous factors such as light availability, drought, and abiotic factors like as competition, diseases, herbivores Sharma *et al.*,(2018).With a noteworthy count of 2681 seedlings, 201 saplings, and 676 mature trees, the Sal forest demonstrated a remarkable regeneration condition in our study. In comparison, there were 398 seedlings, 88 saplings and 680 trees in the riverine forest. In the *S.robusta* forest in central Nepal, a study conducted by (Sharma *et al.*, 2020) discovered larger numbers of 12,5,89 seedlings, 2643 saplings, and 1979 trees for all species. A number of variables, including species composition, habitat, species adaptation, and climate conditions, could be responsible for this discrepancy in the results. Sal forest exhibits a reverse j-shaped pattern with the greatest number of seedlings followed by saplings. The entire forest, including all trees, as well as *S. robusta*, a dominating species, demonstrate this pattern. Trees have a pattern in their distribution throughout their life cycles, with a higher proportion of seedlings than saplings and an outnumbering of adult trees compared to saplings. In the western terai region of Nepal, Timilsina *et al.*, (2007) carried out a systematic random sampling method and found that the forest has a varied floral composition pattern, making it one of the country's best-suited sub-tropical forests. *S. robusta* was found to be the dominating tree species, exhibiting a reverse J-shaped pattern of regeneration.

Riverine forest re-growth follows a reverse J-shaped curve, with younger, narrower trees outnumbering adult trees. *S. catechu* is the dominant species, followed by *A.cordifolia* ,both with reverse J-shaped curves. *D. sissoo* displays a bell-shaped curvature. There were no seedlings or saplings observed in the *D. sissoo* instance, and there were more mature trees than old ones indicating inadequate regeneration. The majority of the adult trees were dead, possibly as a result of diseases or plant invasion.

5.4 Carbon Stock

Tree Carbon stock was significantly higher in Sal Forest than Riverine Forest. Nair *et al.*, (2009) reported that although young, regenerating forests sequester carbon at a higher location, older, more mature trees retain a greater amount of carbon stock in them. Tree carbon stocks vary based on a variety of criteria, such as species, size, and growth habitat. In Chitwan National Park's *S. robusta* forest (tree layer only), Sejuwal (1994) reported a carbon store of 468 tons/ha, which was higher than the current study. According to Singh *et al.,* (2006), this could be because of the forest's maturity, as older trees store more carbon. According to Mandal *et al.,* (2012), various management units and factors have an impact on the amount of carbon stock in forests. Therefore, the management systems in both forests may have an impact on the variation in carbon stock seen in this study. In a study carried out in Kathmandu's Gokarna Forest, Dhakal *et al.,* (2017) estimated a 256.98 t ha^{-1} carbon store of forest. Similarly, the total carbon stock was observed at 234.54 t ha^{-1} and 479.29 t ha^{-1}, respectively, in the community forests of Hill and Terai (Pandey & Bhusal, 2016). In comparison to hills, the terai recorded a far larger carbon stock. This might be caused by variations in the elevation and topography of the terrain.

Giri *et al.*, (1999) in the deciduous Riverine Forest, of Royal Bardiya National Park recorded total aboveground biomass 150.65 t ha^{-1} where *S. catechu* and *D. sissoo* dominate, contributing 75.85 t ha^{-1} and 49.98 t ha^{-1}, respectively which align with the current study. These species are well-adapted to the frequent flooding of the Terai's alluvial riverbeds and are among the first to colonize and thrive in newly disturbed floodplain areas. Their rapid growth and ability to quickly occupy these environments give them a competitive edge, making them the dominant species in the forest.

Regression analysis was performed to determine how species richness, basal area, Shannon's and Simpson's diversity relate to carbon stock. The results of this investigation showed a strong and positive association ($P<0.05$) between basal area and carbon stock. In Rupandehi, Nepal, tree diversity and carbon stock increased as basal area increased, according to research by Paudyal (2022). Regression study also revealed a highly significant positive link between carbon stock and basal area as reported by Joshi (2020) in Dhangadhi. Due to positive relationship between basal area and carbon stock, it was possible that increased basal area of trees would also increase the amount of carbon stored in the forests. This is explained by the fact that larger trees were able to sequester more carbon since they typically had more biomass. It could be altered due to Management practices, age, and density factors. The present study revealed insignificant relationship between Carbon Stock and Shannon's diversity which supports the finding of (Pradhan *et al.*,2023) in Hasantar Community Forest in Nagarjun Municipality, Kathmandu District. Similarly, the relationship between Carbon stock and Simpson's diversity was also insignificant which supports the finding of Pradhan *et al.,* (2023). Mandal *et al.*, (2013) in Mahottari district also found insignificant relationship between Simpson's diversity and Carbon stock.

5.5 Soil Characteristics

Paudel and Sah (2003) reported 4.33 pH in pure Sal Forest and 5.26 in mixed forest which is acidic in nature which coincides with the present study. Gautam and Mandal (2013) also reported slightly acidic nature of the Sal Forest soil of Charkose Jungle of eastern Nepal. Khadgi *et al*., (2013) also reported acidic soil in with pH ranging between 4.23 and 5.08. The acidic soil might be due to acids released by the decomposition of organic residues obtained from forest vegetation (KC *et al*., 2013). Similarly moisture content of soil ranged between 16.3- 41.5% in the Sal Forest of Central Nepal (Basyal *et al*., 2011). Dahal *et al*., (2018) also recorded moisture content 7.8- 58% which is relatively higher than present study.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This research examined the forest structure, carbon stock, and plant invasion in Sal and Riverine forests in Western Nepal. Invasive alien plant species (IAPS) richness, diversity, carbon stock, composition, and population structure between Riverine and Sal forests differed significantly. *S.robusta* was the dominant species in the Sal forest with highest IVI value and a relatively low IAPS prevalence. On the other hand, *S.catechu* was the dominant species in the riverine forest with highest IVI value and increased IAPS richness. Species richness and diversity indices were highest in Riverine Forest than Sal Forest. The regeneration status of Sal Forest reveals reverse J shaped curve with good number of seedling and sapling than Riverine Forest. The total carbon stock of the Sal Forest was higher than Riverine Forest which indicates the forest has been sequestering significantly large amounts of carbon in Sal Forest. Carbon stock analysis revealed significantly higher carbon storage in the Sal Forest compared to the Riverine Forest, with *S. robusta* contributing the most. The relationship between forest structure and carbon stock was positively correlated with tree height and basal area. In terms of plant invasion, the Riverine Forest harbored more invasive species than the Sal Forest, with notable impacts on biodiversity.

These findings have important implications for forest management strategies, particularly in balancing carbon sequestration with biodiversity conservation. The increased carbon store in the Sal Forest suggests it could play an important role in carbon storage programs, whereas the greater diversity and invasion in Riverine forests necessitate tailored management to limit invasive species and conserve native biodiversity. The quantitative analysis of the diversity, carbon stock, population structure, and regeneration status of the tree species may yield baseline data for developing conservation and management plans for the current forest. Thus, in order to maintain the biological balance and biodiversity of Adarsh Community Forest and Deoria Community Forest in the upcoming years, it would be imperative to focus these issues.

6.2 Recommendations

Based on the results of the present study, following recommendations are suggested:

1. Open canopy cover should be reduced.

2. To mitigate the impact of IAPS forest canopy cover should be increased.

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APPENDICES

Appendix I: Field data sheet used for vegetation sampling

Investigators'Name: ………………………………………………… Phone: ……………… Campus: ………………. Email: …………………… Date and time: …………………... Gaupalika/Nagarpalika: ……...…………… Locality: ……………… District: ……… Slope.................. Aspect: ……………... Land use type …………………………… Altitude(m): ….................… Latitude (N): ………………… Longitude (E): …………… Disturbance level (0, 1, 2, 3) Forest type: ……………………………………………...... Date of estd .....………………………… Distance from road: …………………..……. Distance from settlement: ……………………..… Ethnicity of locals: ……………….……. Litter depth (cm): …………... Canopy cover (%) (Average of three): …………………. Soil color: ..……………… Soil moisture (%) ……………. Soil pH …………………… Soil temperature ………… Transect: ………… Plot no: ……… Size of Plot: 20m × 20m

SN	**Species**	**DBH (cm)** **Or** **CBH (cm)**	**Height (m)**	**Remarks** (Tree condition: dead, cut, diseased, fallen, lopped etc.)

Note: For tree, measure DBH ≥ 5cm and height >1.37m.Tree with multiple stems are considered and inventoried as multiple individuals if the stem split below 1.37m in height (along the stem).

For shrubs, saplings and invasive plants

Transect no:………… Plot no:……………. Plot size: 5m × 5m plot inside the main plot.

SN	Species	Number	Height (m)	Cover (%)	Remarks Any observable characters

Note: *Shrub and tree sapling are the individuals with height > 50 cm to DBH < 5cm*

Don't forget to collect soil sample from every plot

Collect soil sample from 10-15 cm depth from four corners and centre, mix them homogenously and take about 400-500 gm. Label properly (plot no., locality, forest type etc.) in zipper lock bag. Dry the soil sample in air for 24 hrs in room temperature as soon as possible. **Take field weight and air dry weight of soil**.

For herb (including Pteridophytes)

Establish three1m × 1m square plots diagonally (two opposite corner and centre) inside the main plot.

Transect: ………… **Main Plot no:** ………………. **Size of Plot:** 1 m x 1m

SN	Species	Number in sub-plots			Cover (%) in sub-plots		
		1	2	3	1	2	3

Note: *Tree and shrub seedlings are with height<50cm. Count Tree seedling in main plot if the seedlings are absent in1m XI m plots.*

Appendix II: Plot characteristics

a) Sal Forest

Plot	Longitude (°E)	Latitude (°N)	Altitude (m/asl)	Slope	Canopy cover (%)	Invasive cover (%)
1	80°38'46"	28°42'3"	163	Plane	40	15
2	80°38'43"	28°42'4"	153	Plane	40	12
3	80°38'48"	28°42'4"	107	Plane	30	0
4	80°38'53"	28°42'5"	110	Plane	40	0
5	80°39'58"	28°42'11"	179	Plane	55	10
6	80°38'49"	28°42'11"	155	Plane	35	9
7	80°38'52"	28°42'11"	111	Plane	40	10
8	80°38'56"	28°42'13"	114	Plane	30	5
9	80°38'44"	28°42'12"	185	Plane	60	0
10	80°38'47"	28°42'13"	176	Plane	60	0
11	80°38'48"	28°42'10"	172	Plane	60	15
12	80°38'48"	28°42'8"	160	Plane	45	0
13	80°38'53"	28°42'7"	150	Plane	50	0
14	80°38'46"	28°42'21"	130	Plane	35	10
15	80°38'47"	28°42'22"	171	Plane	65	10
16	80°38'49"	28°42'23"	165	Plane	50	25
17	80°38'51"	28°42'24"	176	Plane	60	7
18	80°38'54"	28°42'22"	170	Plane	50	8
19	80°38'53"	28°42'22"	186	Plane	40	20
20	80°38'56"	28°42'22"	185	Plane	50	0

b) Riverine Forest

Plot	Longitude (°E)	Latitude (°N)	Altitude (m/asl)	Slope	Canopy cover (%)	Invasive cover (%)
1	80°32'24"	28°42'43"	137	Plane	45	15
2	80°32'27"	28°42'45"	155	Plane	50	15
3	80°32'29"	28°42'47"	154	Plane	40	25
4	80°32'29"	28°42'49"	151	Plane	30	25
5	80°32'29"	28°42'52"	158	Plane	30	20
6	80°32'26"	28°42'52"	158	Plane	35	10
7	80°32'24"	28°42'51"	158	Plane	35	60
8	80°32'22"	28°42'51"	159	Plane	25	65
9	80°32'20"	28°42'48"	161	Plane	50	50
10	80°32'20"	28°42'45"	162	Plane	50	40
11	80°32'21"	28°42'43"	158	Plane	45	20
12	80°32'22"	28°42'41"	160	Plane	50	25
13	80°32'24"	28°42'39"	159	Plane	45	55
14	80°32'26"	28°42'39"	160	Plane	50	45
15	80°32'27"	28°42'39"	159	Plane	40	40
16	80°32'33"	28°42'41"	153	Plane	35	15
17	80°32'31"	28°42'43"	154	Plane	45	60
18	80°32'32"	28°42'46"	154	Plane	55	30
19	80°32'34"	28°42'44"	154	Plane	40	50
20	80°32'34"	28°42'43"	154	Plane	40	35

Appendix III : List of trees, herbs, shrubs, climbers, ferns

Scientific names	**Local names**	**Family**	**Life forms**
Adina cordifolia (Roxb.) Brandis	Haldu, Karam	Rubiaceae	Tree
Senegalia catechu (L.f.) Willd.	Khayer	Fabaceae	Tree
Dalbergia sissoo Roxb. ex DC.	Sissam	Fabaceae	Tree
Terminalia chebula Retz.	Harro	Combretaceae	Tree
Sapindus mukorossi Gaertn.	Rittha	Sapindaceae	Tree
Phyllanthus emblica L.	Amala	Phyllanthaceae	Tree
Syzygium cumini- (L.) Skeels	Jamun	Myrtaceae	Tree
Trewia nudiflora- L.	Bheller	Euphorbiaceae	Tree
*Leucaena leucocephal*a (Lam.) de Wit	Ipil-Ipil	Fabaceae	Tree
Mallotus philippensis (Lam.) Mull.Arg	Sindure	Euphorbiaceae	Tree
Bombax ceiba L.	Simal	Malvaceae	Tree
Prosopsis cineraria (L.) Druce	Khari, Shami	Fabaceae	Tree
Melia azedarach - L.	Bakaino	Meliaceae	Tree
*Cinnamomum tamal*a (Buch. - Ham.) Th. G.G.Nees	Teejapatta	Lauraceae	Tree
Ficus religiosa L.	Peepal	Moraceae	Tree
Dalbergia latifolia Roxb.	Satisal	Fabaceae	Tree
*Magnifera indic*a L.	Aap	Anacardiaceae	Tree
Bauhinia purpurea L.	Tanki	Fabaceae	Tree
Terminalia arjuna (Roxb. Ex DC.) Wight & Arn	Arjun	Combretaceae	Tree
Tectona grandis L.f.	Sagaun	Lamiaceae	Tree
Schleichera oleosa (Lour.) Oken	Kusum	Sapandiacea	Tree
Pisidium guajava L.	Amba	Myrtaceae	Tree
Syzygium nervosum DC.	Kyamuno	Myrtaceae	Tree
Albizia lebbeck (L.) Benth.	Siris	Fabaceae	Tree
Sapindus pinnata (L.f.) Kurz	Amaro	Anacardiaceae	Tree
Shorea robusta - Gaertn. f.	Sal	Dipterocarpaceae	Tree
Holarrhena pubescens Wall. ex	Dudhekhirro	Apocynaceae	Tree

G.Don			
Lagerstroemia parviflora – Roxb	Bot Dhaiyanro	Lythraceae	Tree
Semecarpus anacardium L.fil	Bhalayo	Anacardiaceae	Tree
Terminalia alata - Heyne ex Roth	Saaj	Combretaceae	Tree
*Aegle marmelos*L. Correa	Bel	Rutaceae	Tree
Careya arborea – Roxb	Kumbhi	Lecythidaceae	Tree
Garuga pinnata - Roxb.	Dabdabe	Burseraceae	Tree
Terminalia bellirica- (Gaertn.) Roxb.	Barro	Combretaceae	Tree
Achyranthes aspera L.	Datiwan	Amaranthaceae	Herb
Ageratum conyzoides L.	Seto Gandhe	Asteraceae	Herb
Ageratum houstonianum Mill	Nilo Gandhe	Asteraceae	Herb
Bambusa vulgaris Nees.	Tama, Bans	Poaceae	Herb
Cynodon dactylon (L.) Pers.	Dubo	Poaceae	Herb
Euphorbia hirta L	Dudhe jhar	Euphorbiaceae	Herb
Evolvulus nummularius (L.) L.		Convolvulaceae	Herb
Imperata cylindrica (L.) Raeusch.	Siru	Poaceae	Herb
Panicum notatum Retz		Poaceae	Herb
Ocimum gratissimum L.	Tulasi	Lamiaceae	Herb
Oplismenus sp		Poaceae	Herb
Senna tora (L.) Roxb.	Tapre jhar	Fabaceae	Herb
Saccharum spontaneum L.	Kans	Poaceae	Herb
Xanthium strumarium L.	Bhed	Asteraceae	Herb
Arundinella nepalensis Trin.		Poaceae	Herb
Cyanthillium cinereum (L.) H.Rob	Marchaa jhar	Asteraceae	Herb
Cyperus distans L.f.	Mothe	Cyperaceae	Herb
Desmostachya bipinnata (L.) Stapf	Kush	Poaceae	Herb
Dysphania graveolens (Lag. & Rodr.)		Amaranthaceae	Herb
Ageratina adenophora Spreng.) R.M.King&H.Rob.	Banmara, Kali Jhar	Asteraceae	Herb
Filago arvensis L.		Asteraceae	Herb
Hellenia speciosa (J.Koenig) S.R.Dutta	Betalauri	Costaceae	Herb
Oplismenus burmanni (Retz.)	Ote, Banso	Poaceae	Herb

P.Beauv.			
Zingiber officinale Roscoe	Bayer	Zingiberaceae	Herb
Curculigo latifolia Dryand. ex W.T.Aiton		Hypoxidaceae	Herb
*Clerodendron indicum (*L.*) kuntz*		Lamiaceae	Shrub
Calotropis gigantea (L.) W.T.Aiton	Aank	Apocynaceae	Shrub
Flemingia strobilifera (L.) W.T.Aiton	Bhatmas jhar	Fabaceae	Shrub
Urena lobata L.	Chhipi	Malvaceae	Shrub
Colebrookea oppositifolia Sm.	Dhurseli	Lamiaceae	Shrub
Callicarpa macrophylla Vahl.	Daikamlo	Lamiaceae	Shrub
Calamus tenuis Roxb.		Arecaceae	Shrub
Ziziphus mauritiana Lam.	Bayer	Rhamnaceae	Shrub
Hyptis suaveolens (L.) Poit.	Bhangeri,Ban Silam	Lamiaceae	Shrub
Lantana camara L.	Banphada Kanda	Verbenaceae	Shrub
Sida acuta Burm .F.	Balu	Malvaceae	Shrub
Solanum torvum Sw.		Solanaceae	Shrub
Piper longum L.	Pipla	Piperaceae	Climber
Solena heterophylla Lour.	Gol kaankree	Cucurbitaceae	Climber
Asparagus racemosus Wild.	Kurilo	Liliaceae	Climber
Lygodium flexuosum (L.) Sw.	Parewapoti	Schizaeaceae	Fern
Adiantum philippense L.		Pteridaceae	Fern
Ceratopteris thalictroides (L.) Brongn.		Pteridaceae	Fern
Thelypteris sp.		Thelypteridaceae	Fern

Appendix IV: Vegetation parameters

a) **Sal Forest**

Plots	Mean DBH	Standard Error	Mean Height	Standard Error	Basal area (m²/ha)	Carbon stock (t/ ha)	Tree species richness	Tree canopy cover (%)	IAPS richness	IAPS cover (%)
1	28.25	4.15	9.77	1.26	38.5	140.73	5	40	1	15
2	32.71	4.87	10.66	1.26	52	209.75	5	40	1	12
3	29.80	5.35	12.85	1.54	56	302.13	4	30	0	0
4	38.46	6.05	14.32	1.84	68.75	375.08	5	40	0	0
5	25.95	5.18	9.23	1.45	76.75	412.36	6	55	1	10
6	27.87	5.16	8.33	1.1	53.75	203.44	6	35	1	9
7	35.93	6.33	13.42	1.39	86.25	427.47	4	40	1	10
8	29.33	5.37	11.45	1.73	24.75	106.03	4	30	1	5
9	13.15	2.37	7.41	0.53	31.75	100.75	3	60	0	0
10	15.97	3.08	8.15	0.87	44.25	220.41	5	60	0	0
11	17.89	3.10	8.36	0.81	59.25	261.99	6	60	1	15
12	29.58	4.81	12.18	1.46	70	380.69	5	45	0	0
13	15.51	2.36	7.97	0.75	35.97	152.37	7	50	0	0
14	25.48	5.71	10.45	1.58	53.65	317.02	5	35	1	10
15	12.19	1.07	6.46	0.49	16.6	43.07	4	65	1	10
16	16.90	2.60	7.74	0.77	41.5	166.00	4	50	2	25
17	25.17	5.13	9.96	1.24	71	371.84	6	60	1	7
18	24.6	4.39	11.43	1.20	49.25	238.52	6	50	1	8
19	25.25	4.26	9.40	1.41	41	166.97	4	40	2	20
20	41.95	5.35	14.60	1.17	84.75	411.48	5	50	0	0

b) Riverine forest

Plots	Mean DBH	Standard Error	Mean Height	Standard Error	Basal area (m^2/ha)	Carbon stock (t/ha)	Tree Species richness	Tree canopy cover (%)	IAPS richness	IAPS cover (%)
1	39.51	3.83	12.17	0.89	107.5	385.52	6	45	2	15
2	44.67	3.47	12.53	1.41	137.5	562.98	7	50	2	15
3	17.47	2	9.41	1	30	117.61	7	40	3	25
4	13.18	1.06	7.96	0.78	17.5	50.54	4	30	3	25
5	22.80	4.29	9.86	1.31	22.5	99.71	6	30	2	20
6	22.29	2.46	13.23	1.03	25	110.62	3	35	2	10
7	20.12	2.58	10	1.02	12.5	38.52	3	35	4	60
8	18.99	1.50	10.9	1.12	12.5	38.23	2	25	4	65
9	20.80	3.16	11.11	1.07	22.5	83.49	7	50	3	50
10	16.78	1.21	10.60	0.62	17.5	62.79	6	50	3	40
11	17.51	1.71	9.67	0.67	25	77.90	6	45	2	20
12	15.29	1.62	8.85	0.77	15	38.82	8	50	3	25
13	16.66	1.80	7.68	0.71	25	80.81	5	45	4	55
14	15.91	1.49	9.51	0.43	17.5	46.73	7	50	3	45
15	18.71	2.15	8.17	0.65	42.5	138.34	8	40	3	40
16	23.10	3.14	9.20	0.71	32.5	102.56	9	35	2	15
17	20.47	3.17	9.62	0.91	30	110.43	10	45	3	60
18	19.84	2.12	9.48	0.71	40	140.05	7	55	2	30
19	18.79	2.52	9.67	0.93	22.5	64.23	8	40	3	50
20	27.23	3.47	11.75	1	42.5	180.98	8	40	3	35

Appendix V: Relative frequency, Relative density, Relative Basal Area and IVI of tree species

a) Sal forest

S.N	Tree species	Frequency	Relative Frequency	Density / Ha	Relative density	BA/Ha	Relative BA	IVI (RD + RF + RBA)
1	*Shorea robusta*	100	20.83	415	61.82	26.04	20.83	103.49
2	*Mallotus philippensis*	85	17.70	70	10.42	22.13	17.70	45.84
3	*Holarrhena pubescens*	65	13.54	28.75	4.28	16.92	13.54	31.36
4	*Lagerstroemia parviflora*	5	1.04	1.25	0.18	1.30	1.04	2.26
5	*Semecarpus anacardium*	40	8.33	16.25	2.42	10.41	8.33	19.08
6	*Terminalia alata*	95	19.79	111.25	16.57	24.73	19.79	56.15
7	*Aegle marmelos*	10	2.08	2.5	0.37	2.60	2.08	4.53
8	*Careya arborea*	5	1.04	1.25	0.18	1.30	1.04	2.26
9	*Phyllanthus emblica*	5	1.04	1.25	0.18	1.30	1.04	2.26
10	*Terminalia bellirica*	10	2.08	3.75	0.55	2.60	2.08	4.72
11	*Albizia lebbeck*	10	2.08	2.5	0.37	2.60	2.08	4.53
12	*Garuga pinnata*	15	3.12	6.25	0.93	3.90	3.12	7.18
13	*Syzgium cumini*	15	3.12	3.75	0.55	3.90	3.12	6.80
14	*Trewia nudiflora*	5	1.04	1.25	0.18	1.30	1.04	2.26
15	*Schleichera oleosa*	10	2.08	5	0.74	2.60	2.08	4.91
16	*Adina cordifolia*	5	1.04	1.25	0.18	1.30	1.04	2.26
	Total	**480**	**100**	**671.25**	**100**	**125**	**100**	**300**

b) Riverine Forest

S.N	Tree species	Frequency (%)	Relative frequency	Density/ Ha	Relative density	BA/H a	Relative BA	IVI (RD+ RF+RBA)
1	*Adina cordifolia*	90	14.06	150	22.47	17.57	14.06	50.59
2	*Senegalia catechu*	100	15.62	250	37.45	19.53	15.62	68.70
3	*Dalbergia sissoo*	85	13.28	67.5	10.11	16.60	13.28	36.67
4	*Terminalia chebula*	10	1.56	2.5	0.37	1.95	1.56	3.49
5	*Sapindus mukorossi*	10	1.56	2.5	0.37	1.95	1.56	3.49
6	*Phyllanthus emblica*	20	3.12	7.5	1.12	3.90	3.12	7.37
7	*Syzgium cumini*	35	5.46	22.5	3.37	6.83	5.46	14.30
8	*Trewia nudiflora*	20	3.12	17.5	2.62	3.90	3.12	8.87
9	*Leucaena leucocephala*	10	1.56	5	0.74	1.95	1.56	3.87
10	*Mallotus philippensis*	65	10.15	36.25	5.43	12.69	10.15	25.74
11	*Bombax cebia*	55	8.59	20	2.99	10.74	8.59	20.18
12	*Prosopsis cineraria*	10	1.56	2.5	0.37	1.95	1.56	3.499
13	*Melia azedarach*	10	1.56	3.75	0.56	1.95	1.56	3.68
14	*Cinnamomum tamala*	30	4.68	13.75	2.05	5.85	4.68	11.43
15	*Ficus religiosa*	5	0.78	1.25	0.18	0.97	0.78	1.74
16	*Dalbergia latifolia*	10	1.56	3.75	0.56	1.95	1.56	3.68
17	*Magnifera indica*	5	0.78	5	0.74	0.97	0.78	2.31
18	*Terminalia arjuna*	20	3.12	21.25	3.18	3.90	3.12	9.43
19	*Bauhinia purpurea*	15	2.34	13.75	2.05	2.92	2.34	6.74
20	*Tectona grandis*	5	0.78	2.5	0.37	0.97	0.78	1.93
21	*Schleichera oleosa*	5	0.78	1.25	0.18	0.97	0.78	1.74
22	*Pisidium guajava*	5	0.78	2.5	0.37	0.97	0.78	1.93
23	*Syzgium nervosum*	10	1.56	5	0.74	1.95	1.56	3.87
24	*Albizia lebbeck*	5	0.78	6.25	0.93	0.97	0.78	2.49
25	*Sapindus pinnata*	5	0.78	3.75	0.56	0.975	0.78	2.12
	Total	**640**	**100**	**667.5**	**100**	**125**	**100**	**300**

Appendix VI: Carbon stock among tree species

a) Sal forest

S.N	Tree species	Total Carbon stock (Kg)	Carbon stock (Tonns)	Carbon stock t ha^{-1}
1	*Shorea robusta*	187067.41	187.06	233.83
2	*Mallotus philippensis*	1397.33	1.39	1.74
3	*Holarrhena pubescens*	1239.86	1.23	1.54
4	*Lagerstroemia parviflora*	222.39	0.22	0.27
5	*Semecarpus anacardium*	637.81	0.63	0.79
6	*Terminalia alata*	5036.55	5.03	6.29
7	*Aegle marmelos*	16.78	0.01	0.02
8	*Careya arborea*	11.77	0.01	0.014
9	*Phyllanthus emblica*	9.18	0.009	0.011
10	*Terminalia bellirica*	95.89	0.095	0.11
11	*Albizia lebback*	381.49	0.38	0.47
12	*Garuga pinnate*	56.10	0.056	0.07
13	*Syzgium cumini*	310.88	0.31	0.388
14	*Trewia nudiflora*	18.74	0.018	0.023
15	*Schleichera oleosa*	3822.99	3.82	4.77
16	*Adina cordifolia*	2.48	0.002	0.003
	Total			250.40

b) Riverine forest

S.N	Tree species	Total Carbon stock (kg)	Carbon stock (tons)	Carbon stock t ha^{-1}
1	*Adina cordifolia*	2042.38	2.042	2.55
2	*Senegalia catechu*	42675.23	42.67	53.34
3	*Dalbergia sissoo*	32685.18	32.68	40.85
4	*Terminalia chebula*	473.55	0.47	0.59
5	*Sapindus mukorossi*	223.39	0.22	0.27
6	*Phyllanthus emblica*	2023.30	2.023	2.52
7	*Syzgium cumini*	3570.93	3.57	4.46
8	*Trewia nudiflora*	1637.15	1.63	2.04
9	*Leucaena leucocephala*	1014.83	1.01	1.26
10	*Mallotus philippensis*	1891.70	1.89	2.36
11	*Bombax cebia*	1657.42	1.65	2.07
12	*Prosopsis cineraria*	840.57	0.84	1.050
13	*Melia azedarach*	213.49	0.21	0.266
14	*Cinnamomum tamala*	1162.66	1.16	1.45
15	*Ficus religiosa*	8.37	0.008	0.010
16	*Dalbergia latifolia*	663.53	0.66	0.82
17	*Magnifera indica*	80.42	0.08	0.1005
18	*Terminalia arjuna*	4242.28	4.24	5.30
19	*Bauhinia purpurea*	197.95	0.19	0.24
20	*Tectona grandis*	1126.58	1.12	1.40
21	*Schleichera oleosa*	333.96	0.33	0.41
22	*Pisidium guajava*	4.31	0.004	0.005
23	*Syzgium nervosum*	152.78	0.15	0.19
24	*Albizia lebbeck*	1277.04	1.27	1.59
25	*Sapindus pinnata*	237.61	0.23	0.29
	Total			125.54

Appendix VII: Density of Seedlings, Saplings and Adult (stem/plot)

Plot	Sal forest			Riverine forest		
	Seedlings	Saplings	Adults	Seedlings	Saplings	Adults
1	58	7	18	14	0	28
2	45	0	18	22	6	30
3	64	7	20	40	19	35
4	45	9	17	19	3	41
5	115	12	28	8	0	15
6	74	3	21	12	1	21
7	66	8	21	5	0	13
8	54	0	11	7	0	15
9	217	10	41	7	0	18
10	172	14	38	16	3	29
11	250	17	43	20	4	32
12	49	0	25	10	2	24
13	203	12	40	38	9	33
14	90	11	43	22	11	27
15	334	18	39	15	4	38
16	94	8	28	5	0	22
17	52	5	24	11	1	24
18	50	8	24	29	7	37
19	43	3	21	12	0	20
20	70	9	19	6	0	38

Appendix VIII: Diversity Parameter of the study forest

Plot	Sal forest			Riverine forest		
	Shannon's Index	**Simpson's Index**	**Tree Richness**	**Shannon's Index**	**Simpson's Index**	**Tree Richness**
1	1.38	0.75	5	1.34	0.7	6
2	1.36	0.73	5	1.68	0.8	7
3	1.08	0.61	4	1.61	0.77	7
4	1.18	0.67	5	0.78	0.43	4
5	1.30	0.67	6	1.53	0.8	6
6	1.40	0.70	6	0.71	0.41	3
7	0.80	0.41	4	0.73	0.45	3
8	1.12	0.67	4	0.25	0.14	2
9	0.72	0.47	3	1.43	0.69	7
10	1.06	0.61	5	0.74	0.33	6
11	1.02	0.47	6	1.16	0.6	6
12	0.95	0.47	5	1.55	0.73	8
13	1.19	0.60	7	1.24	0.69	5
14	1.24	0.67	5	1.17	0.52	7
15	0.70	0.36	4	1.97	0.87	8
16	1.00	0.55	4	2.09	0.91	9
17	1.20	0.66	6	2.11	0.9	10
18	1.03	0.49	6	1.74	0.81	7
19	1.14	0.6	4	1.63	0.78	8
20	0.73	0.38	5	1.9	0.88	8
Total	**2.21**	**0.86**	**16**	**2.71**	**0.91**	**25**

Appendix IX: Photo Plates

DBH measurement

Taking field notes

Soil collection

Soil PH measurement

Photo with Forest Guard of Community Forest

सुदूरपश्चिम प्रदेश सरकार
उद्योग, पर्यटन, वन तथा वातावरण मन्त्रालय
वन निर्देशनालय

डिभिजन वन कार्यालय, कैलाली

धनगढी, कैलाली, नेपाल

प.सं. ०७९/८०
च.नं. 80

फोन नं. -०९१-५२११३३

मिति : २०८०।४।०८

श्री देवरिया सामुदायिक वन उपभोक्ता समुह,
धनगढी कैलाली ।

विषय : सहजीकरण गरिदिन हुन ।

उपरोक्त सम्बन्धमा च.नं. २२ मिति २०८०।४।०८ गतेको प्राप्त पत्रानुसार व्यहोरा सोहीबाट अवगत गरी Status & Impact of Invasive plant in different land use types of Dhangadhi Nepal शीर्षकमा Thesis तयारी कार्यको लागी आवश्यक सहजीकरण गरीदिनु हुन अनुरोध छ ।

भिम प्रसाद ढकाल
नि. डिभिजनल वन अधिकृत

वोधार्थ :
श्री पुजा भट्ट : अध्ययन कार्य गर्नुहुन अनुरोध छ ।

सुदूरपश्चिम प्रदेश सरकार

उद्योग, पर्यटन, वन तथा वातावरण मन्त्रालय

धनगढी, कैलाली, नेपाल

प.सं. २०८०/०८१
च.नं ८२

मिति: २०८०।०४।०८

श्री डिभिजन वन कार्यालय कैलाली,
धनगढी, कैलाली ।

विषयः अध्ययन कार्य सम्बन्धमा ।

प्रस्तुत विषयमा अमृत क्याम्पस लैनचौर काठमाण्डौंमा अध्ययनरत विद्यार्थी श्री पुजा भट्टले Status & Impact of Invasive plant species in different land use types of Dhangadhi Nepal शीर्षकमा Thesis तयारी कार्य सम्बन्धमा आवश्यक सहयोगका लागि निवेदन दिनु भएकोमा तहाँ डिभिजन वन कार्यालयको कार्य क्षेत्र भित्रको वन क्षेत्रमा वातावरणीय हिसाबले कुनै पनि किसिमको हानी नोक्सानी नहुने गरी सो छात्रालाई अध्ययन प्रयोजनका लागि Invasive Species बोट बिरुवा संकलन गरी अध्ययन कार्यमा सहयोग गर्नहुन अनुरोध छ ।

२०८०।४।८
जनक पाध्या
(उपसचिव)

बोधार्थ :
श्री पुजा भट्ट : डिभिजन वन कार्यालय कैलालीसंग समन्वय गरी अध्ययन कार्य गर्नहुन ।