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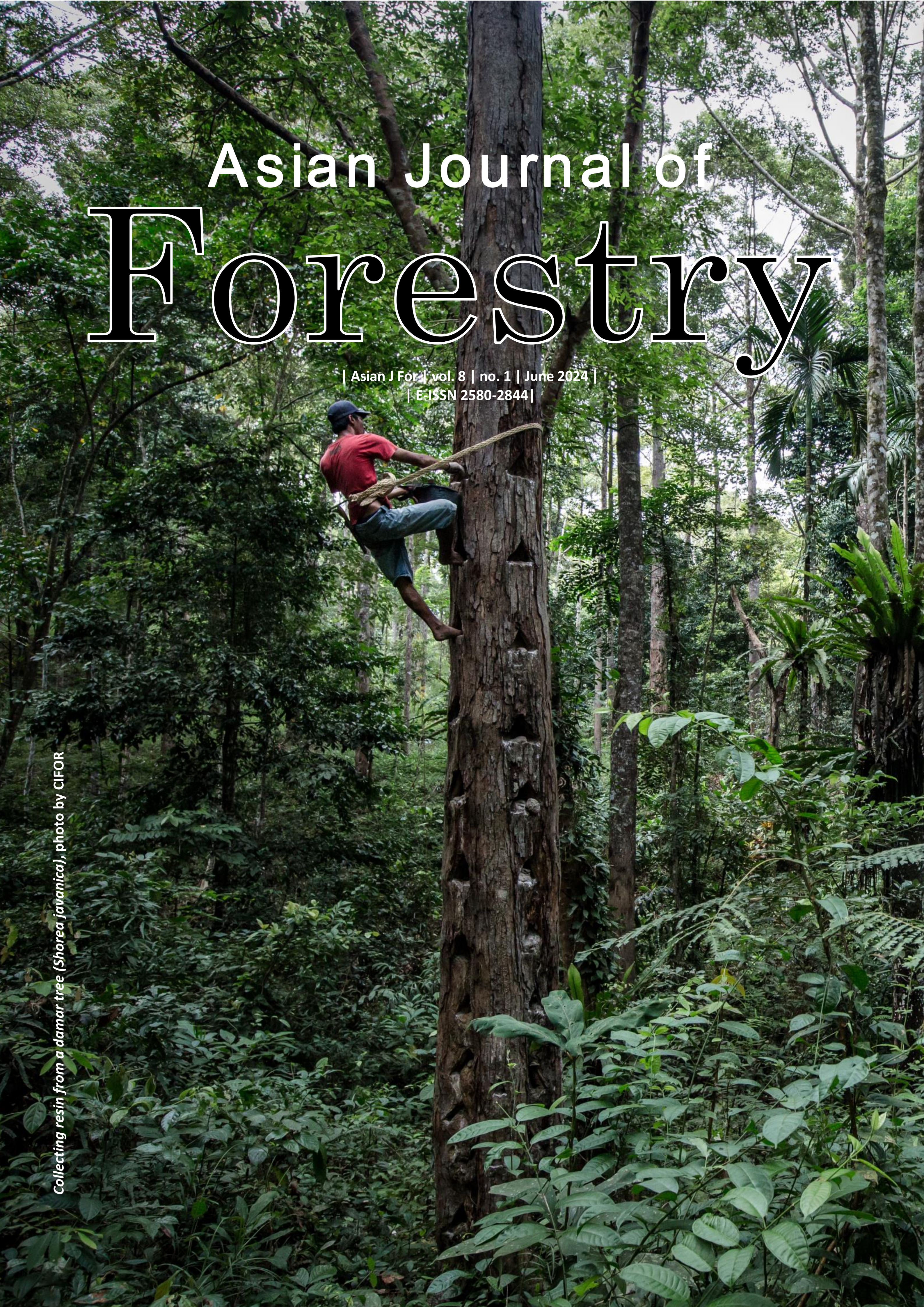

Collecting resin from a damar tree (Shorea javanica), photo by CIFOR

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Abstract A concise abstract is required (about 200 words). The abstract should be informative and state briefly the aim of the research, the principal results and major conclusions. An abstract is often presented separately from the article, thus it must be able to stand alone (completely self-explanatory). References should not be cited, but if essential, then cite the author(s) and year(s). Abbreviations should be avoided, but if essential, they must be defined at their first mention. **Keywords** are about five words, covering scientific and local name (if any), research themes, and special methods used; and sorted from A to Z. **Abbreviations** (if any): All important abbreviations must be defined at their first mention there. **Running title** is about five words.

Introduction is about 600 words, covering the aims of the research and provide an adequate background, avoiding a detailed literature survey or a summary of the results. **Materials and Methods** should emphasize on the procedures and data analysis. **Results and Discussion** should be written as a series of connecting sentences, however, for a manuscript with long discussion should be divided into subtitles. Thorough discussion represents the causal effect mainly explains why and how the results of the research were taken place, and do not only re-express the mentioned results in the form of sentences. **Concluding** sentence should be given at the end of the discussion. **Acknowledgements** are expressed in a brief; all sources of institutional, private and corporate financial support for the work must be fully acknowledged, and any potential conflicts of interest are noted.

Figures and Tables of a maximum of three pages should be clearly presented. The title of a picture is written down below the picture, while the title of a table is written above the table. Colored figures can only be accepted if the information in the manuscript can lose without those images; the chart is preferred to use black and white images. The author could consign any picture or photo for the front cover, although it does not print in the manuscript. All images property of others should be mentioned the source. Author is suggested referring to Wikipedia for international boundaries and Google Earth for satellite imagery. If not specifically mentioned, it is assumed to refer to these sources. **There is no appendix**, all data or data analysis is incorporated into Results and Discussions. For broad data, it can be displayed on the website as a supplement.

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Journal:

Saharjo BH, Nurhayati AD. 2006. Domination and composition structure change at hemic peat natural regeneration following burning; a case study in Pelalawan, Riau Province. Biodiversitas 7: 154-158. DOI: 10.13057/biodiv/d070213.

The usage of "et al." in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al. 1999. Future of health insurance. N Engl J Med 965: 325-329. DOI: 10.10007/s002149800025.

Book:

Rai MK, Carpinella C. 2006. Naturally Occurring Bioactive Compounds. Elsevier, Amsterdam.

Chapter in the book:

Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of rainforest tree communities. In: Carson W, Schnitzer S (eds.). Tropical Forest Community Ecology. Wiley-Blackwell, New York.

Abstract:

Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th annual symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.). Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

Sugiyarto. 2004. Soil Macro-invertebrates Diversity and Inter-Cropping Plants Productivity in Agroforestry System based on Sengon. [Dissertation]. Universitas Brawijaya, Malang. [Indonesian]

Information from the internet:

Balagadde FK, Song H, Ozaki J, Collins CH, Barnet M, Arnold FH, Quake SR, You L. 2008. A synthetic *Escherichia coli* predator-prey ecosystem. Mol Syst Biol 4: 187. DOI: 10.1038/msb.2008.24. www.molecularsystembiology.com.

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Review: The potential of agroforestry in South Asian countries towards achieving the climate goals

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Manuscript received: 18 July 2023. Revision accepted: 11 September 2023.

Abstract. *Raihan A. 2024. Review: The potential of agroforestry in South Asian countries towards achieving the climate goals. Asian J For 8: 1-17.* Throughout history, millions of South Asian smallholder farmers have relied on traditional agroforestry techniques. Since last two decades, agroforestry's potential as a carbon sink has been debated in international climate negotiations. Greenhouse Gases (GHGs) offsetting, livelihood provision, Sustainable Development Goals (SDGs) localization, and achievements towards biodiversity conservation are the areas in which agroforestry plays a pivotal role. This paper reviews the benefits of agroforestry practices to human well-being and assesses their contribution on adaptation and mitigation of climate change in South Asian countries. This research delves into the factors that can help or hinder the mainstream adoption of agroforestry systems, which could be used to achieve international goals for reducing consequences of global warming. The South Asian countries who have joined hands in the Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC) recognize the value of agroforestry systems in mitigating global warming. A major enabling condition for ensuring the efficacy of employing agroforestry to achieve climate targets was established in 2016 with the adoption of the South Asian Association for Regional Cooperation (SAARC) resolution on agroforestry by all regional governments. One of the main obstacles to effectively monitoring plant and soil carbon stocks is the lack of standardized approaches to database building. Other challenges that should be properly addressed by nations in the region in order to enhance their capacities to accomplish national climate ambitions include water shortages, inadequate governance through interaction, property rights for farmers, legal protections complications, and inadequate financial assistance to small-scale farmers for agroforestry. Strong examples were provided from Nepal and India, encompassing sustainable local economies, carbon-free futures, and financial incentives, all of which point to the need to move from planning to implementation to improve readiness.

Keywords: Agroforestry, carbon neutrality, climate change, emission reduction, South Asia

INTRODUCTION

Human-caused climate change is currently recognized as a global climate emergency (Ripple et al. 2020; Raihan and Said 2022; Evans-Agnew et al. 2023; Raihan and Himu 2023; Raihan 2023a). Many places have been hit harder by climate change due to greater vulnerability to climatic risks and poor adaptability (IPCC 2022; Isfat and Raihan 2022; Caretta et al. 2023; Johnson et al. 2023; Raihan 2023b). Sustainable Development Goals (SDGs) including food security, biodiversity protection, ecosystem restoration are major worldwide challenges (Feliciano et al. 2018; Begum et al. 2020; Kok et al. 2023; Raihan 2023c). Natural disasters and climatic variability are increasing, making climate adaptation and mitigation more important (Raihan and Tuspekova 2023a; Ghosh et al. 2023; Usman et al. 2023). Adaptation activities to enhance methods for managing water and land are vital to climate risk resilience (Amer et al. 2023; Kyriakopoulos and Sebos 2023; Raihan and Tuspekova 2023b).

Countries like Sri Lanka, Pakistan, Bangladesh, India, the Maldives, Nepal, Afghanistan, and Pakistan make up South Asia. South Asia has many civilizations and ecosystems (Steger 2023; Voumik et al. 2023). South Asia's growing population, poverty, dependency on natural resources, and low adaptive capacity make it vulnerable to climate change (Raihan and Voumik 2022a; Ranasinghe et al. 2023). Approximately 25% of the world's population lives in South Asia (Maharjan et al. 2020; Sarkar et al. 2023). Rapid population growth and the geographical position of the countries (cyclone prone coastal areas of India, Bangladesh, Sri Lanka, and the Maldives) make the region a hotspot of climate crisis (Dutta et al. 2013). It is becoming harder to feed a growing population without jeopardizing agricultural land (Raihan and Tuspekova 2022a; Rabbi et al. 2023). Expanding and intensifying agriculture worsens biodiversity loss and deforestation (Mulinge 2023; Raihan 2023d). Food production must be environment friendly because of limited agricultural land per population (Beal et al. 2023; Raihan et al. 2023a). Multifunctional land use systems support productive landscapes, ecosystems, social, economic, and regulatory goals while meeting rising regional land and food demands and climatic dangers (Westholm and Ostwald 2020; Baldwin et al. 2023; Raihan et al. 2023b).

Adaptation is necessary since climate extremes are expected to strike developing nations the hardest (Yang et al. 2020; Stange et al. 2023). Farmers must adapt to changing climates and invest in productive, cost-effective farms to achieve the SDGs (Jat et al. 2020; Wang et al.

2023; Raihan 2023e). The Intergovernmental Panel on Climate Change (IPCC) has highlighted South Asia's ability to embrace alternatives for both adaptation and mitigation, with the potential for carbon-offset partnerships to advance pro-poor development. Farmers oversee techniques like agroforestry, natural regeneration, and adaptive agriculture (Raihan et al. 2018; Cialdella et al. 2023). When contemplating adaptation-mitigation synergy, income diversification from trees and forests shouldn't be the exclusive focus. Restoring ecosystems improves soil health, biodiversity, and fire safety (Raihan et al. 2019; Kirkland et al. 2023). Thus, restoring ecosystem through agroforestry is a good adaptation and mitigation approach. The Paris Agreement's Intended Nationally Determined Contributions (INDCs) are the primary pathway for the countries to set targets and report progress. Another NDC-achievable adaptation and mitigation approach is terrestrial vegetation carbon sequestration. Several studies found that agroforestry in critical landscapes can help developing nations meet NDC obligations (Rosenstock et al. 2019; Telwala 2023).

Trees Outside Forests (TOFs) boost biomass, carbon stocks, and improves the socio-economic conditions of people by providing livelihood and tangible ecosystem services. In recent decades, policymakers have included TOFs in national forest inventories due to their expanding importance (Raihan et al. 2021a; Reiner et al. 2023). Agroforestry improves lives by providing, regulating, and preserving ecosystem services (Kumar 2016; Santoro 2023). Trees on fertile land can absorb carbon and help adapt to and mitigate climate change (Raihan et al. 2022a; Critchley et al. 2023). IPCC (2022) reported that global temperatures are expected to rise 1.5˚C over pre-industrial levels between 2030 and 2052 due to the increasing rate of carbon emissions. On the other hand, trees absorb the atmospheric carbon dioxide and store it as biomass carbon. Thus, the role of trees to mitigate climate change is becoming more important (Raihan et al. 2021b). Adapting to climate change needs understanding regional agroforestry practices, developing pathways for future promotion to fulfill climatic promises, and ensuring widespread adoption (Dhakal and Rai 2020; Wakweya 2023). However, there is a research gap exploring the potential of agroforestry to achieve climate change adaptation and mitigation targets by the South Asian countries although agroforestry is being practiced vastly throughout the region. Thus, the present study reviewed Agroforestry Systems's (AFS) ability to support South Asian countries' mitigation targets and NDCs. The study also highlights significant concerns, existing policies, and places where agroforestry gaps need to be addressed in the region and explores the need to incorporate AFS into MRV (Monitoring, Reporting, and Verification). This review critically examines the extensive proof that AFS and its operations provide broad ecological function in South Asia, the crucial climate-related discourse involving agroforestry as a tool for climate change adaptation and mitigation; the essential features and limitations of agroforestry for climate change adaptation and mitigation. This effort of this review to aggregate and communicate AFS information and mainstream it in climate debates will benefit academics, politicians, and researchers. This study would be helpful for the policymakers for formulating effective policies in the areas of climate-smart agroforestry practices to reduce the negative impacts of global warming and climate change.

SOUTH ASIAN AGROFORESTRY PRACTICES

Agroforestry techniques are widely utilized and accepted in tropical developing South-East Asian, South Asian, Central American, and South American nations (Ramirez-Santos et al. 2023). This is due to the fact that agroforestry techniques are dynamic and sustainable means of food production and management (Wienhold and Goulao 2023). Despite the fact that the Agroforestry Systems's (AFS) are well-known, it is still difficult to locate real and reliable statistics on the true scope of the AFS in South Asia. The International Assessment of Agricultural Knowledge, Science, and Technology for Development (IAASTD) has prepared a list of countries all over the world, that have land areas with agroforestry use. This list contains locations where trees are cultivated for use in agricultural production. According to Zomer et al. (2022), agroforestry covers one billion hectares of land worldwide. The agroforestry environment around the world is broken down into its essential components and are summarized in Table 1.

The AFS of South Asia are well-known for their resistance to a extensive climate and environment variations, which is one of their most prominent traits (Eydivandi et al. 2021; Kos et al. 2023). Throughout the course of millennia, numerous smallholder farmers and marginalized communities have accumulated knowledge on strategies of climate adaptation and mitigation (Raihan and Tuspekova 2022b; Mardero et al. 2023). India, China, Indonesia, and Australia account for more than 60% of all of the AFS research carried out in the region, with a particular emphasis placed on agroforestry and agropastoral practices. Shin et al. (2020) offered an outline of the many research initiatives carried out on AFS in India between the years 1970 and 2018. A comprehensive description of various cases of traditional AFS from all over the world, including South Asia, was presented by Nair et al. (2017).

Table 1. An overview of agro-forestation around the world

Covering farmland with trees	Tree-covered farmland around the world (km^2)	Agricultural tree coverage
Less than 10%	10,120,000	46%
Less than 20%	5,960,000	27%
Less than 50%	1,670,000	7.5%

Source: Adapted from Nair et al. (2009) and Zomer et al. (2014)

Among many AFS practiced in the South Asian region, private home gardens are most frequently used (Chavan et al. 2023; Darge et al. 2023). Because of the tremendous benefits that come with working with such small portions of land, people in South Asia have faith in the traditional AFS (Melvani et al. 2022). Because of this, working with AFS becomes an appealing alternative. The application of time-honored techniques of agroforestry may be observed in Table 2, and this practice has been widely implemented across the entirety of South Asia. Growing fuelwood, fodder, and fruit trees on top of farming bunds is a common practice among locals in Nepal, India, Bhutan, Sri Lanka, Bangladesh, and the Maldives (Raihan and Tuspekova 2022c). These practices also contain significant opportunities for those living in poverty in rural areas of the region to earn a living. Farmers in Pakistan are hesitant to plant trees on their agricultural bunds out of concern for the potential negative effects this could have on their crops (Ahmad and Ekanayake 2023). Because of this, natural forests and other types of vegetation provide the vast majority of their requirements for fuelwood and fodder (Jaafar et al. 2020; Raihan 2023f).

According to Rosenstock et al. (2019), the genuine size of agroforestry in the South Asian region is now grossly undervalued as a result of difficulties in detecting low-density tree cover, which is typical of the tiny landholdings of rural farmers. This results in an underestimation of the true extent of agroforestry in the region. South Asia is said to have a lower percentage of land covered in trees in comparison to other regions of Asia, according to data on agroforestry cover collected from throughout the continent (Paradis 2021). Table 3 provides an outline of the geographic distribution of agroforestry systems across Asia.

According to the findings of a research project that was carried out by the Central Agroforestry Research Institute (CAFRI 2022) India, AFS cover a combined total of 13.75 million acres of land over the entirety of India. According to the Indian State Forest Report (ISFR 2019), As a fraction of the country's total landmass, AFS occupies 9 percent, which are classified as Trees Outside Forests (TOF) and span a total landmass of 294 thousand km^2 of the nation. AFS is able to fulfill more than 65% of the nation's wood requirements and 50% of the nation's firewood demand.

Oli et al. (2015) found that agroforests in Nepal had a greater variety of tree species when compared to wild forests in Nepal. A study of Chakraborty et al. (2015) raised awareness to the significance of agroforests in Bangladesh. Fuelwood for homes is sourced from agroforests in Bangladesh, which lowers the country's reliance on natural forests and the amount of money spent on purchasing wood.

Table 3. Location-specific agroforestry coverage across Asia

Area	Tree-covered farmland (million km^2)	Agricultural tree coverage
Total (Global)	10.12	46%
South Asia	0.38	21%
South-East Asia	1.34	82%
East Asia	0.41	23%
Northern and Central Asia	0.65	27%
Western Asia and North Africa	0.1	9%

Source: Adapted from Zomer et al. (2014)

Table 2. Adoption of conventional agroforestry techniques in South Asia

AFS		Area with agricultural and ecological change
Agri-silvicultural	Shifting cultivation, Taungya, Chena, Bewat, dippa, dhya, erka, kumara, jhum, peenda, podu, pothur, zabo, rep syrti	North-East India's tropical forests, Bangladesh, Sri Lanka
	Windbreaks and shelterbelts	Areas prone to high winds include the coasts, deserts, and mountains of India, Sri Lanka, Bangladesh, and the Maldives
	Agricultural method based on plantations	Primarily hot and muggy tropical regions (India, Sri Lanka, Bangladesh, Maldives)
	Boundary Planting and live hedges	In every country in the area
	Scattered trees on farms, parklands	Everywhere, but mainly the dry and semiarid lands
	Crop plantations in an industrial setting	Areas with dense plantings and bunds
	Protection of soil through wooded areas	In the valley and hills of the area, as well as its coastal sections
Silvi-pastoral	Horti- pastoral	In orchards, both hilly and flat, to prevent soil erosion
	Silvi-pastures	Subtropical and tropical regions with distinct bio-edaphic climaxes
	Tree on rangelands	In every country in the area
	Crop plantations with grazing lands	Climates that are predominantly humid or sub-humid and where plantation lands have less grazing pressure
	Grazing in the forests seasonally	Ecosystems in the mountains and the semi-desert
Agro-silvi-pastoral	Homestead plots	Sri Lanka, India, the Maldives, and Bangladesh are highlighted as key countries in the region.
Other AFS	Aqua forestry	The lowlands in all countries of the region
	Tree-based beekeeping	In all countries of the region

The National Research Centre for Agroforestry (Dev et al. 2019) has released estimations indicating that India's 25.4 million ha of agricultural forests have the ability to support 943 million person-days yearly. According to Dagar et al. (2014), an investment in agroforests that include species like silver oak (*Grevillea robusta*) and teak (*Tectona grandis*) offer both short term and long term ecological and social benefits. Eucalyptus (*Eucalyptus* spp.) and Poplar (*Populus* spp.) are two species that are frequently utilized for commercial planting in India and Pakistan due to the fact that they have a high growth rate and produce a significant amount of biomass. It has been shown that the best trees for industrial agroforestry plantations and shelterbelts are those that develop quickly, such as *Eucalyptus* spp., *Populus* spp., *T. grandis*, and *Casuarina equisetifolia* (Basu 2014; Shah et al. 2023). This is because of the economic benefits that fast-growing trees bring as well as the ecological benefits that they provide, in addition to their high growth rates. Farmers in this region choose agroforestry trees that have market value since these trees have a lower risk of failing as yearly crops (San et al. 2023). The great popularity of *Moringa oleifera* in India can be attributed to its market value and the various health benefits associated with every portion of the plant (Maryam and Manzoor 2023). In a similar vein, many harvests can be acquired from the same common fodder trees by harvesting them at different times of the year (Kumar 2016; Bödeker et al. 2023). This can be done by picking the leaves, flowers, or fruits.

According to Gupta et al. (2023), important examples of AFS may be found in Bangladesh, Sri Lanka, India, and the Maldives. Home gardens and other multipurpose agroforestry ecosystems foster food security and contribute to the conservation of rare and threatened species (Bacon et al. 2023). Land management strategies based on trees (plantations of spices in India, Sri Lanka, and Kerala) have shown promise in terms of assisting rural industrialisation and enabling communities a variety of options for their means of survival. This is because these tree-based land management programs are built on the premise that trees are good land managers (Raihan and Tuspekova 2022d). The most effective strategy for adapting to the consequences of climate change as well as for mitigating those effects is the use of integrated agri-silvi-horti farming practices (Dinesha et al. 2023). These approaches place an emphasis on resource conservation and support the conservation of traditional agrobiodiversity (Raihan and Tuspekova 2022e; Gupta et al. 2023).

The benefits of agroforestry for society

According to the study of Potschin-Young et al. (2018), people reap environmental, material, and psychological benefits as a result of ecosystem services that are offered by natural or semi-natural ecosystems. These ecosystem services may be found in both natural and semi-natural settings. Agroforests, which are defined as forests planted in agricultural or pastoral contexts, are said to give a variety of benefits to society, including economic, ecological, and climate change adaptation potential (Shin et al. 2020; Raihan and Tuspekova 2022f; Tschora and Cherubini 2020; Ntawuruhunga et al. 2023; Dissanayaka et al. 2023). One of the numerous ecosystem services supplied by agroforestry is climate adaptation, which is a vital component in combating global warming (Feliciano et al. 2018; Raihan and Tuspekova 2022g). Another one of the many ecosystem services offered is biodiversity conservation (Raihan and Tuspekova 2022h; Raihan et al. 2023c). According to Ali et al. (2022), AFS programs in South Asian countries have developed throughout the course of time to take advantage of and optimize a wide range of good effects for individuals. This development has occurred in an effort to maximize the number of benefits that people receive from participating in the programs. According to the study of Udawatta et al. (2019), the presence of multifunctional landscapes results in an increase in the benefits that pollinators receive, the support of traditional agrobiodiversity, and the conservation of less well-known species of wild animals. According to Oli et al. (2015), the upkeep of these AFS in such a way that they serve many functions in a sustainable manner safeguards a wide variety of ecological processes while also giving considerable advantages to the well-being of humans. It is vital to keep in mind that farmers do not make decisions regarding land usage based on a benefit cost ratio; rather, they do so based on the projected net revenue. According to Rahman et al. (2020), farmers in Bangladesh are more interested in cultivating horticulture agroforestry rather than agroforestry on croplands and homesteads.

According to Gupta et al. (2023), ecosystem services have the potential to be revived with the assistance of AFS if these systems are used to restore and rehabilitate ecosystems that have been destroyed. The availability of food, ownership assurances, upgraded farm-based earnings, managing biodiversity (both terrestrial in nature and soil), ecological sinks, hydrological processes, corridors for wildlife, reduced erosion of soil, higher levels of biodiversity conservation, better microclimate, boosted retention of nutrients (through root captivate and cycling), etc. are just a few of the many indicated advantages associated with AFS in this area (Rosenstock et al. 2019; Duffy et al. 2021; Park et al. 2022; Paudel and Shrestha 2022; Raihan et al. 2023d; Tan and Kuebbing 2023). According to Cedamon et al. (2019), the high biomass of fodder and meat as well as the output of non-timber forest products are all in favor of agroforestry interventions as a strategy to guarantee food security in Nepal. This is because these factors contribute to manufacturing of forest byproducts other than timber. The practice of agroforestry in Bhutan has led to enhanced nitrogen fixation and decreased soil erosion, as per the study of Nkonya et al. (2016) and Koirala et al. (2023). In Bangladesh, the use of the AFS farming approach resulted in significantly less soil erosion and nutrient loss as compared to agriculture practices such as jhum or slash and burn (Das et al. 2020).

There is a wealth of evidence to demonstrate that AFS helps to sustainable production by assisting in the conservation of natural resources, the recharging of aquifers, the providing of various products to auxiliary homes, and so on (Shin et al. 2020; Ruba and Talucder 2023). Within the framework of a paradigm for land use, agroforests are said to assist "sustainable intensification" (Muschler 2016; Raihan and Tuspekova 2022i). In contrast to the conventional reliance on chemistry and climate studies, this approach uses other factors. Article 2 of the Paris Agreement includes provisions for sustainable growth and ending poverty go hand in hand, and its goal is to boost global efforts to prevent the repercussions of climatic change (Raihan and Voumik 2022b; Raihan et al. 2022b; Voumik et al. 2022; Sultana et al. 2023). It is impossible to overstate the importance of agroforestry, and if the global climate goals are to be achieved, it is necessary that regular agriculture practices at the national level incorporate agroforestry (Litschel et al. 2023; Ntawuruhunga et al. 2023). It is absolutely vital for us to take advantage of the potential that exists in the land use sectors in order for us to be successful in our efforts to reduce emissions (IPCC 2022; Raihan 2023g). If we are going to be successful in our efforts, we must take advantage of the potential that exists in these sectors. It will be feasible to embrace less fertile marginal croplands that have a low level of productivity across South Asia with the deployment of a wide range of AFS techniques. This will allow for greater agricultural diversity. Adaptive rainfed dryland agriculture (Kattumuri et al. 2017) can be improved in several ways (Castro et al. 2019), the most important of which are the restoration of the soil's health, the enhancement of the efficiency of irrigation, and the creation of carbon sinks (Raihan et al. 2022c; Han et al. 2023).

AGROFORESTRY SYSTEMS AND GLOBAL CLIMATE

According to the IPCC (2019), the United Nations Framework Convention on Climate Change (UNFCCC) and the other major multinational scientific and environmental groups have focussed on the significance of mainstreaming and putting into practice sustainable land management approaches such as Agroforestry Systems's (AFS) (Bongaarts 2019; Raihan et al. 2022d). The UNFCCC, the FAO, the World Bank and the CBD, have all praise on AFS. The important conventions and studies that have brought AFS to the attention of scholars and policymakers on a global basis are depicted in Figure 1. The Kyoto Protocol was the first international arrangement to acknowledge the importance of AFS in climate mitigation. Since that time, there has been a rising interest in AFS as a potential strategy for enhancing carbon sequestration (Zomer et al. 2016; Raihan et al. 2022e). This can be attributed to the fact that AFS can increase the period of time that carbon is stored. In spite of the fact that the Kyoto Protocol was used as the foundation for the Clean Development Mechanism (CDM), the incorporation of AFS into the CDM was slowed considerably by a inconsistency in methods used to calculate emissions sinks as well as attendant land right difficulties (Atangana et al. 2014). This was the case despite the fact that the Kyoto Protocol served as the framework for the CDM (Mele et al. 2021).

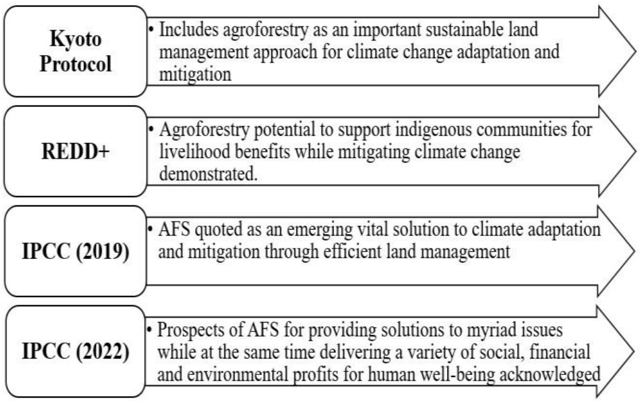

Figure 1. Significant commitments and reports addressing agroforestry systems

The Agriculture, Forestry and Other Land Use (AFOLU) sector, however, were thrust back into the public eye in 2007 by REDD+. Since that time, a number of nations put efforts to enhance each country's preparation by acknowledging the part that these AFOLU industries play in adaptation and mitigation of climate change (Fortuna et al. 2019; Raihan et al. 2022f). A few of the seventeen SDGs that AFS is known to contribute to include the following: SDG 15 (life on land), SDG 13 (climate action), SDG 12 (sustainable consumption and production), SDG 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health and well-being), SDG 8 (decent work and economic growth), SDG 5 (gender equality), and SDG 10 (reduced inequalities). By promoting technological, geographical, legal, and economic synergy in policy, AFS can assist both developing and underdeveloped countries in meeting their climate mitigation goals (especially 2.4; 13.2 and 15.3), restoring multifunctional landscapes, adapting to and mitigating climate change, meeting goals for tree planting in response to the Bonn challenge, the United Nations' Restoration Decade (2021-2030), and bolstering water and food availability (Waldron et al. 2017; Borah et al. 2018; Fagan et al. 2020; Raihan et al. 2022g).

Mitigation and adaptation for climate change through agroforestry

Due to a lack of accurate carbon stock information for agroforestry strategies in comparison to forestry and agriculture, our knowledge of carbon sinks in the region's varied AFS is still at a very fundamental and limited (Ali et al. 2022; Panwar et al. 2022; Raihan et al. 2022h). Among all land uses considered by the IPCC (2022), agroforestry has been found to have the most promising for the capture of carbon. Despite the fact that agriculture and forestry together are responsible for about 21% of total emissions (Raihan 2023h), In global carbon finance schemes and local carbon finances, AFS offers a large mitigation capacity that has not yet been empirically assessed (Zomer et al. 2016; Khatri-Chhetri et al. 2022; Raihan et al. 2022i; Kumara et al. 2023). Despite the fact that AFS has not been subjected to experimental evaluation in regional carbon accounts. The carbon reserves that can be discovered in agroforestry systems are outlined in Table 4. On a global, national, and zonal basis, only a small portion of the carbon reserves in AFS have been investigated (Raihan and Tuspekova 2022j; Yasin et al. 2023). On the other hand, research and reporting in South Asia are typically carried out at the regional level (Raihan et al. 2022j). According to Yasin et al. (2019), the variation in carbon stocks of trees and Soil Organic Carbon (SOC) is not frequently addressed together in scientific research. When conducting research on agroforestry, one of the most difficult tasks is trying to determine how various kinds of systems can possibly serve as carbon sinks (Westholm et al. 2020; Raihan and Tuspekova 2022k; Nguyen et al. 2023; Rodrigues et al. 2023).

Because of their significance in easing and stimulating the movement of wildlife throughout the landscape and supporting biodiversity and agricultural activities, the trees that make up an agroforest are analogous to "keystone species" (Carbutt and Kirkman 2022; Raihan et al. 2023e). Agroforests are a type of forest that is managed for agricultural purposes (Yahya et a. 2023). According to Mbow et al. (2014), AFS serve an important function as wildlife corridors because they provide the necessary migration channels for species to adapt to changing climatic circumstances. This makes AFS an essential component of wildlife conservation (Ambele et al. 2023; Raihan 2023i). The importance of AFS can be seen from this perspective. It needs to make concentrated and coordinated efforts to maximize the good impacts while decreasing the unfavorable effects on the climate to get the most out of AFS for both mitigation and adaptation. This will allow to get the most bang for buck out of AFS. Mbow et al. (2014) presented a comprehensive study of the opportunities for adaptation and mitigation in relation to AFS. Because South Asia is predominantly an agricultural region (Raihan et al. 2023f), there is a large amount of untapped potential in the region for the mitigation and adaptation of the consequences of climate change via the utilization of agroforestry (Bernzen et al. 2023). This potential may be found throughout South Asia. According to Ahmad et al. (2020), based on a criteria of 55% or higher, 69% of South Asia's entire landmass is still suitable for agroforestry.

Table 4. Carbon stored in AFS as reported

Area	Carbon Stock (Mg C ha^{-1})
Global	6.3
Temperate	63
Humid	50
Sub-humid	21
Semi-arid	9
Sri Lanka	38.8
Pakistan	29.7
India	25.4
Bangladesh	23

Source: Adapted from Baul et al. (2021) and Lowe et al. (2022)

Agroforestry in NDCs

The "Intended Nationally Determined Contributions" (INDCs) were something that were also submitted by every country that signed the Paris Agreement. NDCs are the primary tool for lowering emissions in accordance with national priorities, capacities, and responsibilities (Quandt et al. 2023; Raihan et al. 2023g). These NDCs are reported to the UNFCCC. These vows are often referred to as the INDCs. According to Duguma et al. (2017), agroforestry has the potential to make a contribution to NDCs by providing support for initiatives related to both mitigation and adaptation of the influences of climate change. Agroforestry is specifically included in the Nationally Determined Contributions of about 40% of the countries that are not part of Annex I (Zhai et al. 2023). These are the developing nations that the UNFCCC has identified as being particularly susceptible to the damaging effects of climate change, such as being at risk from rising sea levels, desertification, and drought (Beillouin et al. 2023). Only 21 percent of Asia's governments have included AFS in their national development commitments (Rosenstock et al. 2019). This ratio is considerably lower when compared to the proportions of countries in Africa (71%), the Americas (34%), and Oceania (7%), respectively.

The countries of South Asian region have put into practice a large number of different adaptation strategies, ranging from ecological to agricultural in nature (Tiemann and Douxchamps 2023). Bangladesh, Nepal, Sri Lanka, and Bhutan have each taken steps to advance the ideas of "ecosystem-based adaptation" and "landscape-scale adaptation," respectively. Water resource management, agroforestry, agricultural management via rotation of crops, and natural management of vegetation are all examples of such practices (Dinesha et al. 2023). Because the composition of trees is the primary determinant of the total carbon flux, there is a greater need for comprehension of this topic during the implementation phase (Harmon et al. 2020). As the Table 5 indicates, even though several nations have not officially stated AFS in their NDCs, NDC of these countries used AFS as potential measure of climate change mitigation. It is absolutely necessary to broaden the scope of forestry activity while simultaneously reducing the amount of emissions produced by agriculture. In light of this, Bangladesh's 4.1 million hectares of Trees Outside Forests (TOF) (croplands, homesteads, and horticulture-based agroforestry) presents a vast array of business prospects. This constitutes 27 percent of the entire land area of the country (Sheikh et al. 2021).

The SAARC Regional Coordinated Program on Agroforestry (SARCOPA) was founded in 2016 by the SAARC group of states, which consists of Bangladesh, Afghanistan, Bhutan, the Maldives, India, Nepal, Sri Lanka, and Pakistan. Both the ICRAF and the SAC were instrumental in this goal's successful completion. The project will be completed in two distinct phases: the first phase will last for a period of six years and will concentrate on developing mechanism and methods of administration; the next stage will also last for a period of six years and will extend the scope of the AFS to include a larger group of individuals. Both phases will run for the same amount of time. The initial stage in SARCOPA is to raise public awareness of the issue, as well as to create any relevant guidelines, policies, and databases of data already collected on AFS. Although India and Nepal's national agroforestry policies demonstrate their commitment to the development of AFS, Bhutan and Bangladesh's national agroforestry policies are just in the preliminary stages of development at this point. It is expected that India will have greatly reduced its overall emissions by the year 2050 with only a 30% expansion in the quantity of land covered by AFS (Nath et al. 2021). SARCOPA has provided support for diversified activities, consisting of the development of institutional and sole capacity, the locating, revamping, and dissemination of AFS that are successful, and others. Nepal's national government came up with a Local Adaptation Plan of Actions. In addition, the positive aspects of woods, conservation activities at the local level, and conventional AFS will be incorporated into the nearly 2200 community forest adaptation plans, in addition to the approximately 375 local adaptation plans that have been produced in the past (Darjee et al. 2021). When India implemented an agroforestry policy in 2014, it was a first for the region. The policy was praised as a simple technique to reap the benefits of a productive land-use system and to boost the economy (Bose 2015). The policy was welcomed as a straightforward method that might easily enjoy the benefits of an effective land-use system.

In order to provide necessary economic assistance and to contribute to the creation of human settlements that are more resistant to the effects of climate change, Sri Lanka has made a commitment to the conservation of natural resources and biodiversity, as well as to the enhancement of climate resilience (De Zoysa and Inoue 2016). Again, agroforestry isn't officially addressed, but it's thought to be included due to the vast number of backyard gardens in the country (which make up around 13% of the overall land area). Historically, the cultivation of these gardens has promoted climate adaptability and assisted in mitigating the effects of natural calamities such as drought and storms. The Green Pakistan Program, which is also known as the Plantation Tsunami, was started by the government of Pakistan in order to reach the Bonn Targets (Baig et al. 2021). This will be accomplished by planting one hundred million trees over the course of the next five years as a part of the Green Pakistan Program. However, this status might shift in the near or far future. The currently available data makes it clear that all of the South Asian countries are cooperating with one another to exchange information and resources in order to make it feasible for all of them to put AFS into practice and enjoy its benefits. This is because all of the South Asian countries want to ensure that it is possible for all of them to put AFS into practice and enjoy its benefits (Shin et al. 2020).

Table 5. South Asian NDCs and the involvement of agroforestry

Countries	NDC Obligation	Aspects of Agroforestry in the NDC
India	Reduce emissions by 33–35% from 2005 levels by 2030, with non-fossil fuel share growing by 40% and another 2.5–3 billion metric tons of carbon sequestered through increased tree cover by that year.	Although agroforestry is not specifically mentioned in India's INDC, among the eight goals listed under the NAPCC, it is widely believed to play a crucial part in the country's efforts to reduce carbon emissions.
Pakistan	Aiming to reduce emissions by 20% from 2030 projections with the help of international funding.	Among the many ways for dealing with climate change, agroforestry is one.
Bangladesh	Agriculture and forest sector development to reduce emissions. Commitment, without preconditions, to using existing resources to cut greenhouse gas emissions by 5% from the power, transportation, and industrial segments by 2030. Reducing GHG emissions from the electricity, transport, and industrial sectors by 15% by 2030, contingent on receiving adequate international help to do so.	The NDC's ecosystem-based adaptation makes no reference to agroforestry. However, the NDC incorporated replanting of mangroves, green belt Afforestation, and wetlands and coastline preservation through community action.
Nepal	Reduce reliance on fossil fuels and work toward reforesting at least 40% of the country by 2050.	Agroforestry and other forest restoration methods are included as means to meet NDC goals.
Sri Lanka	The energy sector's emissions should be cut by 20% by 2030; emissions from the forest, transportation, industry, and other sectors should be cut by 10%.	Agroforestry systems are prioritized along with urban forests, green pathways, green roofs, and parks in urban and semi-urban areas.
Bhutan	To maintain carbon neutrality, where emissions are balanced by forest carbon sequestration.	Mitigation strategies include the prospect of climate-smart agriculture, such as the growth of agroforestry, agri-silvi-pastoral frameworks in order to raise livestock, cultivate organically, or practice conservation agriculture.
Maldives	A target of a 26% decrease in emissions by 2030 relative to "business as usual".	No mention of agroforestry.
Afghanistan	Reducing emissions by 13.6% below the "business as usual" level by the year 2030.	Agroforestry is not mentioned.

Agroforestry under REDD+ and NAMAs

According to Ntawuruhunga et al. (2023), marginalized groups in underdeveloped and undeveloped nations that participate in agroforestry may be able to make a financial profit from the sale of carbon sinks. The AFS are able to make a contribution toward the conservation of natural woodlands by reducing the need for fuelwood and lumber among the countries of South Asia (Duffy et al. 2021). Since 2007, the UNFCCC is in charge of climate change discussions, and REDD+ has been an integral part of these talks ever since. According to Fortuna et al. (2019), significant progress has been achieved toward integrating the agriculture, forestry and other land use (AFOLU) sectors into national plans for mitigating the catastrophic consequences of global warming by the utilization of REDD+. These plans have been developed to lower GHG emissions from forest clearing and deterioration. According to Atangana et al. (2014), goals of the REDD+ initiative is to provide financial incentives to participating nations so that these nations will take actions to conserve and responsibly manage their forest resources. As part of the REDD+ program, eco-agricultural practices have been promoted because they help boost food production without having a bad impact on native biodiversity (Roberts 2019; Villa et al. 2020). This is because eco-agricultural methods have been shown to help increase food production without having a negative impact on native species (Aich et al. 2022).

AFS is one type of farming method that is considered to be environmentally friendly (Li et al. 2021; Shennan-Farpón et al. 2022). According to Rosenstock et al. (2019), AFS makes a major contribution to the UNFCCC's Koronivia Joint Work on Agriculture (KJWA), which focuses on increasing resilience, boosting carbon stores, soil quality, species richness, and soil fertility. This is accomplished by AFS through the promotion of sustainable livestock management, the delivery of a variety of nutritional advantages, and the diversification of livelihood options. On the other hand, the KJWA makes no reference to the AFS in any part of its text. Extensive research (Holmes et al. 2017; Owusu et al. 2021; Hastings et al. 2023) reveals that native and community-based organizations are warmly supporting AFS. REDD+ is based on the concept that there should be an increase forest's ability to sequester carbon, a decrease in the amount of pressure that is placed on forests, and progress toward more diverse methods of sustenance (Basnet and Karki 2020). These three things are all interconnected and should occur in tandem. When REDD+ projects in the region are examined, it becomes evident that the countries in South Asia have extremely varied implementation techniques. The REDD+ policies and programs that South Asian countries have established are summarized in Table 6.

CHALLENGES TO AGROFORESTRY'S POTENTIAL IN ACHIEVING GLOBAL CLIMATE GOALS

The technological capacity to monitor carbon stocks from agroforestry systems, including an update to the UNFCCC lags well behind national intentions, resulting in a significant gap between the two sets of goals (He et al. 2020; Low et al. 2022). Although it will take some time for capacity to emerge in terms of carbon stock warehouses in AFS, SARCOPA will be of significant aid in filling this deficit over the next few years. According to Feliciano et al. (2018), the current AFS database in the region suffers from a large absence of information on soil carbon reserves, and a dearth of data on carbon reserves before land use alteration. Monitoring, reporting, and verification (MRV) is a procedure that is important for accomplishing national goals connected to economic growth and climate adaption (Perosa et al. 2023). The development of a dependable MRV system for AFS in South Asia is a significant step in simplifying the process of gaining access to national and international sources of finance and other forms of support (Nunes et al. 2020; Raihan 2023j). Agroforestry and MRV systems have proved difficult to combine, despite the growing prominence of AFS and TOF in talks taking place all over the globe on the topic of global warming. This is in spite of the fact that the UNFCCC proposes that they need to be combined. It's probable that certain countries won't have any trouble employing the MRV methods developed by others, but some might have trouble doing so (Rosenstock et al. 2019; Raihan 2023k). Despite the fact that the inclusion of AFS in MRV is supported by Nepal's extremely low forest requirement, Bangladesh's forest definition does not include TOF (also known as AFS). The inclusion of AFS in MRV is given further weight by the fact that Nepal meets the very low forest requirement. One constraint is the dependence on local variables, which play a role in determining the amount of carbon stock. Other potential barriers that could stand in the way of achieving the benefits of AFS in the region include a lack of regular financial support, changes in the instructions supplied by the government, concerns over the limitations of data collecting and analysis, and so on (Raihan 2023l). All of these factors could make it more difficult to realize the potential benefits of AFS in the region. According to Duguma et al. (2017), one of the most significant structural barriers to the adoption of AFS is the inadequate amount of money that is allocated to the agroforestry business in comparison to intensive agriculture.

The majority of South Asian states have been unable to move forward due to the limits imposed on them by their institutions, which has resulted in stagnation (Kasuya and Reilly 2023). Some of the additional challenges that must be overcome in order to realize the beneficial effects that AFS will have on climate policies along with their implementation include having unreasonable expectations for agricultural output per hectare; lack of markets; lack of land rights; and lack of assistance in technology (Cechin et al. 2021; Lojka et al. 2021; Raihan 2023m). The presence of a considerable number of smaller farms in the area acts as a key barrier to the disease's progression throughout the area. In addition, there are geographical issues that work against the general implementation of AFS, such as the number of animals, the proximity of the forest to the villages, and the susceptibility as well as illiteracy of the farmers. According to Baig et al. (2021), an additional key barrier to the transmission and implementation of AFS is the shortage of adequate water. The Forest Conservation Amendment Act of 1988 in India, which outlawed the harvesting of timber in state forests, gave a financial incentive to apply AFS. This act was passed in order to encourage the adoption of AFS. This served as a monetary incentive to submit an application to AFS.

The poor adoption of AFS despite its economic and environmental benefits is a result of legal and legislative hurdles, such as insecure land tenure, onerous transportation laws, tariffs on agriculture-based products, and the socioeconomic isolation of local farmers (Siankwilimba et al. 2023). A increasing desire in regional countries to satisfy market requirements is a significant criterion for acceptance, as is the implementation of rules that offer transparent data on ownership of land and trees in order to authorize NAMA and REDD+ benefaction (Wallbott and Florian-Rivero 2018). On the other hand, farmers in the region are not interested in planting trees because they do not hold the logging rights that are required for them to make a financial profit from the trees they grow. In addition, harvesting and moving the wood transported from agroforests to sell is not permitted until authorized by the forest department, which is another barrier that inhibits the adoption and marketing of AFS (Baig et al. 2021). This is one of the reasons why AFS has not been widely adopted.

According to farmers in Nepal, the inadequate controls placed on tree harvesting and marketing prevent them from taking advantage of the economic potential given by AFS (Cedamon et al. 2019). Farmers and agricultural professionals in Bangladesh are in agreement that in order to fully embrace AFS and reap the climatic, economic, and environmental benefits it delivers, regulation and standards are essential. Baig et al. (2021) cites a lack of competent forest workers, farmers' lack of access to technological assistance, an inadequate knowledge of tree varieties, low market access, and low wood price as some of the primary limiting restrictions facing Pakistan's wood business. Other major limitations include an inadequate understanding of tree species. Because South Asian countries are unable to engage in outreach initiatives linked to agroforestry, the potential of AFS to enhance land management and encourage its acquisition in order to focus on worldwide climate disputes has been severely limited (Rivera-Ferre et al. 2021; Karada et al. 2023; Yasin et al. 2023).

Table 6. Policies and plans for implementing REDD+ in South Asian nations

Countries	Status	Extent of REDD+
India	Implementation of REDD+ in light of major COP-16 resolutions, the Warsaw Framework for REDD+, the Paris Agreement, and the national legislative and policy agenda for forest conservation and enhancement.	Includes trees and other forest types (TOFs), which may also contain AFS. Coalition with the National Forest Policy is achieved through the efforts of REDD+ to increase forest and tree cover.
Nepal	The REDD+ strategy's first draft was completed in 2014, paving the way for additional consultations and the development of the strategy's second iteration.	The national forestry industry's dream of thriving woods and happy people is included in the REDD+ strategy statement produced in accordance with the fundamentals of the goals of sustainable development. The Forests Act (2019) recognized the necessity to operate agroforest crops or livestock firms in a way that is compatible with the conservation and development of the forest. The Forests Act (2019) also mentioned that agroforestry system may be pursued as prescribed in the land of forest area without changing the land use. Expanding the definition of REDD+ to include private forests, public forests, forest leases, and religiously protected forests all exist is likely at this point.
Pakistan	Initiated in 2010, REDD+ views forest ecosystems as a public asset, a source of numerous benefits necessary for development, and one that may help to mitigate global warming whereas simultaneously improving the resilience of local communities and their natural environments.	The National Forest Policy of 2015, the Climate Change Policy of 2012, and the Environment Policy of 2005–the cornerstones of the REDD+ strategy–all work together to enhance forest conservation.
Sri Lanka	National REDD+ Investment Framework and Action Plan developed with assistance from the UN-REDD Programme for the next five years (2018-2022). A high level of preparedness for REDD+, as defined by the Warsaw Framework, and including the technical basics of REDD+.	There were 13 different policies found to be effective in dealing with the causes of forest cover change. With the goal of "creating favorable circumstances to render present agroforestry systems economically feasible for adoption and implementation," policy measures that extend coverage to other wooded lands lend assistance to agroforestry models for combating forest degradation.

Policy issues

Because it is already familiar to small and medium size farms, AFS is a prospective easy pickings for meeting the NDCs as well as helping with climate change prevention and adaptation (Handa et al. 2020; Chavan et al. 2022). This is due to the fact that AFS is already familiar with farmers. As a direct result of this, elevating knowledge of AFS will not be sufficient to overcome the more fundamental problem of relying on it to combat climate change on a global scale. In order to accomplish the NDCs, it is absolutely necessary to provide a legislative policy framework that is acceptable and effective, as well as strategic execution, in order to back the expansion of AFS in the region. It is possible that a market-based infrastructure may be constructed with the assistance of such governmental backing (Raihan 2023n). This infrastructure would protect the rights and ownership of communities while simultaneously attracting incentives and investments. As a result of the many advantages it provides, AFS should be given a more prominent position in REDD+ and NAMAs (Getnet et al. 2023; Katayi et al. 2023; Kumar 2023). However, in order for agroforestry to attain its full potential, it is necessary to take into consideration the numerous obstacles that were mentioned in the portions that came before it and to solve them in an appropriate manner. Only then will the agroforestry industry be able to realize its entire potential. The following courses of action are suggested as potential remedies to the problem: (i) In order to increase the fund flow to AFS as well as increase knowledge and collaboration amongst key stakeholders, federal and the state's legislation should support techniques to detect, group, and record AFS. This should be done in order for national and state policies to promote approaches to identify, categorize, and report on AFS. In addition to this, the amount of funding that will be made available to AFS needs to be increased (Table 7). (ii) In order for agriculture and forestry practices to be able to share cutting-edge technology on a worldwide basis and to make better use of land resources, national policies that address agriculture and forestry practices need to take into account both effective mitigation and adaptation approaches (Table 7). (iii) It is essential to keep in mind that future implementation will be influenced by land-use decisions in addition to rising social, political, and economic powers even though monetary incentives and regulatory measures are presently being used (Raihan 2023o).

The legislative framework that is built to cope with climate risks should be comprehensive enough to stimulate income from AFS while also internalizing the harmful effects of climate change (Feliciano et al. 2018).

By implementing the Agroforestry Policy in India, the AFS hopes to contribute to the objective of expanding the region's forest cover from the current 23% to the target of 33% of the region (Nath et al. 2021). In contrast to the goal of the REDD+ strategy, which is to put an end to deforestation and slow down the rate at which lower-lying forests degrade, this objective will not be achieved. The Green India Mission is an extra effort that is aimed at aiding the American Friends Service Committee (AFS) in its expansion into rural parts of the country (Basu 2014). Both Nepal's Climate Change Strategies (2011) and NDCs (2016) acknowledge the significance of forests and trees, particularly AFS, in the process of encouraging climate adaptation and mitigation. As a result, the The next stage is to establish a national policy on agroforestry that should be taken and should be implemented as soon as possible. In Bhutan, the EU-TACS project was started in June of 2020. The funds necessary for the initiative are being provided by the European Union (EU). Additional work will need to be done below the larger aegis of SARCOPA for the Maldives, Pakistan, and Sri Lanka in order to establish agroforestry strategies that are applicable to these countries and their respective agricultural climates in which they are located. Other smaller nations, such as Bangladesh and Bhutan, are already working hard working hard to develop policies that are applicable to agroforestry.

Table 7. An overview of South Asian agroforestry policy and programs

Countries	Policies and Programs	Description
India	National Agroforestry Policy	Focuses on the positive effects of AFS on the environment, such as lessening GHG emissions, the stimulation of carbon stocks, the preservation of biodiversity, and the protection of soil and water.
	National REDD+ Policy	Consists of general principles for developing and implementing REDD+ programs in order to reap the rewards of the worldwide REDDprocess and generate economic benefits for the community at large to participate in forest ecosystem protection.
	Green India Mission	Among of the eight goals under the National Plan of Action on Climate Change is to target AFS in 10 Mha of agricultural land with irrigation and 18 Mha of soaked land.
Nepal	National Agroforestry Policy	Developed by the World Agroforestry Centre and the Climate Technology Centre and Network
Pakistan	Green Pakistan Program	Global tree-planting initiatives aim to fulfill the Bonn Commitment and slow climate change.
Bhutan	Analyzing AFS and its implementation	To aid in formulating an agroforestry plan and a nationwide agroforestry initiative.

Source: Adapted from Dev et al. (2019) and Baig et al. (2021)

CONCLUSION AND RECOMMENDATION

The ICRAF, the SAC, and all local administrators have thrown their support behind SARCOPA, making it a historic initiative in the field of acknowledging and mainstreaming the benefits of AFS, with an emphasis on national scale climate change. The UNFCCC urges governments to generate information from regional field surveys and complete detailed reporting in line with MRV in order to generate factors unique to each country for accurate stock estimations of biomass and SOC. MRV stands for "monitoring, reporting, and verification." A two-step procedure that begins with laser scanning and is followed by field surveys is the most efficient technique for evaluating TOF resources. This method consists of laser scanning as the first step and field surveys as the second. In this part of the world, there is a pressing need for further national studies of TOF models for estimating biomass, with those models tailored to account for AFS tree resources. The first thing that has to be done in order to properly implement a national REDD+ plan is to create standard operating procedures for evaluating carbon stocks. Since the 1980s, India is among few countries to routinely use satellites for surveying changes in forest cover. Both the National REDD+ program of India, which was adopted in 2018, and the National Agroforestry Policy of India, which was enacted in 2014, would be of assistance to the government in achieving its NDC goal through TOF. The AFS incentive programs that are already in existence have a requirement that additional funding be provided from sources that are located outside of the region. The next stage in bolstering foresters' and communities' ability may be to construct agroforestry projects for REDD+, as well as creating awareness on the integration of AFS for increased benefits. This would also be the next step in raising awareness. Because it would assist in increasing awareness of the potential benefits of incorporating AFS, this would be an essential step to take. When it comes to the construction of projects, having a cautious, community-based, and inclusive approach can assist to lessen the likelihood that disagreements will arise as a result of AFS. The first phase of the SARCOPA plan of action, which involves the establishment of model agroforestry farms, is currently in the process of being put into operation throughout the entirety of the SAARC area. This phase also includes the creation of model agroforestry farms. The number of people participating in the national and subnational levels in India, Nepal, Bangladesh, and Bhutan who are interested in these topics is growing. Future research on AFS in the region will require additional mechanical and process-oriented investigations, as well as models linking AFS and crop development with water in the soil, carbon, and biogeochemical processes.

The synthesis that has been presented in this paper provides strong evidence for the relevance and promise of AFS in protecting the human well-being of those in the globe who are most at risk, in addition to those who are marginalized and poor, while also assisting South Asian nations in fulfilling their nationally determined contributions and helping to mitigate climate change. In spite of the fact that AFS has already provided a large deal of benefits, these advantages have not been exploited to the extent of their full potential on either a regional or national level. A regional agreement at the country level is required in order to mainstream AFS, and this is beginning to take shape as countries work together to facilitate and provide aid to together under SARCOPA. The pursuit of commitments from governments to acknowledge the advantages of AFS within the context of national agroforestry policy is an important step toward achieving important goals for the future. The SAARC agreement on agroforestry is currently being implemented, and this process, which is being carried out in stages, has already begun. It is anticipated that its implementation will proceed during the course of the following years as planned. Hearing these commitments from regional states and the administrations of those nations gives one reason for optimism. The AFS is an easy win that requires caution; as a result, nations like Nepal and India have built proactive agroforestry strategies. The Maldives, Bangladesh, and Bhutan have all made concerted attempts in recent years to create national agroforestry programs. These efforts have been successful to varying degrees. Coastal Bangladesh, the Maldives and Sri Lanka, two island nations, as well as mountainous Bhutan, would all benefit from concerted efforts in this area to establish synergies for the aim of adapting and mitigating the consequences of climatic change. Because only Central Asia has a lower percentage of agricultural land that is covered with trees (11%), South Asia has the second-lowest percentage in all of Asia. To begin, the countries in the area need to coordinate their efforts in order to identify a goal that is both feasible and ambitious: to improve and restore their AFS by at least 50% over the course of the next five years. This improvement and restoration must take place over the period of the next five years. AFS practitioners in the region have accumulated years of experiences and a wealth of information that is peculiar to the area. Both of these components have the potential to be utilized in order to enhance the present conditions and take on NDCs. The momentum that is already there in the region with regard to AFS needs to be strengthened, and in order to do so, it is required to move behind consciousness and technological collaboration in order to reap the advantages, satisfy the demands that are placed on local livelihoods, and give further opportunities. Critical tools for boosting the agricultural output of forest-dependent, economically disadvantaged populations as well as smallholders through the use of improved inputs, cutting-edge innovations, and incentives to enhance the intensification of agriculture and diversification of income sources can contribute to success in reaching NDC goals and making progress on a number of SDGs. This improvement in agricultural productivity can be achieved through the use of improved inputs, cutting-edge innovations, and incentives to enhance the intensification of agriculture and livelihood diversification.

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Forest ecosystem services and local communities neighboring Biha Resort in Bukit Barisan Selatan National Park, Southern Sumatra, Indonesia

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Abstract. *Mardiyanto A, Riyanto, Sianipar CPM, Shibata S. 2024. Forest ecosystem services and local communities neighboring Biha Resort in Bukit Barisan Selatan National Park, Southern Sumatra, Indonesia. Asian J For 8: 18-30.* The Biha Resort in Bukit Barisan Selatan National Park, Indonesia, provides essential resources for biodiversity conservation and local livelihoods. However, spatial borders between surrounding villages and the resort are improperly mapped, resulting in border disputes and unmonitored exploitation of forest ecosystem services. In this study, spatial mapping of villages home to forest local communities in the resort's buffer area was conducted via face-to-face interviews with key informants and Geographic Information System (GIS) analysis. Focus Group Discussions (FGDs) with several key informants were conducted to clarify the type and locations of forest ecosystem services utilized by the local community and related harvesting schedules, and the results were analyzed thematically. The study found that local communities were distributed among eight villages, with national park land, protected forest land, limited-production forest land and customary forest land providing ecosystem resources. Villagers reported usage for water, food, pets, construction materials, fuel, medicine, raw commercial materials and other items. These services fulfill basic needs and provide a crucial source of income, underlining their critical role in sustaining rural livelihoods. The study highlights interaction between people and diverse forest ecosystems, each with unique ecological characteristics and resource offerings, and consequentially, presents distinct implications for local-community livelihood strategies. The results are expected to support forest management toward a win-win balance between conservation and local-community wellbeing.

Keywords: Biodiversity conservation, customary forests, forest ecosystem services, forest management, rural region

INTRODUCTION

In previous work, Chao (2012) estimated that over 300 million people reside within forest ecosystems globally. In this sense, forests can be seen as social-ecological systems in which people maintain deep connections to their surroundings. Local communities thus share a long-standing symbiotic relationship with the forests where they live, representing a rich ground for research in the field. However, boundary disputes are a key issue in such communities, often leading to local frictions and conflicts. Riggs et al. (2016) and Hettiarachchi et al. (2022) suggested that such disputes are often fueled by the absence of distinct or clear land boundaries; conflicts can intensify due to differing viewpoints, adding another layer of complexity. These disputes, particularly when escalated to actual conflict level, can pose substantial challenges to local governments and authorities in formulating effective policies for natural resource conservation. Such disputes are also barriers to sustainable natural resource management and, more broadly, to socio-economic sustainability in forest local communities (van der Muur 2018). Thus, mapping of clear boundaries for forest areas and communities is critical within the larger efforts of sustainable forest management.

Understanding the precise location of forest local communities and the sources of the services they rely on is necessary for research on forest ecosystem services. Spatial mapping is a vital requirement for this, along with a thorough investigation of interactions between forests and communities and the functions provided by forest ecosystems (Palomo et al. 2013; Paudyal et al. 2015; Damastuti and de Groot 2019). The use of baseline mapping of residential locations and interactions with ecosystem services allows policymakers, researchers, and other stakeholders to have a more precise and complete knowledge of the causes of disputes. This would enable the formulation of conservation plans, particularly for national parks, aimed at striking a delicate balance between biodiversity preservation and the sustainability of local forest populations' livelihoods (Brown and Fagerholm 2015).

Buffer areas around national parks play a pivotal role in preserving internal integrity by providing a barrier between human activity and protected areas (Lynagh and Urich 2002), and such areas are home to communities that rely heavily on park ecosystem services for their livelihoods (Amacher et al. 1998). In Indonesia, Bukit Barisan Selatan

National Park (BBSNP) provides a good example of efforts toward balance between nature conservation and provision of ecosystem services for local communities in buffer areas (Bukit Barisan Selatan National Park Bureau 2019). Within the global conservation movement, BBSNP provides natural habitats for the Sumatran tiger (IUCN 2008), the Sumatran elephant (IUCN 2011) and the Sumatran rhino (IUCN 2020g). Among 17 resorts (sections) across the park, Biha Resort is the most critical habitat for these animals (Arimbi et al. 2021). Local communities neighboring the resort rely on forest ecosystem services for their own consumption and livelihoods in line with needs and culture. However, boundary disputes in the resort remain a problem for both BBSNP and neighboring local communities. In practice, the success of national park management is contingent upon consideration for the livelihoods of local communities, as related efforts form an integral part of holistic conservation work. Given the intimate community understanding of the local ecosystem and individuals' intensive interactions with the park, community members are potential key stakeholders in conservation efforts. Accordingly, they should ideally be involved in the mapping of forest/community boundaries to support forest governance efforts and conflict resolution.

This study was conducted toward inclusive mapping of forest/community and inter-community boundaries in the buffer area of Biha Resort. In addition to usage of satellite imagery, the involvement of local communities neighboring the resort is an essential part of mapping in the field. The authors attempted to determine the utilization of forest ecosystem services by local communities in the resort and surrounding forests with focus on the following research questions (RQs): (i) RQ1: How local communities living neighboring Biha Resort are mapped? (ii) RQ2: What kind of forest ecosystem services utilized by local communities? (iii) RQ3: When and where do communities take or use forest ecosystem services?

MATERIALS AND METHODS

Research design

The study employed a qualitative methodology in three stages (Figure 1). The approach included a preliminary study, sampling and data collection and data analysis. The procedures to respond to the first research question included selecting a case study and key informants, collection of maps, map processing and spatial mapping. Literature reviews and interviews with BBSNP, Indonesia, staff were conducted to select case studies. The key informants (eight local village leaders, one district-level forest management unit representative and two resort managers) were chosen via interviews with BBSNP staff with focus on background diversity to optimize the information gathered (Chaigneau et al. 2019). Maps were collected to illustrate general site situations and clarify the location of local communities neighboring Biha Resort. The mapping approach has been widely used in ecosystem service studies, such as those conducted by Hauck et al. (2013) on the potential benefits and challenges of ecosystem service map production for different levels of decision-making in Germany, Finland, the UK and Poland. Willemen et al. (2013) also highlighted the need for spatial methods to assess ecosystem service trade-offs in the Democratic Republic of Congo. Mapping pre-processing was also carried out to validate and ensure that all maps collected were appropriate for spatial map production. The Geographic Information System (GIS) was used for spatial mapping.

The second and third research questions were answered via questionnaire content and related Focus Group Discussions (FGDs) with key informants. This is a common technique used in qualitative research, especially in evaluation studies (Kaplowitz and Hoehn 2001), with mutual complementing of information and participant data (Doyle et al. 2020). However, caution was applied in relation to the potential for dominant participants to influence others in conveying their own ideas. FGDs are often used in studies related to evaluation of forest ecosystem services (e.g., Cuni-Sanchez et al. (2019) for the Democratic Republic of Congo, Iqbal (2020) for Sundarbans mangrove forest areas in Bangladesh, Chaigneau et al. (2019) for coastal Kenya and Mozambique, and van Oort et al. (2015) for the Koshi river basin in Nepal). FGDs were conducted to clarify the type, locations and collecting time of forest ecosystem services by local communities, with resulting data subjected to thematic analysis.

Study area

Biha Resort plays a vital role in BBSNP conservation efforts, with an area of 19,874.41 ha between 5°10' to 5°24' south latitude and 104°2' to 104°14' east longitude (Figure 2). It is part of Pesisir Barat District, around a six-hour drive from Bandar Lampung (the capital of Lampung) via the *Lintas Barat* road or seven hours via the *Lintas Timur* road.Biha Resort area is covered by a core zone (73%), wilderness zone (22%), rehabilitation zone (3%) and traditional zone (2%). This formation demonstrates how the ecosystem (especially in the core zone) remains natural and ideal as a crucial habitat for the Sumatran tiger, the Sumatran elephant and the Sumatran rhino, whose presence is much higher than in other resorts (Arimbi et al. 2021).

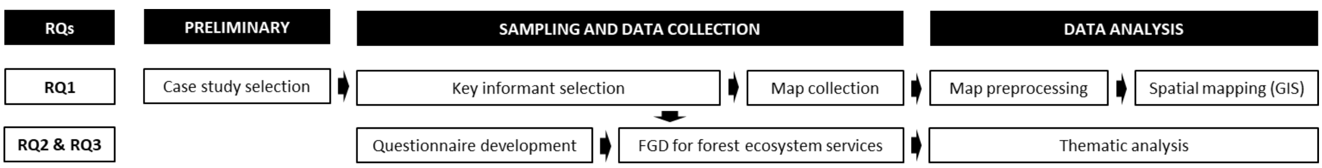

Figure 1. Research design

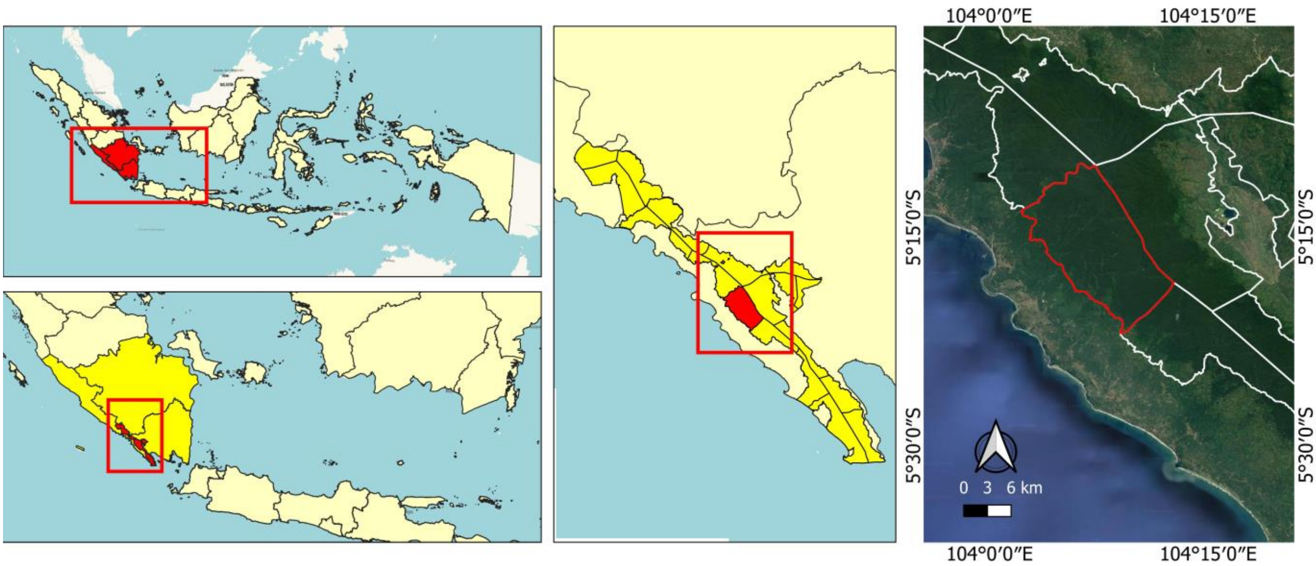

Figure 2. Biha Resort and the surrounding area in Bukit Barisan Selatan National Park, Southern Sumatra, Indonesia

Several villages have communities that interact with forest areas around Biha Resort and use BBSNP for their livelihoods (Arimbi et al. 2021). The map layout in Figure 2 is based on: (i) Land cover data from Sentinel 2 satellite imagery captured on 11 July 2021 (from the USGS website: https://earthexplorer.usgs.gov/) with a kappa accuracy of 77%, (ii) Biha Resort map data from the BBSNP bureau.

Data collection and analysis

Data were collected from May to July 2022, with spatial mapping based on interviews with key informants assumed to be knowledgeable about each site and to have diverse backgrounds to enrich basic information (Sandelowski 2000; Kim et al. 2016). First, BBSNP managers were interviewed regarding villages neighboring Biha Resort, and several studies conducted by BBSNP managers were reviewed. Second, the authors visited and interviewed leaders of adjacent villages to clarify their areas. Third, a representative of the local district-level forest management unit (KPH) of Pesisir Barat was interviewed to clarify Biha Resort buffer areas. Information on the locations of villages, the Biha Resort area, buffer areas and customary forests was obtained to enable mapping forest local community's location in BBSNP's borders.

All base maps were organized into village, BBSNP, Biha Resort, buffer area and approximate customary forest types. Village maps were obtained from *Badan Informasi Geospasial* (BIG), or the Indonesia Geospatial Agency. Buffer area maps were obtained from *Balai Pemantapan Kawasan Hutan* (BPKH), or the Forest Area Consolidation Agency Region XX Bandar Lampung, BBSNP maps and Biha Resort maps were obtained from the BBSNP bureau, and approximate customary forest maps were determined from Sentinel 2 satellite imagery captured on 26 July 2021 and validated by key informants. The information was delineated using ArcGIS 2.7.0 software and overlaid to map the forest local community location and surrounding areas. Identification of customary forests via satellite imagery can be problematic due to tree density, but classification showed moderately dense forest outside the legal boundaries of BBSNP, protected forests and limited production forests.

The questionnaire (asking 1. What items were used or taken by the village community from forest areas, 2. Where and when they were used or taken) was formulated to support FGDs, with key informants clarifying forest ecosystem services utilized by the local communities. Hong and Saizen (2019) used similar techniques to estimate the utilization of forest ecosystem services in Vietnam's Bach Ma National Park forest community. The first question related to current and past utilization of forest ecosystem services. Multiple choices (BBSNP, protected forests, limited production forests and customary forests) to answer the location of forest ecosystem services and questions related to the harvesting calendar in monthly aggregates were provided for the second question.

FGDs were conducted via online Zoom meetings due to the Covid-19 pandemic, as well as to reduce the cost of data collection and provide increased flexibility as compared to face-to-face interviews (Doyle et al. 2020). Data from the discussions were subjected to Thematic Analysis (TA), which is commonly used in qualitative studies to identify, arrange and analyze information (Braun and Clarke 2006). The questions were posed to all group members, with the ability for free-form answers. The responses were reviewed, and clarification was sought where necessary.

Transcripts from the FGDs were sorted by theme, including ecosystem service types, resource types (scientific, common and family), life forms, elements used, usage purpose, collection sites, and the harvesting calendar for monthly aggregates. Animal forest resources were grouped into wild aquatic and wild land types, and plants were classified as wild, semi-wild, semi-cultivated and cultivated, with elaborated definitions of how plants grow and their environments. A difference between cultivated and naturally growing plants was made, although this was sometimes unclear due to the characteristics of growth sites. Wild plants grew wild in natural environments without human intervention; semi-wild plants grew naturally in environments that had some level of human intervention; semi-cultivated plants grew in cultivated environments with minimized human intervention, and cultivated plants grew in environments with human intervention and intensive maintenance.

RESULTS AND DISCUSSION

Spatial mapping of local communities neighboring Biha Resort

Spatial mapping shows local communities distributed among eight villages (Sukarame, Pelita Jaya, Sumur Jaya, Tanjung Setia, Paku Negara, Tanjung Raya, Marang and Ulok Mukti (Figure 3)) using: (i) the state-managed Bukit Barisan Selatan National Park (*Taman Nasional Bukit Barisan Selatan*; a protected forest variety); (ii) protected forests controlled by *Kesatuan Pengelolaan Hutan* (KPH), or the district-level forest management unit of Pesisir Barat (*Hutan Lindung*; a protected forest variety); (iii) limited-production forests managed by the KPH of Pesisir Barat (*Hutan Produksi Terbatas* (HPT)), and (iv) community-managed customary forests (*Hutan Marga* or *Repong Damar).*

Customary forest areas are located on *Tanah Marga* land – a local term referring to areas long controlled and managed by community groups. *Repong Damar* also accommodates traditional agroforestry practices dominated by dammar trees (*Shorea javanica*) in customary forests along with fruit, vegetable and medicinal plant growth. Communities use land in limited production forest areas for agroforestry, agriculture (horticulture and staple-food growth) and plantations (e.g., for fruit, palm oil, coconuts and rubber), while land in protected forests is used to grow fruit. These activities are permitted under an agreement between farmers and the authority of *Kesatuan Pengelolaan Hutan* (KPH) – the regency level-forest management unit of Pesisir Barat – in designated areas. In the Biha Resort Area, the community is allowed to collect non-timber forest products (e.g., resin from dammar species, *S. javanica* and durian, langsat, bitter bean and *jengkol* fruit) under a similar agreement with the BBSNP authority in traditional zones. Collection of forest resources and use of BBSNP areas outside the scope of the agreement are illegal.

Three villages (Sumur Jaya, Paku Negara and Ulok Mukti) covered four types of forest, four villages (Sukarame, Pelita Jaya, Tanjung Raya and Marang) covered three types, and one (Tanjung Setia) covered two types. The Biha Resort buffer area consisted of protected forests and a larger area of limited-production forests, as seen in all villages. Protected forests were found only in Sumur Jaya, Paku Negara and Ulok Mukti, while customary forests were seen outside the resort and its buffer area. These were close to community settlements in all villages. There were several ethnic groups in all villages (Lampung, Java, Bali, and other groups from Sumatra), with many long-term migrant residents. There are still differences in perception among local leaders regarding village boundaries and divisions between villages and forests due unclear demarcations.

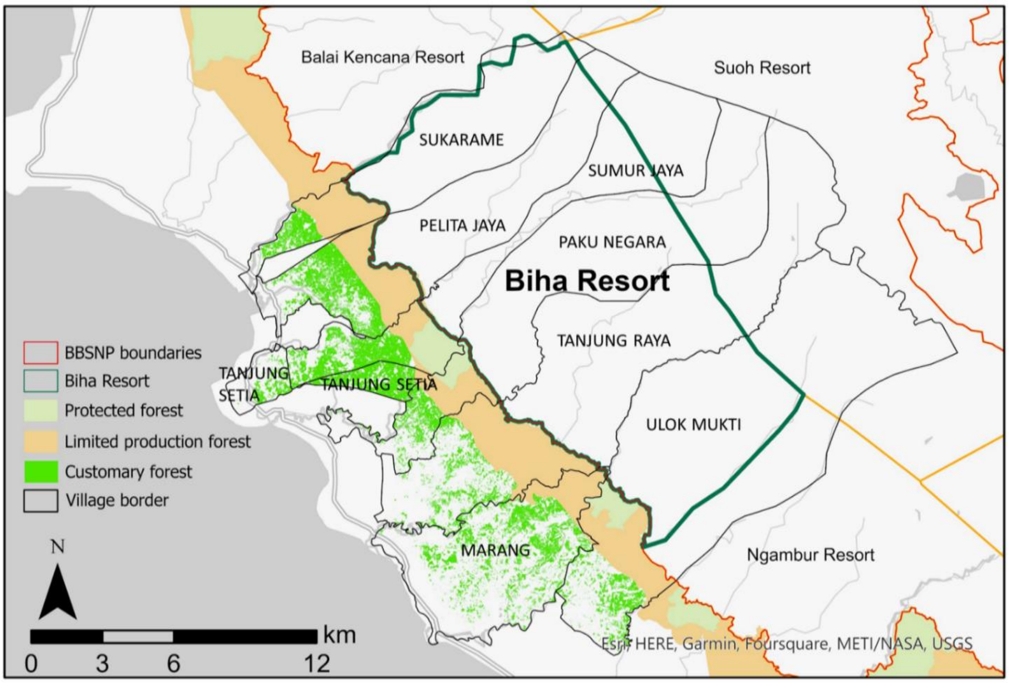

Figure 3. Local communities neighboring Biha Resort in Bukit Barisan Selatan National Park, Southern Sumatra, Indonesia

Table 1. Local river/spring usage

Name		Usage	Sites* and Collectors**			
Common	Local		BBSNP	PF	LPF	CF
Basohan River	Way Basohan	Transportation, sanitation	2, 3	3	2, 3	2, 3
Biha River	Way Biha	Irrigation, transportation, sanitation	5, 6, 8		5, 6, 8	5, 6, 8
Tenumbang River	Way Tenumbang	Transportation, sanitation	1, 2		1, 2	1, 2
Marang River	Way Marang	Transportation, sanitation	7	7	7	7
Ngambur River	Way Ngambur	Irrigation, transportation, sanitation	8		8	8
Way Curug Spring	Mata Air Way Curug	Drinking water			5	

Note: * BBSNP: Bukit Barisan Selatan National Park; PF: protected forests; lpf: limited production forests; cf: customary forests, ** 1: Sukarame; 2: Pelita Jaya; 3: Sumur Jaya; 4: Tanjung Setia; 5: Paku Negara; 6: Tanjung Raya; 7: Marang; 8: Ulok Mukti

Forest ecosystem services

The results from FGDs on forest ecosystem services utilized by the community cover water resources, food, pets, construction materials, fuel, medicine, raw commercial materials and other matter (Table 2). Table 1 shows water resources used by villagers, who also utilized ecosystem services in customary, limited-production, protected and BBSNP forests. Villagers in Sukarame, Pelita Jaya, Tanjung Setia, Paku Negara, Tanjung Raya, Ulok Mukti Sumur Jaya and Marang utilized resources from these four forest types as detailed below.

Water resources

The *Tenumbang*, *Basohan*, *Biha*, *Marang* and *Ngambur* rivers are utilized primarily for sanitation, drinking water and flow through local forests. Locals also use the *Way Curug* spring for drinking water (Table 1). They also used local rivers to collect stones and wooden boat transportation.

Food

Ecosystem services are utilized by villagers in the form of food derived from animals and plants. These are harvested on a monthly basis or as needed. Harvests include fruit (*Artocarpus heterophyllus*, *Artocarpus integer*, *Carica papaya*, *Cocos nucifera*, *Durio oxleyanus*, *Durio zibethinus*, *Garcinia mangostana*, *Lansium parasiticum*, *Mangifera indica*, *Musa paradisiaca*, *Nephelium lappaceum*, *Persea americana*, *Psidium guajava*, *Syzygium queum*), vegetables (*Archidendron bubalinum*, *Archidendron pauciflorum*, *Capsicum annum*, *Capsicum annum* var. annuum, *Capsicum frutescens*, *Gnetum gnemon, Parkia speciosa*) and content for drinks such as coffee (*Coffea canephora*) in June and July. The harvest calendar for other fruits is presented in Table 3. Flowering plants are used for vegetable content (*Alpinia galangal*, *C. papaya*, *G. gnemon*, *Musa acuminata*, and *M. paradisiaca*) and spices (*Syzygium aromaticum*), with most available year-round except *G. gnemon* (July) and *S. aromaticum* (May).

Several bamboo species provide year-round vegetable content, such as *Dendrocalamus asper* and *Gigantochloa robusta*. Villagers used stems from the perennial *Saccharum officinarum* for beverages, and numerous leafy vegetables were provided by *C. papaya*, *Diplazium esculentum*, *Manihot esculenta* and *Sauropus androgynus*. Leaves were also used year-round for food coloring (*Pandanus amaryllifolius*), spice (*Syzygium polyanthum*) and wrapping (*M. acuminata* and *M. paradisiaca*). Rhizomes from *A. galanga*, *Curcuma longa*, *Kaempferia galanga*, and *Zingiber officinale* were also consumed.

Pet

Villagers leveraged wild birds as pets and for income. Hunting is illegal in the BBSNP area, protected forests and limited-production forests, with birds protected under the regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.92/MENLHK/SETJEN/KUM.1/8/2018 (the great hornbill, the rhinoceros hornbill, the helmeted hornbill, the Javan leafbird and the lesser green leafbird, which are on the IUCN red list of threatened species (IUCN 2020a,b,c,d). Bird hunting was found to be only occasional in the survey.

Construction materials and fuel

Timber from various tree species and bamboo were used to construct houses. Villagers harvested them as needed. Villagers collected fallen leaves, branches, twigs and tree trunks for fuel on a year-round basis. These come from a variety of species and were used for cooking.

Medicine and raw commercial materials

Villagers used various animals and plants for medicinal resources. The Sumatran serow (IUCN 2020e) and the Sunda pangolin (IUCN 2019b) are on the IUCN Red List of threatened species. Wild animals were also occasionally hunted for medicinal purposes. Plant-based medicine comes from plant resources such as rhizomes, roots and leaves perennially, with occasional harvesting. Villagers use various forest resources for sale and as perennial commercial raw materials to get cash. These materials are available every month.

Fodder and other materials

Fodder comes from the several leaves. They were available perennially, with occasional collection. Other forest materials were used for decorations, bird traps, dammar resin harvesting, textile dyes, kitchen utensils and traditional ceremonies. Horns from sambar deer (*Cervus unicolor*), southern red muntjacs (*Muntiacus muntjak*) and Sumatran serows (*Capricornis sumatraensis*) and ivory from Sumatran elephants (*Elephas maximus sumatranus*) were used decoratively, with occasional hunting.

Table 2. Animal and plant resources collected by villagers in Biha Resort, Bukit Barisan Selatan National Park, Southern Sumatra, Indonesia

Scientific Name*	Common Name	Local Name	Family	Lifeform	Element	Usage	Ecosystem Service	Collection Site**
Wild aquatic animals								
Achatina fulica	Giant African land snail	*Sioh, siput*	Achatinidae	Snail	Meat	Protein, income	Food	1, 2, 3, 4
Anguilla spp.	Freshwater eel	*Ikan sidat, pelus, lindung*	Anguillidae	Fish	All	Protein, income	Food	1, 2, 3, 4
Metapenaeus ensis	Greasyback shrimp, Sand shrimp	*Udang batu, urang napal*	Penaeidae	Shrimp	All	Protein	Food	1, 2, 3, 4
Oreochromis mossambicus [VU]	Oreochromine cichlid	*Ikan mujair*	Cichlidae	Fish	All	Protein, income	Food	1, 2, 3, 4
Osteochilus vittatus	Bonylip barb, hard-lipped barb, silver shark minnow	*Ikan palau, nilam*	Cyprinidae	Fish	All	Protein, income	Food	1, 2, 3, 4
Sicyopterus cynocephalus, Sicyopterus micrurus	Cleft-lipped goby	*Ikan lekok*	Gobiidae	Fish	All	Protein, income	Food	1, 2, 3, 4
Tor duoronensis	Ray-finned fish	*Ikan siran*	Cyprinidae	Fish	All	Protein, income	Food	1, 2, 3, 4
Wild terrestrial animals								
Aethopyga temminckii	Temminck's sunbird	*Kolibri*	Nectariniidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Apis dorsata	Giant honeybee	*Lebah madu hutan*	Apidae	Insect	Honey	Food supplement	Food	1, 2, 3, 4
Buceros bicornis [VU]	Great hornbill	*Enggang papan*	Bucerotidae	Bird	All	Pets, income	Pets	1
Buceros rhinoceros [VU]	Rhinoceros hornbill	*Enggang cula*	Bucerotidae	Bird	All	Pets, income	Pets	1
Capricornis sumatraensis [VU]	Sumatran serow, mainland serow	*Kambing hutan*	Bovidae	Mammal	Meat, horns	Protein, traditional medicine, income, decoration	Food, medicine, other materials	1, 2
Cervus unicolor [VU]	Sambar deer	*Rusa sambar*	Cervidae	Mammal	Meat	Protein, income, decoration	Food, other materials	1, 2, 3, 4
Chloropsis cochinchinensis [EN]	Javan Leafbird	*Cucak ranting*	Chloropseidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Chloropsis cyanopogon [NT]	Lesser green leafbird	*Cucak daun*	Chloropseidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Chloropsis sonnerati [EN]	Greater green leafbird	*Cucak hijau*	Chloropseidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Cisticola juncidis	Zitting cisticola	*Ciblek*	Cisticolidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Copsychus malabaricus	White-rumped shama	*Murai batu*	Muscicapidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Copsychus saularis	Oriental magpie-robin	*Kacer*	Muscicapidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Elephas maximus sumatranus [EN]	Sumatran elephant	*Gajah sumatera*	Elephantidae	Mammal	Ivory	Decoration, income	Other materials	1
Enicurus leschenaulti, Enicurus velatus	White-crowned forktail, Sunda forktail	*Meninting air*	Muscicapidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Geopelia striata	Zebra dove	*Perkutut*	Columbidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Hystrix brachyura	Malayan porcupine	*Landak*	Hystricidae	Mammal	Intestines	Traditional medicine, income	Medicine	1, 2, 3, 4
Leptocoma sperata	Purple-throated sunbird	*Konin*	Nectariniidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Manis javanica [CR]	Sunda pangolin	*Trenggiling*	Manidae	Mammal	Meat, scales	Protein, traditional medicine, income	Food, medicine	1, 2, 3, 4
Muntiacus muntjak	Southern red muntjac	*Kijang*	Cervidae	Mammal	Meat	Protein, income, decoration	Food, other materials	1, 2, 3, 4

Platylophus galericulatus [NT]	Crested jay	*Cililin, cucak jambul*	Platylophidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Prinia familiaris [NT]	Bar-winged prinia	*Perenjak*	Cisticolidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Pycnonotus aurigaster	Sooty-headed bulbul	*Kutilang*	Pycnonotidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Pycnonotus goiavier	Yellow-vented bulbul	*Crocokan, cerukcuk*	Pycnonotidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Pycnonotus melanicterus	Black-capped bulbul	*Cucak kuning, kutilang emas*	Pycnonotidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Pycnonotus plumosus	Olive-winged bulbul	*Kapas tembak*	Pycnonotidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Rhinoplax vigil [CR]	Helmeted hornbill	*Rangkong gading*	Bucerotidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Spilopelia chinensis	Eastern spotted dove	*Tekukur*	Columbidae	Bird	All	Pets, income	Pets	1, 2, 3, 4
Sus scrofa	Wild boar	*Babi hutan*	Suidae	Mammal	Meat	Protein, income	Food	1, 2, 3, 4
Tragulus napu	Greater oriental chevrotain	*Napuh pelanduk*	Tragulidae	Mammal	Meat	Protein, income	Food	1, 2, 3, 4
Trigona apicalis	Stingless bee	*Lebah madu klanceng*	Apidae	Insect	Honey	Food supplements	Food	1, 2, 3, 4
Plants								
Albizia chinensis	Chinese albizia	*Sengon merah*	Fabaceae	Tree	Trunks, leaves	Roofs, doors, fodder	Construction materials, fodder	4 [sc]
Aleurites moluccanus	Candlenut	*Kemiri*	Euphorbiaceae	Tree	Fruit	Income, spices	Food	3 [sc], 4 [sc]
Alpinia galanga	Greater galangal	*Lengkuas*	Zingiberaceae	Herb	Flowers, rhizomes	Vegetables, spices, income	Food	1 [sw], 2 [sw], 3 [sc], 4 [sc]
Alstonia scholaris	Blackboard tree	*Pulai*	Apocynaceae	Tree	Trunks, leaves	Domestic construction, fodder	Construction materials, fodder	4 [sc]
Amomum compactum	Java cardamom	*Kapu laga*	Zingiberaceae	Herb	Rhizomes	Traditional medicine, income	Medicine	3 [sc], 4 [sc]
Aquilaria malaccensis [CR]	Agarwood	*Gaharu*	Thymelaeceae	Tree	Bark, trunks, branches, twigs	Cosmetics, income	Raw commercial materials, fuel	1 [sw], 2 [sw], 3 [sc], 4 [sc]
Archidendron bubalinum	Kerdas	*Kuau*	Fabaceae	Tree	Fruit, branches, twigs	Vegetables, income, firewood	Food, fuel	1 [sw], 2 [sw], 3 [sw], 4 [sw]
Archidendron pauciflorum	Djengkol	*Jengkol*	Fabaceae	Tree	Fruit, branches, twigs	Vegetables, income, firewood	Food, fuel	1 [sc], 2 [sc], 3 [sc], 4 [sc]
Areca catechu	Betel palm	*Pinang*	Arecaceae	Tree	Fruit, leaves	Traditional medicine, income, firewood	Medicine, fuel	1 [sc], 2 [sc], 3 [sc], 4 [sc]
Artocarpus elasticus	Terap	*Bendo, kerbang*	Moraceae	Tree	Trunks, sap	Domestic construction, bird traps	Construction/other	4 [sc]
Artocarpus heterophyllus	Jackfruit	*Nangka*	Moraceae	Tree	Fruit, branches, twigs, leaves	Fruit, vegetables, firewood	Food, fuel, fodder	3 [sc], 4 [sc]
Artocarpus integer	Cempedak	*Cempedak*	Moraceae	Tree	Fruit, branches, twigs	Fruit, income, firewood	Food, fuel	1 [sc], 2 [sc], 3 [sc], 4 [sc]
Bambusa arundinacea	Bamboo	*Bambu ori*	Poaceae	Tree	Stems	Roofs, livestock/bird cages	Construction	3 [sw], 4 [sw]
Calamus sp.	Rattan	*Rotan*	Arecaceae	Tree	Stems, fruit	Resin harvesting tools, textile dyes	Other	1 [sw], 2 [sw], 3 [sw]
Canna edulis	Edible canna	*Ganyong*	Cannaceae	Herb	Tubers	Side dishes, income	Food	3 [c], 4 [c]

Capsicum annum	Sweet chilli pepper	*Cabai merah*	Solanaceae	Tree	Fruit	Vegetable	Food	3 [c], 4 [c]
Capsicum annum var. annuum	Green chilli pepper	*Cabai hijau*	Solanaceae	Tree	Fruit	Vegetable	Food	3 [c], 4 [c]
Capsicum frutescens	Tabasco pepper	*Cabai rawit*	Solanaceae	Tree	Fruit	Vegetable	Food	3 [c], 4 [c]
Carica papaya	Papaya	*Pepaya*	Caricaceae	Tree	Fruit, leaves, flowers	Fruit, income, vegetables	Food	3 [sc], 4 [sc]
Cocos nucifera	Coconut	*Kelapa*	Arecaceae	Tree	Fruit, leaves	Fruit, food commerce, income	Food, raw commercial materials, fuel	4 [sc]
Coffea canephora	Coffee	*Kopi*	Rubiaceae	Tree	Fruit, branches, twigs, trunks	Drink, income, firewood, roofs, walls, windows, doors	Food, fuel, construction materials	3 [sc], 4 [sc]
Curcuma longa	Turmeric	Turmeric	Zingiberaceae	Herb	Rhizomes	Spices, food coloring, traditional medicine	Food, medicine	3 [sc], 4 [sc]
Curcuma zanthorrhiza	Temulawak	*Temu lawak*	Zingiberaceae	Herb	Rhizomes	Traditional medicine	Medicine	3 [sc], 4 [sc]
Dendrocalamus asper	Bamboo	*Bambu betung*	Poaceae	Tree	Shoots, stems	Columns, roofs, livestock/bird cages, kitchen utensils	Construction/other	3 [sw], 4 [sw]
Diplazium esculentum	Climbing swamp fern	*Pakis*	Athyriaceae	Fern	Leaves	Vegetables	Food	4 [sw]
Durio oxleyanus	Durian	*Durian*	Malvaceae	Tree	Fruit	Fruit, income	Food	1 [sw,w]
Durio zibethinus	Durian	*Durian*	Malvaceae	Tree	Fruit, branches, twigs	Fruit, income, firewood	Food, fuel	1 [sc], 2 [sc], 3 [sc], 4 [sc]
Elaeis guineensis	African oil palm	*Kelapa sawit*	Arecaceae	Tree	Fruit	Oil palm commerce, income	Raw commercial materials	3 [sc], 4 [sc]
Eurycoma longifolia	Longjack	*Pasak bumi*	Simaroubaceae	Tree	Roots	Traditional medicine, income	Medicine	1 [sw], 2 [sw], 3 [sc], 4 [sc]
Garcinia mangostana	Magosteen	*Manggis*	Clusiaceae	Tree	Fruit, branches, twigs	Fruit, income, firewood	Food, fuel	1 [sc], 2 [sc], 3 [sc], 4 [sc]
Gigantochloa apus	Bamboo	*Bambu apus, bambu tali*	Poaceae	Tree	Stems	Roofs, walls, livestock/bird cages, kitchen utensils	Construction/other	3 [sw], 4 [sw]
Gigantochloa atroviolacea	Bamboo	*Bambu wulung*	Poaceae	Tree	Stems	Columns, livestock/bird cages	Construction	3 [sw], 4 [sw]
Gigantochloa robusta	Bamboo	*Bambu mayan*	Poaceae	Tree	Shoots	Vegetables	Food	3 [sw], 4 [sw]
Gliricidia sepium	Quickstick	*Gamal*	Fabaceae		Branches, twigs, leaves	Firewood, fodder	Fuel, fodder	4 [sw, sc]
Gnetum gnemon	Melinjo	*Melinjo, tangkil*	Gnetaceae	Tree	Fruit, flowers, leaves, branches, twigs	Vegetables, income, firewood	Food, fuel	1 [sw], 2 [sw], 3 [sw], 4 [sw]
Hevea brasiliensis	Pará rubber tree	*Karet*	Euphorbiaceae	Tree	Latex	Rubber commerce, income, bird traps	Raw commercial/other	3 [sc], 4 [sc]
Kaempferia galanga	Aromatic ginger	*Kencur*	Zingiberaceae	Herb	Rhizomes	Traditional medicine, spices	Medicine, food	3 [sw, sc], 4 [sw, sc]
Lansium parasiticum	Langsat, lanzones, longkang	*Duku*	Meliaceae	Tree	Fruit, branches, twigs	Fruit, income, firewood	Food, fuel	1 [sc], 2 [sc], 3 [sc], 4 [sc]
Leea indica	Bandicoot berry	*Handamali*	Vitaceae	Tree	Trunks	Traditional ceremonies	Other	4 [sw]
Maesopsis eminii	Umbrella tree	*Afrika*	Rhamnaceae	Tree	Leaves	Fodder	Fodder	3 [sc], 4 [sc]

Mangifera indica	Mango	*Mangga*	Anacardiaceae	Tree	Fruit, branches, twigs	Fruit, income, firewood	Food, fuel	3 [sc], 4 [sc]
Manihot esculenta	Cassava	*Singkong*	Euphorbiaceae	Tree	Tubers, leaves	Side dishes, vegetables, income	Food	3 [sc], 4 [sc]
Musa acuminata	Banana	*Pisang kepok*	Musaceae	Tree	Fruit, leaves, flowers	Side dishes, vegetables, food wrapping, income	Food	3 [sw, sc], 4 [sw, sc]
Musa paradisiaca	Banana	*Pisang ambon, pisang lilin, pisang muli, raja nangka*	Musaceae	Tree	Fruit, leaves, flowers	Fruit, vegetables, food wrapping, income	Food	3 [sw, sc], 4 [sw, sc]
Myristica fragrans	Nutmeg	*Pala*	Myristicaceae	Tree	Fruit	Spices, income	Food	3 [sc], 4 [sc]
Neolamarckia cadamba	Burflower tree	*Jabon*	Rubiaceae	Tree	Trunks	Walls	Construction	4 [sc]
Nephelium lappaceum	Rambutan	*Rambutan*	Sapindaceae	Tree	Fruit, branches, twigs	Fruit, income, firewood	Food, fuel	4 [sc]
Pandanus amaryllifolius	Pandan	*Pandan*	Pandanaceae	Tree	Leaves	Food coloring	Food	3 [sw, sc], 4 [sw, sc]
Paraserianthes falcataria	Batay	*Sengon putih*	Fabaceae	Tree	Trunks, leaves	Roofs, fodder	Construction/fodder	4 [sc]
Parkia speciosa	Bitter bean	*Petai*	Fabaceae	Tree	Fruit, branches, twigs	Vegetables, income, firewood	Food, fuel	1 [sw, sc], 2 [sw, sc], 3 [sw, sc], 4 [sw, sc]
Pennisetum purpureum	Elephant grass	*Rumput gajah*	Poaceae	Grass	Leaves	Fodder	Fodder	3 [sw, sc], 4 [sw, sc]
Peronema canescens	False elder	*Sungkai*	Lamiaceae	Tree	Trunks, leaves	Roofs, doors, traditional medicine	Construction, medicine	4 [sc]
Persea americana	Avocado	*Alpukat*	Lauraceae	Tree	Fruit	Fruit, income	Food	4 [sc]
Piper nigrum	Black pepper	*Lada*	Piperaceae	Climber	Fruit	Spices, income	Food	3 [c], 4 [c]
Psidium guajava	Common guava	*Jambu biji*	Myrtaceae	Tree	Fruit, branches, twigs	Fruit, firewood	Food, fuel	3 [sc], 4 [sc]
Saccharum officinarum	Sugar cane	*Tebu*	Poaceae	Grass	Stems	Drinks	Food	3 [sc], 4 [sc]
Sauropus androgynus	Katuk	*Katuk*	Phyllanthaceae	Shrub	Leaves	Vegetables	Food	4 [sw, sc]
Schima wallichii	Needlewood tree	*Medang*	Theaceae	Tree	Trunks	Domestic construction	Construction	4 [sc]
Schizostachyum brachycladum	Bamboo	*Bambu lemang*	Poaceae	Tree	Stems	Kitchen utensils	Other	3 [sw], 4 [sw]
Shorea javanica [EN]	White meranti, Dammar	*Damar mata kucing*	Dipterocarpaceae	Tree	Resin, trunks	Income, domestic construction	Raw commercial/ construction materials	1 [sw, sc], 2 [sc], 3 [sc], 4 [sc]
Syzygium aromaticum	Clove	*Cengkeh*	Myrtaceae	Tree	Flowers	Spices, income	Food	3 [sc], 4 [sc]
Syzygium polyanthum	Indonesian bay leaf	*Salam*	Myrtaceae	Tree	Leaves	Spices	Food	1 [sw], 2 [sw], 3 [sw], 4 [sw]
Syzygium queum	Watery rose apple	*Jambu air*	Myrtaceae	Tree	Fruit, branches, twigs	Fruit, firewood	Food, fuel	3 [sc], 4 [sc]
Theobroma cacao	Cacao tree	*Kakao*	Malvaceae	Tree	Fruit, branches, twigs	Income, firewood	Raw commercial materials, fuel	4 [sc]
Vitex pinnata	Round leaf chaste tree	*Laban*	Lamiaceae	Tree	Trunks	Doors	Construction	3 [sc], 4 [sc]
Zingiber officinale	Ginger	*Jahe*	Zingiberaceae	Herb	Rhizomes	Traditional medicine, spices	Medicine, food	3 [sc], 4 [sc]

Note: *IUCN Red List threatened species. NT: near-threatened, VU: vulnerable, EN: endangered, CR: critically endangered; ** Collection site. 1: Bukit Barisan Selatan National Park, 2: protected forests, 3: limited production forests, 4: customary forests; Plant acquisition: w: wild; sw: semi-wild; sc: semi-cultivated; c: cultivated

Table 3. Fruit-harvesting calendar

Scientific Name	Harvest Calendar
Fruit	
Artocarpus heterophyllus	July, August
Artocarpus integer	April, May
Carica papaya	Perennial
Cocos nucifera	Perennial
Durio oxleyanus	June, July
Durio zibethinus	June, July
Garcinia mangostana	July
Lansium parasiticum	February, March
Mangifera indica	March
Musa acuminata	Perennial
Musa paradisiaca	Perennial
Nephelium lappaceum	March, April
Persea americana	January, February
Psidium guajava	Perennial
Syzygium queum	February, March, June, July, September, October
Vegetables	
Archidendron bubalinum	August, September
Archidendron pauciflorum	June, July
Capsicum annum	Perennial
Capsicum annum var. *annuum*	Perennial
Capsicum frutescens	Perennial
Gnetum gnemon	July
Parkia speciosa	June, July

Pará rubber tree (*Hevea brasiliensis*) latex and terap (*Artocarpus elasticus*) sap were used for bird hunting on a perennial basis, rattan (*Calamus* sp.) stems were used as dammar resin harvesting tools, and rattan fruit was used as a textile dye. Bamboo stems from *Gigantochloa apus* and *Schizostachyum brachycladum* were used as kitchen utensils, and bandicoot berry (*Leea indica*) trunks were used ceremonially. Most materials were available perennially, with occasional collection.

Discussion

The spatial map highlights Biha Resort's vital local community and livelihood roles for them, who coexist with multiple forest types in villages overlapping BBSNP areas including Biha Resort and buffer forests. Natural forests and communities have long coexisted in the area, although reliable demarcations of forest and village boundaries (e.g., roads, rivers and mountains (Hettiarachchi et al. 2022)) remain unavailable. This lack of territorial clarity may lead to conflicts of interest in developing villages and BBSNP conservation areas. Boundary disputes in the study area have continued for a long time, especially between communities and state forest managers, regardless of local efforts to determine state forest boundaries, resulting in overlapping boundaries with cultural-heritage *Repong Damar* land (Suporahardjo and Wodicka 2003). To prevent conflicts, the Indonesian government provides access to local communities for management of *Repong Damar* land in state forest areas (BBSNP, protected forests, limited-production forests and protected forests) through a social forestry (*perhutanan sosial*) program, which also allows communities to cultivate plants and collect non-timber forest products in limited-production forest areas and protected forests. In BBSNP areas, communities can collect non-timber forest products.

The study found that BBSNP forest areas and their surroundings exhibited high biodiversity and played significant roles in providing resources for local livelihoods. The majority of forest ecosystem services used by communities were mainly in customary forests, followed by limited-production forests, protected forests and BBSNP areas. Customary forests are more easily accessed due to community control, and tend to be closer to residential areas. Forest ecosystem services in protected forests were only used by Sumur Jaya and Marang villagers. However, the map shows protected forests within Sumur Jaya, Paku Negara, and Ulok Mukti boundaries. This is a result of unclear forest boundaries, highlighting a need for clarification and consideration of how community forests sometimes do not follow legal boundaries.

The findings also show that forests provide ecosystem services relating to water resources, wild animals, plants and similar to support livelihoods and generate income. This demonstrates the importance of forest resources in fulfilling the basic needs of locals, with semi-cultivated and semi-wild types playing essential livelihood roles. Plants were the main forest resource reported, providing more ecosystem services than wild animals (e.g., food, medicine, construction materials). Food is the most important ecosystem service because it fulfils a basic human need, with most coming from plants rather than animals. The study demonstrated the significant contribution of trees to local livelihoods and reserves, reflecting the finding of Reed et al. (2017) that trees play an important role in livelihoods and food resources for people in tropical zones. Provisioning services are the most frequently mentioned forest ecosystem services because they are easy to identify and directly benefit community needs and livelihoods. Our study did not identify other forest ecosystem services such as supporting, regulating and cultural services. However, it enriches information regarding the local community's detailed use of forest resources, especially related to provisioning services. A study by Muhamad et al. (2014) in several households neighboring Gunung Gede Pangrango National Park, West Java, Indonesia, identified the benefits of more various forest-agricultural landscape ecosystem services such as provisioning, supporting, regulating and cultural services, also showing that provisioning services are the most dominant services mentioned by the community, especially food. It aligns with this study's results that food is the ecosystem service most widely used by local communities around forests. A study from Hong and Saizen (2019) on the use of forest ecosystem services by local communities in the buffer area of Bach Ma National Park, Vietnam, also demonstrates that food is the most frequently mentioned by respondents.

The most-hunted animals are generally birds and mammals (Wiratno et al. 2004), and this study highlighted birds as the most popular targets. Villagers hunted for purposes relating to food, livelihoods and pets. To reduce the poaching of protected animals, BBSNP managers educate villagers in door-to-door visits, face-to-face presentations, posters and information boards. However, illegal hunting is still rife due to information/education limitations. Due to their proximity to and greater influence within the community, local leaders must be involved in the effort to reduce illegal hunting.

Birds on the IUCN Red List of threatened species include the great hornbill (IUCN 2020a), the rhinoceros hornbill (IUCN 2020f), the helmeted hornbill (IUCN 2020b), the Javan leafbird (IUCN 2020c), the lesser green leafbird (IUCN 2020d), the crested jay (IUCN 2019a) and the bar-winged prinia (IUCN 2018b). Protected mammals include the Sumatran serow (IUCN 2020e), the Sambar deer (IUCN 2014), the Sumatran elephant (IUCN 2011) and the southern red muntjac (IUCN 2015). The plant species of agarwood (*Aquilaria malaccensis)* or *gaharu* (IUCN 2018a) and dammar (*S. javanica*) or *damar mata kucing* (IUCN 2018c) are also on the list. Such protected species require special attention in forest resource management, as extinction would adversely affect ecosystem sustainability. Sustaining such resources needs to educate local communities on threatened resources and encourage them to conserve and cultivate them on privately owned or government-prepared land. Cultivating threatened resources can be a way to prevent extinction and improve local economies through work-labor absorption (Bariyah 2020). *Gaharu* is a popular forest product with high global demand (Großmann 2017). This product is a raw material for various cosmetics, medicines, perfumes and jewelry. Several studies note the use of products from *gaharu* by local forest communities in Indonesia, such as wood for bracelets and necklaces (Großmann 2017), resin for sale to get cash (Kamarudin et al.2022) and leaves for cancer and hypertension medicine (Yanti et al. 2020). Education regarding the use of other products from *gaharu*, such as leaves for medicine, can increase the local community’s livelihood around Biha Resort. Forest resources may be seasonal or perennial, affecting local utilization and incomes. This situation may be affected by climatic conditions and community needs. The study's findings indicate that forests in BBSNP buffer areas are vital to local livelihoods, as per similar studies in other regions (Poffenberger 2006; Palomo et al. 2013). Attention to the sustainability of forests in such areas helps to reduce BBSNP exploitation. More ecosystem services are derived from customary forests (CFs) than other forest types, demonstrating their benefits in livelihood support and their rich biodiversity. CFs also tend to be closer to residential areas, making them easier to access and cultivate. Such forests (*Repong Damar*) are formed on the basis of traditional ecological management, providing various ecosystem services for community livelihoods with agroforestry techniques (Muhamad et al. 2014).

Repong Damar and surrounding forest types in BBSNP are challenged by the expansion of monoculture farming for crops such as oil palm, coconut and coffee, the latter of which has the most serious effects. Encroachment by non-locals in particular severely threatens BBSNP and surrounding forests. Such operators generally come from neighboring regions, cities and areas outside Sumatra, such as Java, engaging in local cultivation for various reasons such as infertile land in their own areas, a lack of employment opportunities and other economic issues. They mostly work as farm laborers, and have limited educational backgrounds. These conditions threaten ecosystem sustainability, impacting biodiversity and eroding local livelihoods. To address this, management of national parks and forests in buffer areas is required with the involvement of local governments, communities and forest managers in buffer areas as well as non-governmental organizations.

To prevent and reduce land encroachment and poaching of wild animals in forests, the Indonesian government runs a program promoting forest management and involvement from local communities under an agreement that obliges residents to preserve forests and report any encroachment or wild-animal poaching in *perhutanan sosial*. This mitigates negative outsider influence by increasing familiarity of local areas and surroundings. The results of this study show the importance of state forests in providing a source of livelihood for local communities and the need to provide access and legal protection to local communities through *perhutanan sosial* programs. Such training and assistance from experts regarding sustainable forest management to the local community can be embedded in this program to maintain the sustainability of forests for environmental benefit and local community benefit.

Forest has multiple benefits, as shown in these study results that not only fulfill local community needs but also provide livelihoods and have important socio-cultural value. It echoes the study results from Setiawan et al. (2021) in the buffer village communities of Alas Purwo National Park, Banyuwangi, East Java, Indonesia, that forests around buffer village communities provide multiple functions for them, including economic, social and cultural. This study shows that forests in BBSNP and forests in buffer areas provide many ecosystem services to communities around Biha Resort. This study is in line with a study from Palomo et al. (2013) in Don˜ana National Park and Sierra Nevada National Park in Spain, showing that both national parks and their buffer areas provide abundant ecosystem services for local communities. Those highlight that buffer forests have an important role in reducing local pressures and providing livelihoods for local communities around the national park. Additionally, these study results emphasize the importance of buffer area management for the sustainability of national parks and local community's quality of life.

In conclusions, this study examines the mapping of forest-local community and inter-community boundaries in Biha Resort buffer areas, focusing on settlement distribution across eight villages. Differences in community perspectives on these boundaries highlight ongoing issues, leading to potential conflicts and loss of inter-community harmony. Community-participation mapping is encouraged for a more democratic approach, allowing for collective identification and clarification of critical resource boundaries. Forest ecosystem services, such as water, food, and construction materials, are crucial for sustaining rural livelihoods. The study highlights the interdependencies between local communities and surrounding forest ecosystems (BBSNP’s forests and buffer forests), emphasizing the importance of context-specific conservation strategies. Buffer-zone forests play a crucial role in minimizing resource extraction within BBSNP buffer areas, offering alternative resources and relieving pressure on vulnerable areas. The fostering of community-based forest ecosystem management thus becomes a key objective in creating inclusive solutions that balance biodiversity conservation with sustainable community livelihoods. The findings of the study thus provide valuable insights serving as a baseline for rural development in BBSNP buffer areas and other national parks, supporting understanding of the current situation and serving as a foundation for future interventions and strategies.

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Forest recovery assessment in degraded dry evergreen forestlands in Vientiane Province, Lao People's Democratic Republic

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Abstract. *Alias MAB, Rahmani W, Azizi F, Ninchaleune B, Abdu A. 2024. Forest recovery assessment in degraded dry evergreen forestlands in Vientiane Province, Lao People's Democratic Republic. Asian J For 8: 31-40.* Shifting cultivation and logging are the significant causes of deforestation and forest degradation in tropical region. Lao PDR has vast shifting cultivation areas, and regrowth forests have spontaneously been established on fallow fields. This study aims to assess the forest recovery through vegetative succession after fallow cultivation and logging in degraded dry evergreen forestlands in Vientiane Province, Lao PDR. Braun-Blanquet method was applied to assess vegetation composition in primary forest, logged-over forest and fallow lands with age of 1-, 5- and 15-year-old. Data obtained from the vegetation study has enabled the community plant identification and forest recovery calculation by various analytical methods using statistical software. Based on the phytosociological analysis, logged-over forests had the highest vegetation composition similarity to primary forests with a similarity of 42.29%, followed by the 15, 5, and 1-year-old fallows with similarity value of 39.90%, 34.80%, and 26.10%, respectively. The three fallows with 1-, 5- and 15-year-old age and two forest types were compared for their canopy structure recovery with each other. The logged-over forest, harvested by wood logging companies and local villagers in the past two decades, recorded the lowest recovery in the canopy structure. The sites of 1-, 5- and 15-year-old fallows have not fully recovered their top layers (ST and T1). Only the T2 layer of the 15-year-old fallow recovered. This indicated that the three fallow types heavily degraded and required a longer time to recover naturally. In conclusion, local authorities should avoid over-using the natural forest in the future and should control timber and non-timber forest products. Alternative land use with integrated land management should be established. Long-term tree planting programs will enable the people to use and own their land.

Keywords: Forest fallows, primary forest, recovery assessment, shifting cultivation

INTRODUCTION

Lao People's Democratic Republic (Lao PDR) is a Southeast Asian country covering an area of 23.68 million hectares (JICA 2001) that presented the highest forest cover (70% of land area) in the 1940s (Chien 2019). Nonetheless, forest cover in Lao PDR has declined significantly in recent decades. Compared to that in 1940s, forest cover had declined to 47% (11.1 million hectares) by 1992, and decreasing further to 41.5% (9.7 million hectares) by 2002. By 2010, forest cover was estimated at 40.34% (9.5 million hectares) of total land area of the country (Phimmavong et al. 2009; Thomas 2015).

Changes in land use are the primary causes of deforestation in Lao PDR including forest conversion into commercial agriculture, hydropower, logging, and plantations (Thomas 2015). Legal and illegal logging, especially salvage logging and pioneering shifting agriculture, are the major drivers of degradation (Liebsch et al. 2008). The lack of consistent rules, compliance procedures, and land use planning and management processes, including sustainable forest management and planning, led to forest depletion (Phongoudome and Sirivong 2007). That includes significant deforestation at a rate of 1.25% each year, equating to a reduction of 140,000 ha of forest annually (FAO 2015). Agriculture land expanded significantly, almost doubling from 708,700 ha in 1982 to 1,200,000 ha in 2002. This was followed by a reduction in the area of other forested land from 1.5 million ha to 287,000 ha (Phongoudome and Sirivong 2007).

Shifting cultivation and inappropriate logging are the practices that depleted the forest cover and caused serious environmental degradation, e.g., drought, flooding, and plant diseases in many parts of Lao PDR. Shifting cultivation, also known as swidden or slash-and-burn, is a traditional land use in the tropical forest-agriculture frontier that has shaped the foundation of land uses, livelihoods, and traditions in upland areas for centuries (Metzger 2003; Mertz et al. 2009; van Vliet et al. 2012; Dressler et al. 2015). Shifting cultivation is one of the major causes of habitat destruction as well as forest and land degradation in Lao PDR (Phompila et al. 2017). Shifting cultivation, practiced by most of the rural population, which accounts for about 70% of the total population, is also a significant cause of deforestation and forest destruction (Koch 2017). Despite ongoing efforts to eliminate the age-old farming tradition of slash and burn, this continues to be practiced across large areas of the region. One important prevalence of slash-and-burn farming activity in rural Lao PDR is the lack of alternative livelihood sources (Heinimann et al. 2017).

In Lao PDR, regrowth forests provide valuable local livelihoods and ecological services (Heinimann et al. 2017; Phompila et al. 2017). In regrowth forests, many early successional and shade-tolerant plants initially colonize such abandoned areas, primarily determined by recruitment, competition, mortality, and species regeneration (van Breugel 2007). Following the elimination of invasive species, some pioneer and later-stage species would gradually dominate fallow areas, each giving way to a successor until the appearance of a climax community, according to the classical relay floristics concept. Therefore, barring human interference, the initial floristic composition is largely determined by species dispersal through natural predators, resprouting from stumps and root suckers, and regeneration from soil seed banks (Egler 1954; Kammesheidt 1999; Norman et al. 2006; Vieira and Proctor 2007). With the latest global pattern of abandonment of swidden agriculture for other means of subsistence, such regrowth forests offer an excellent opportunity to be studied regarding the long-term successional changes in vegetation (Teegalapalli and Datta 2016).

Over the last two decades, there have been rising research activities in Southeast Asia to investigate species diversity and biomass regeneration trends in regrowth forests on former swidden land (Widiyatno et al. 2017). This understanding of the natural ecosystem serves as the basis for both passive and active restoration methods in the now-burgeoning research and practice of ecological restoration (SER 2004; Walker and Del Moral 2008; Jacobs et al. 2015). The wider ecological and environmental literature development has begun attracting more due to the potential of regrowth forests in promoting landscape regeneration (Chazdon et al. 2009; Chazdon 2014). However, the rate and trajectory of vegetation transition on former fallow lands are still poorly understood due to the different biotic and abiotic factors, and their dynamic interactions that influence forest succession (Maza-Villalobos et al. 2011; Mwampamba and Schwartz 2011).

In Lao PDR, the encroachment of natural forests by the three main ethnic groups (i.e., Lao Loum, Lao Theung, and Lao Soung), mainly for agricultural production and livestock raising, has exacerbated the country's deforestation rate. Other issues that disturb forest in this country include inappropriate logging, diminishing national timber and important habitats, and shifting cultivation in areas with short fallows and steep terrain. Allowing the disturbed forests to regrow naturally might be a realistic policy and management option in Lao PDR considering the socio-economic and political conditions. However, the trajectory of such regrowing forests remains unclear. Therefore, this study aims to assess the forest recovery through vegetative succession after fallow cultivation and logging in degraded dry evergreen forestlands in Vientiane Province, Lao People's Democratic Republic. In doing so, we compared vegetation composition in primary forest with that in fallow lands with age of 1, 5 and 15-year-old, and logged-over forest.

MATERIALS AND METHODS

Study site

The study site is situated in the nine villages in Feuang District, Vientiane Province, Lao PDR, which lie between the latitude of 18°10'10" N and 18°64'45" N and the longitude of 102°06'25" E and 102°88'30" E in the North-western Vientiane City. Lao PDR has a traditional monsoon climate with two distinct seasons: wet seasons from May to October and dry seasons from November to April. The southwest monsoon prevails from mid-May to early October, while the northeast monsoon prevails from early November to mid-March. The estimated annual rainfall varies between 1,400 mm and 2,500 mm, with the central and southwest regions receiving more than 3,500 mm. Temperatures remain high throughout the year, except in the northern parts of the region, with an average maximum temperature of 35-38^{o}C and a minimum temperature of 16-18°C (Soares and Himmelfarb 2018).

According to the FAO (2015), the natural forests in the study area are dry evergreen forest located at an altitude above 200 masl and classified as upper evergreen forests found in mountain areas. These forests consist of more than 80% of evergreen species; usually, the height of the trees of the upper storey is more than 30 m. Another typical characteristic of this forest type is climbers and lichens on tree stems; bamboo is usually not found except when the canopy is open. The study area geologically belongs to the Lower Indochina and Mountain chain (Sayphoupha) formations. These formations particularly consist of reddish and greyish sandstone of the Precambrian (JICA 2001).

Phytosociological studies

The study was carried out in several vegetation types to assess the status of natural vegetation succession after the agricultural practices and forest utilization of the three main ethnic groups (i.e. Lao Loum, Lao Theung, and Lao Soung). The condition of the study area is dependent on the explanation of the main vegetation and plant communities, species composition of the degraded land area of secondary, and primary forests, composition of vegetation succession in degraded forest areas. forty-four various vegetation samples (relatives) which were established in several vegetation types such as 1-, 5- and 15-year-old fallows, logged-over forest, and primary forest in nine villages, Feuang District, Vientiane Province, Lao PDR, could be characterized as selection of homogenous sites without a gap, creation of survey boundary areas with homogenous species composition, identification and record of all species found in each layer such as emergent or super tree (ST), dominant (T1), co-dominant and suppressed (T2), shrub (S), herb (H), and moss layer (M), estimation of canopy coverage, sociability, and identification of communities. Based on Dümmler et al. (1973) and Fujiwara and Ariki (1978), the sample size of five various vegetation types were 40x60 m for primary forest and logged-over forest, 20x30 m for 15-year-old fallow, 20x20 m for 5-year-old fallow, and 10x20 m for 1 year-old fallow. The assessment was mainly based on the rate of natural recovery of 3 fallow types and logged-over forests after slashing and burning and harvesting towards achieving their natural status prior to disturbance. The assessment was carried out in three steps, namely forest layer coverage, species composition, and dominance and height recovery, and Braun-Blanquet (van der Maarel 1979) method was applied to assess vegetation composition in primary forest, logged-over forest and fallow lands with age of 1-, 5- and 15-year-old.

Data analysis

The assessment mainly focused on the natural recovery rate in logged-over forest and fallow land after shifting cultivation towards achieving their natural status before disturbance. Analysis of the Variance (ANOVA) followed by Duncan Multiple's Range Test (DMRT) and the Principal Component Analysis (PCA) were applied to assess the canopy structure recovery. Additionally, the cluster analysis was used to calculate the Jaccard's Coefficient for assessment of species dominance recovery. The further calculation used the Euclidean Distance Coefficient to assess the species composition's recovery. The Statistical Application System (SAS) and Multivariate Statistical Package (MVSP) were used to analyze the collected data.

RESULTS AND DISCUSSION

The assessment of forest recovery carried out in this study is primarily based on the results of the phytosociological study. Primary forest was used as a standard for each vegetation type-site to assess the recovery of natural succession. To assess the forest recovery trajectory, we made the comparisons on canopy structure and coverage, and species composition and dominance among primary forest, logged-over forest and fallow lands with age of 1-, 5- and 15-year-old.

The three fallows with 1-, 5- and 15-year-old age and two forest types were compared for their canopy structure recovery with each other. The logged-over forest, harvested by wood logging companies and local villagers in the past two decades, recorded the lowest recovery in the canopy structure. The sites of 1-, 5- and 15-year-old fallows have not fully recovered their top layers (ST and T1). Only the T2 layer of the 15-year-old fallow recovered. All the 1- and 5-year-old fallows only recovered their S and H layers with coverage of 26.43% to 68.44% and 70.56% to 78.89%, respectively (Table 1).

Table 1 shows that the sites harvested in 1978/79 attained moderate canopy structure recovery of 9.44%, 27.22%, 31.67%, 59.44%, 72.77%, and 3.33% for ST, T1, T2, S, H, and M layers, respectively. The ST-layer coverage of 9.44% was lower than the primary forest; however, *Lagerstroemia* was mainly followed by *Ficus* in these forest stands. Valuable commercial tree species like *Dalbergia cultrata, Pterocarpus pedatus,* and *Afzelia xylocarpa* were totally extracted by logging companies in the past two decades. Some herbs were found on the logging road and timber landing sites, such as *Eupatorium odoratum* and *Lycopodium* sp.

ANOVA was used to determine the difference in-group means of different layers to assess the canopy structure recovery of various vegetation types. The result of the analysis is shown in Table 2.

The ANOVA result showed significant differences in ST, T1, T2, S, H and M layers. Therefore, to determine which groups were significantly different, the results of the Duncan Multiple's Range Test (DMRT) was presented in Table 3.

From the above summary Table 3, the following pairs of groups were found to be significantly different at a 5% confidence level (P <0.05) of significance. For emergent or supertree layer (ST), the average height cover of ST in primary forest is higher than that of 15-, 5- and 1-year-old fallows. The mean height cover of ST in logged-over forests is higher than the average height cover of 15-, 5-, and 1-year-old fallows. The differences amongst all other height cover values of ST are not significant.

For dominant (T1) layer, the average height cover of T1 in primary forest is higher than that of 1-year-old fallow and 5-year-old fallow. The mean height cover of T1 in logged-over forest is higher than the average cover of 5- and 1-year-old fallows. The average height cover of T1 in 5-year-old fallow is higher than 1-year-old fallow. The mean height covers of T1 are not significantly different from all others.

Table 1. Average canopy coverage at different vegetation types and forest layers

Forest layer	Vegetation types: 1-year-old fallow (%)	5-year-old fallow (%)	15-year-old fallow (%)	Logged-over forest (%)	Primary forest (%)
ST	0	0	0	9.44	11.67
T1	0	0	5.00	27.22	31.11
T2	0	33.33	35.00	31.67	25.56
S	26.43	68.44	66.78	59.44	66.11
H	78.89	70.56	71.67	72.77	65.56
M	0	0	0	3.33	3.33
Recovery rate	Almost grasses and herbs	Very low	Low-medium	Medium	Good

Table 2. Result of ANOVA on canopy structure recovery

Vegetation layer	CV%	Sum of square	Mean square	F value
ST	4.44	0.54	0.14	42.90 S2*
T1	7.88	2.07	0.52	45.32 S2*
T2	11.12	1.50	0.37	13.15 S2*
S	6.88	1.09	0.27	17.44 S2*
H	5.14	0.03	0.01	0.56 S2*
M	1.51	0.08	0.02	60.04 S2*

Note: *S2- Significant difference at 0.05 level (p<0.05), ns – not significantly different

Table 3. Result of Duncan's Multiple Range Test (DMRT)

Duncan grouping		Mean difference
Primary forest layer (I)	**Vegetation type (J)**	**(I-J)**
ST	Primary forest	1.42 a*
	Logged-over forest	1.38 a
	15-year-old fallow	1.18 b
	5-year-old fallow	1.18 b
	1-year-old fallow	1.18 b
T1	Primary forest	1.59 ab*
	Logged-over forest	1.67 a
	15-year-old fallow	1.67 a
	5-year-old fallow	1.49 b
	1-year-old fallow	1.18 c
T2	Primary forest	1.64 a*
	Logged-over forest	1. 60 a
	15-year-old fallow	1.19 b
	5-year-old fallow	1.18 b
	1-year-old fallow	1.18 b
S	Primary forest	1.90 a*
	Logged-over forest	1.86 a
	15-year-old fallow	1.91 a
	5-year-old fallow	1.90 a
	1-year-old fallow	1.51 b
H	Primary forest	1.88 a
	Logged-over forest	1.94 a
	15-year-old fallow	1.93 a
	5-year-old fallow	1.93 a
	1-year-old fallow	1.96 a
M	Primary forest	1.26 a*
	Logged-over forest	1.26 a
	15-year-old fallow	1.18 b
	5-year-old fallow	1.18 b
	1-year-old fallow	1.17 b

Note: *range of height cover means with the same alphabet are not significant differences at a 5% confidence level (P<0.05), according to DMRT

For suppressed (T2) layer, the mean height cover of T2 in primary forest is higher than 15-, 5- and 1-year-old fallows. The average height cover of T2 in logged-over forest is higher than 15-, 5- and 1-year-old fallows. Differences amongst all other average T2 height cover values are not significant.

For shrub (S) layer, the mean height cover of S in the primary forest is higher than that in the 1-year-old fallow. The average height cover of S in logged-over forest is higher than 1-year-old fallow. The average height cover of S in 15-year-old fallow is higher than that in the 1-year-old. The average height cover of S in 5-year-old fallow is higher than that in the 1-year-old. Differences among all other average covers of S are not significant.

For herb (H) layer, differences amongst all average height H covers in different forests are insignificant. On the other hand, for moss layer (M), the mean height cover of M in primary forest was higher than 15-, 5- and 1-year-old fallows. The average height cover of M in logged-over forest was higher than 15-, 5- and 1-year-old fallows. Differences amongst all other height cover values of M were not significant. ST, T2, and M layers share the same trend regarding the differences.

Species composition and dominance

The 1-year-old fallow sites was previously used for upland rice agriculture and had high level of land degradation. The recovery (succession) in term of species composition and dominance was very slow in this site. Only the early-succession species, such as herbs, grasses, shrubs, and climbers such as *Eupatorium, Imperata, Microstegium, Calycopteris, Lycopodium, Meyna, Erioglossum, Crassocephalum, Toxocarpus, Ardisia, Blumea, Echinochloa, Salacia, Diospyros, Trema, Barringtonia, Xerospermum* and *Peltophorum* were able to establish themselves on these sites. The dominant species in the recovery process were *E. odoratum, Microstegium ciliatum, Calycopteris floribunda,* and *Lycopodium cernuum* as herbs and grasses. In comparison, the tree species were mainly identified: *Trema angustifolium, Dyospyros embryopteris, Barringtonia longipes,* and *Salacia prinoides.*

Farmers used the 5-year-old fallows for upland rice cultivation and other food crops for 5 years. The succession species, including *Lycopodium, Erioglossum, Barringtonia, Eupatorium, Microstegium, Melanorrhoea, Dyospyros, Alpinia, Cinnamomum, Eurycoma, Schizostachyum, Bauhinia, Zizyphus, Combretum, Meyna, Croton, Flemingia, Acacia, Terminalia, Peltophorum, Oxytenanthera, Ardisia,* and *Phyllanthus*, recovered more than in 1-year-old fallow sites in terms of the number of species.

The 15-year-old fallow was abandoned after cultivating upland rice and other food crops. The succession species were dominated by perennial herbs, bamboo, climbers, shrubs, and tree species, e.g., *Lycopodium, Bauhinia, Erioglossum, Trema, Terminalia, Ardisia, Calamus, Combretum, Cinnamomum, Dyospyros, Ixora, Zizyphus, Barringtonia, Peltophorum, Lagerstroemia, Aporosa, Meyna, Arenga, Oxytenanthera, Alpinia, Toxocarpus, Microstegium, Melanorrhoea, Mucuna, Schizostachyum,* and *Amomum* found on these sites. Most 15-year-old fallows in Nontong and Nanhao's villages were dominated by bamboo species such as *Schizostachyum* and *Oxytenanthera* in the upper storey on the hill foot. At the same time, 15-year-old fallows recovered with tree species, for example, *Barringtonia, Peltophorum,* and *Lagerstroemia*, at the first and second layers in Phonexay's, Naphung and Phonthon's villages. In the ground layer, there were some non-timber forest products (NTFPs), such as *Alpinia* (wild ginger), *Amomum* (cardamom), *Cinnamomum,* and *Calamus* (rattan). These indicated that the soil condition and microclimate had improved in these forest stands.

The logged-over forests had low coverage of emergent species; only a few Lythraceae, Meliaceae and Moraceae, *Lagerstroemia balansae, Sandorium indicum,* and *Ficus gibbosa* were represented in these forest stands. *Lagerstroemia, Sandoricum,* and *Dyospyros* generally dominate this forest stand. The understorey of these forest stands had high coverage of bamboo species, herbs, shrubs, and climbers such as *Schizostachyum, Oxytenanthera, Lycopodium, Calamus, Rhaphiolepis, Alpinia, Acacia, Erioglossum, Paederia, Anaphora, Amomum, Cnestis,* and

Halopegia in the S and H layers. The valuable commercial tree species such as *Pterocarpus, Dalbergia, Sindora, Quercus, Vatica,* and *Fagraea* were also found in the forest stands, but in small quantities. Most of them were small trees or saplings in the understorey. These indicate that the logging company did not harvest them due to small-diameter trees. The saplings might disseminate from wind or wildlife. The species dominance recovery in these forest stands identified as bamboo (*Schizostachyum, Oxytenanthera)*, *Calamus* (rattan), *Lycopodium* (fern), herb, shrub, and climber where canopy had been widely opened.

Species composition similarity

The classification analysis was used to identify similarity in species composition among the five vegetation types. The row matrix with five vegetation types and the column matrix with the number of tree species were prepared in the program Multivariate Statistical Packages (MVSP), version 3.1 for Windows. A similarity matrix of five vegetation types collected from forty-four vegetation recoveries was estimated using the centroid method using Jaccard's coefficient. The result shows the highest similarity to primary forests observed in logged-over forests with a value of 0.429, which means 42.90% of similarity in species composition. While the 15-, 5- and 1-year-old fallows resulted a value of 0.399 (39.90%), 0.348 (34.80%), and 0.261 (26.10%), respectively (Figure 1).

Dissimilarity distance (species abundance)

As shown in Table 4, the resulting dendrogram based on the dissimilarity coefficient represented the degree of dissimilarity distance among five various vegetation types as follows:

Group I had two sub-groups for comparison, 1 and 2, with a third sub-group of 1-year-old fallows. Compared to the sub-group of 1-year-old fallows, the subgroup of 1-year-old fallows also had an Euclidean distance value of 0.0. This indicates that there are no dissimilarity species among them. Further comparison included the sub-groups 4, 5, 6 and. The sub-groups 5-year-old fallows compared with those of 15-year-old fallows, which had an Euclidean Distance value of 0.0. This also indicates that there were no dissimilarity species in these sub-groups. The last sub-groups were sub-groups 8, which compared between the sub-groups of logged-over forest and those of primary forest. These sub-groups also had an Euclidean Distance value of 0.0 that meant nothing in terms of dissimilarity species. The above result shows no dissimilarity species among group I (Table 4).

In Group II, the first sub-groups in the second group were sub-groups 9 and 10, compared among 1-year-old fallows, including six sub-groups of 1-year-old fallows. These had an Euclidean Distance value of an average of 0.106 (10.60%), which indicates that 10% of dissimilarity species were found among them. The next comparison was between sub-groups 11, 12, 13, and 14, including sub-groups 5-year-old fallows, those of 15-year-old fallows, and sub-groups of logged-over forests and those of primary forest. These sub-groups had an Euclidean Distance value of 0.110 (11.10%), which indicates that dissimilarity species reached gradually. The last sub-groups in Group II were 15, 16, and 17 sub-groups, compared between sub-groups of 5-year-old fallows and those of 15-year-old fallows. The result shows a high Euclidean Distance value of 0.156 (16%), which indicates that among the sub-group of 5-year-old and 15-year-old fallows, many dissimilarity species were found among them. In Group III, there were two sub-groups. The first sub-groups were compared, including sub-groups:18, 19. These two sub-groups comprise 15-year-old fallow, and primary forest, which showed a dissimilarity coefficient of an average of 0.271. This indicates that two were about 27% dissimilarity species among them. A further comparison involved sub-groups of 20, 21, 22, 23, 24, 25, and 26, including logged-over forests, primary forests, 5-, 15- and 1-year-old fallows; the result shows a dissimilarity coefficient value of an average of 0.356 (36%). This indicates that there were dissimilarity species found in these sub-groups. In Group II, the highest dissimilarity species found were in sub-groups of primary forest and those of logged-over forest, with an Euclidean Distance value of 0.390 (39%).

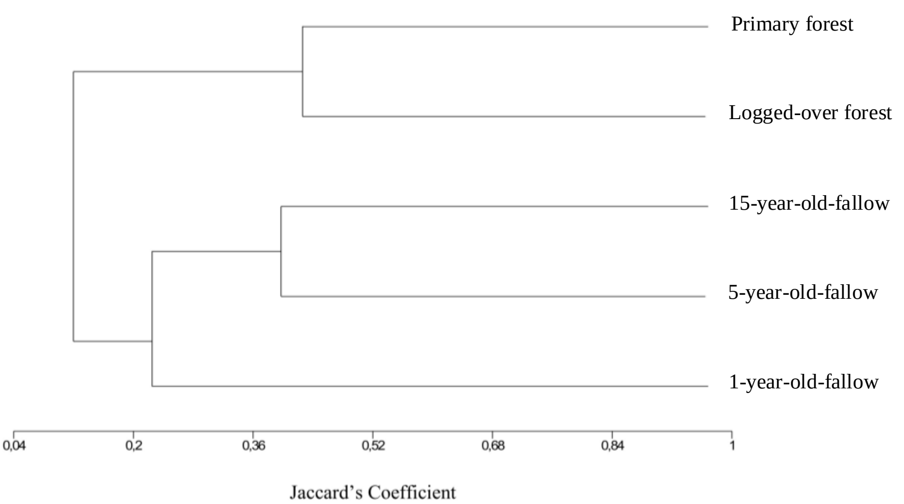

Figure 1. Dendrogram of similarity in species composition among the vegetation types calculated as Jaccard's coefficient

Table 4. Dissimilarity coefficient of the recovery vegetation types

Node/group	Sub-group	Sub-group	Dissimilarity coefficient	Object in group
Group I				
1	1-year-old fallow	1-year-old fallow	0.000	2
2	1-year-old fallow	1-year-old fallow	0.000	2
3	1-year-old fallow	1-year-old fallow	0.000	2
4	5-year-old fallow	15-year-old fallow	0.000	2
5	5-year-old fallow	15-year-old fallow	0.000	2
6	logged-over forest	15-year-old fallow	0.000	3
7	Primary forest	15-year-old fallow	0.000	4
8	Logged-over forest	Primary forest	0.000	2
Group II				
9	1-year-old fallows	1-year-old fallow with 1-year-old fallow	0.111	4
10	1-year-old fallow	1-year-old fallow	0.101	2
11	5-year-old fallows	15-year-old fallow	0.111	3
12	15-year-old fallows	15-year-old fallow	0.111	5
13	5-year-old fallow	5-year-old fallow	0.111	2
14	Logged-over forest	Primary forest	0.111	2
15	15-year-old fallow	5-year-old fallow	0.156	4
16	5-year-old fallow	15-year-old fallow	0.156	6
17	15-year-old fallow	5-year-old fallow	0.156	3
Group III				
18	1-year-old fallow	15-year-old fallow	0.271	7
19	5-year-old fallow	Primary forest	0.271	3
20	Logged-over forest	Logged-over forest	0.301	2
21	Primary forest	Primary forest	0.321	3
22	5-year-old fallow	15-year-old fallow	0.350	2
23	15-year-old fallow	1-year-old fallow	0.358	5
24	Logged-over forest	Primary forest	0.387	2
25	Logged-over forest	Primary forest	0.387	2
26	1-year-old fallow	Primary forest	0.390	4
Group IV				
27	1-year-old fallow	Primary forest	0.507	8
28	15-year-old fallow	Logged-over forest	0.549	3
29	Primary forest	1-year-old fallow	0.564	9
30	Logged-over forest	Primary forest	0.601	2
31	15-year-old fallow	Logged-over forest	0.607	7
32	Logged-over forest	15-year-old fallow	0.612	5
33	Primary forest	Logged-over forest	0.681	4
34	15-year-old fallow	Primary forest	0.681	10
35	Logged-over forest	5-year-old forest	0.743	9
36	Primary forest	Logged-over forest	0.882	11
37	15-year-old fallow	Primary forest	0.942	14
38	Logged-over forest	15-year-old fallow	0.945	14
Group V				
39	Primary forest	Logged-over forest	1.187	16
40	Logged-over forest	Primary forest	1.381	2
41	Primary forest	1-year-old forest	1.564	18
42	1-year-old forest	5-year-old forest	1.948	25
43	5-year-old forest	15-year-old forest	2.601	27
44	15-year-old forest	Logged-over forest	3.267	45

Note: Node: Joint or combined groups of five various vegetation types, which were divided into group I, group II, group III, group IV, and group V by the author, based on similar dissimilarity coefficients

In Group IV, the first sub-groups compared were sub-groups of 27, 28, and 29, including 1-year-old fallows, logged-over forests, primary forests, and 15-year-old fallows. The result shows a dissimilarity coefficient value of an average of 0.54. This meant that 54% of dissimilarity species were found among them. The next comparison included the sub-groups 30, 31, 32, 33, and 34, with an average dissimilarity coefficient value of 0.636. This indicates that 64% of dissimilarity species were in these sub-groups. Further comparison with sub-groups 35 and 36 had the Euclidean Distance values of an average of 0.812. This indicates that there were 81% dissimilarity species among these sub-groups. The last sub-groups of groups IV were sub-groups 37 and 38 and recorded with a dissimilarity coefficient value of an average of 0.94. This indicated that 94% of dissimilarity species were found among these sub-groups. The Euclidean Distance Values increased as the objects in groups increased.

Group V was the final group with the highest Euclidean Distance values compared to the previous groups. The first sub-groups were comprised of sub-groups: 39, 40, 41 and 42. This comparison included different sub-groups such as logged-over forest, primary forest, 1-, and 5-year-old fallows, which showed Euclidean Distance values of an average of 1.52. This indicates that 152% of dissimilarity species were highly recorded among these sub-groups. A further comparison involved sub-group 43, which comprised 1-, 5- and 15-year-old fallows with 27 objects in groups reaching a high dissimilarity coefficient value of 2.601. This indicates that 260% of dissimilarity species are found among these sub-groups. The last one was sub-group 44, which consisted of all vegetation types, such as 1-, 5-, 15-year-old fallows, logged-over forests, and primary forests, with 44 objects in groups. The result shows the highest dissimilarity coefficient value of 3.267; this indicates 327% dissimilarity species found by comparing all objects in groups. It could be concluded that the more disturbance to the primary forest, the more significant dissimilarity species found among various vegetation types.

Discussion

The study revealed that the more frequent the site for shifting cultivation, the longer the recovery process would become. Moreover, the rate of return to primary forest composition is contingent upon the proximity of seed sources. According to Yirdaw et al. (2019), regrowth forests in Napo and Dog Na Tard take even longer (more than 15 years) to achieve the structure of an old-growth forest. Finegan (1996) stated that for decades, the species diversity in secondary forests could be different or may never equate to that of a primary forest (Chazdon 2008). Furthermore, according to Liebsch et al. (2008), the Brazilian Atlantic Forest would take up to three centuries to approach the proportion of species present in mature forests and even longer (between one and four thousand years) to reach their original stages of endemism.

The sites of 1-, 5-, and 15-year-old fallows were heavily degraded by shortened-rotation of shifting cultivation by the three main ethnic groups and need a long time to recover their top layers fully. Previous analysis has also shown that regrowth forests require many decades to reach the structure of primary forests (Guariguata and Ostertag 2001; Chua et al. 2013; Mukul and Herbohn 2016). According to Liebsch et al. (2008), certain aspects of the Brazilian Atlantic Forest, could return quickly–within 65 years. However, the landscape to regain its native identity takes a lot longer–up to 4,000 years. Sobrinho et al. (2016) reported that Caatinga vegetation cannot recover completely in 15 years following land abandonment. This study, together with earlier studies, agrees that most woody plant assemblages take 20-70 years to recover after land abandonment in the absence of intense habitat degradation or disturbance (Kennard 2002; Chazdon 2003; Lebrija-Trejos et al. 2010; Maza-Villalobos et al. 2011). According to Hamzah (1999), the forest recovery rate in the logged-over forest after harvesting greatly depends on the extent of degradation during forest harvesting. Silvicultural treatment is necessary if these forest types have failed to recover valuable commercial tree species.

As shown in Table 1, the logged-over forests attained a moderate canopy structure, and the pre-harvesting survey was not carried out before logging. In this case, the logging company in the studied area harvested more logs as needed; the remaining were only non-commercial species. According to Hamzah (1999), concerning natural succession (recovery), it was suggested that a low-intensity logged-over area would recover in 40 to 50 years, while the patches within the forest area would take a maximum of 50 years.

The overall recovery (forest canopy structure and species) of heavily degraded and compacted sites, such as those formerly used as timber landings (decking sites) and logging roads during forest harvesting by the logging company in the study area, was shallow and slow. According to Baharuddin et al. (1995), land resource degradation is one of the most severe effects of deforestation and harvesting. He defines land degradation in general as the loss of the productive capacity of the land to sustain life, further defined as soil degradation and the loss or impoverishment of vegetation cover. Forestland degradation can be physical, chemical, or biological (Hamzah 1999). Physical degradation mainly involves soil compaction and erosion. Chemical degradation primarily reduces soil fertility, while biological degradation affects the loss of fauna and soil organisms. Natural forest regeneration does not proceed well in a natural way. According to Laycock (1991), forest succession alters species diversity as plants rise, die, and are replaced over time; more shade-tolerant climax species gradually replace it. Site factors such as soil type, topography, climate, environment, and local vegetation interact with disturbance type, diversity, and frequency to determine which plants invade a site after disturbance. In the case of three fallows, the three main ethnic groups' farmers could affect plant succession by slashing and burning, the severity and frequency of disturbance. The comparison among the five groups revealed that groups of 1-, 5- and 15-year-old fallows, along with the logged-over forest and primary forest groups, were far away from each other in terms of dissimilarity of species or species differences. The sites of 1-year-old fallows exhibited the lowest Jarcard's coefficient value (0.227). In addition, Dalmaso et al. (2020) found that the youngest site was more floristically distinct, showed fewer species, and had a less structured stand. Therefore, regarding structural composition and phylogeny, Hai et al. (2020) discovered a substantial difference between secondary forests (early and early mid-successions) and old-growth forests but no significant difference among early-successional forests. This indicates that complete disturbances in natural forests through slash-and-burn practices make forest regeneration by natural means difficult. Even if vegetation can recover on its own, it will take longer.

We found that logged-over forests recover naturally faster than shifting cultivation sites. This study shows the highest similarity to primary forests observed in logged-over forests with a coefficient of similarity of 0.429 (42.90%). While the 15-, 5- and 1-year-old fallows achieved a value of 0.399 (39.90%), 0.348 (34.80%), and 0.261 (26.10%), respectively. The average height cover of ST, T2 and M layer in primary forest is higher than that of 15-, 5- and 1-year-old fallows while the average height cover of T1 in primary forest is higher than that of 1-year-old fallow and 5-year-old fallow. The result of this study agrees with Ding et al. (2012) that recovery in logged-over forests is better than in shifting cultivation sites. When it comes to species diversity and composition, logging is less harmful than shifting cultivation, according to Ding et al. (2012). In Brazil, Piotto et al. (2009) reported that restoring an old-growth forest's structure after it has been used for shifting cultivation could take up to 40 years. Cameroon also discovered that forest structure recovers more steadily in fallow secondary forests after shifting cultivation than logged forests, taking 30 to 60 years versus 5 to 14 years, respectively (van Gemerden et al. 2003).

Regrowth forests can act as buffer areas across degraded old-growth forests, mitigating edge impacts, reducing anthropogenic disruptions, and enhancing landscape connectivity (Pardini et al. 2005; van Breugel et al. 2013). Buffer areas comprising regrowth trees provide extra shelter for the species living in the core habitat (Chazdon et al. 2009). Furthermore, by linking isolated remnant forest and agroforestry patches, regrowth forests can act as ecological corridors, improving flora and fauna dispersal and movement, as well as the viability of small populations in fragmented ecosystems (Chazdon et al. 2009; Morse et al. 2009; Schroeder et al. 2010).

Regrowth forests in the riparian area serve as stream bank stabilizers and natural corridors between upstream and downstream areas (Heartsill-Scalley and Aide 2003). In general, the location of regrowth forests in human-modified environments is critical for in-situ biodiversity restoration and degraded forestland regeneration. In Lao PDR, shifting cultivation employs over a quarter of the rural population, affecting about 34.6% of the country's forests a considerable amount of land (Sovu et al. 2009; Higashi 2015). Lao PDR can rehabilitate a significant portion of its degraded forests and raise the country's forest cover by protecting the vast area of regrowth forests that have sprung up on fallow lands due to changing agriculture. By 2020, Lao PDR expects to have 70% of its land covered in forest (Sovu et al. 2009). This mainly passive restoration is a low-cost and quick enough process. To summarize, regrowth forests occurring on fallow lands in Lao PDR are crucial in habitat protection and the regeneration of depleted forests and lands; as a result, regrowth forests should be the main consideration in Lao PDR' national forest conservation and restoration strategy.

In conclusion, according to the phytosociological study, it has proven to be very useful in elucidating the present status of the deforested area's natural recovery (succession). Data obtained from the vegetation study have enabled the calculation of forest recovery assessments using Jaccard's coefficient and the Euclidean Distance coefficient. Logged-over forests recover naturally faster than shifting cultivation sites. However, these forest stands require enrichment planting to ensure valuable commercial tree species, such as *A. xylocarpa*, *P. pedatus*, and other *Dipterocarpus* species. The natural recovery of species dominance and abundance, forest height, and canopy structure is still low. The required time is longer due to the extensive damage to the forest during harvesting. On the other hand, the three fallows need more time to regenerate in terms of soil condition and tree species naturally. The 5- and 15-year-old fallows must be protected from illegal slashing and burning by local farmers. The biggest forest recovery problem lies in the sites that were heavily degraded forestland areas through shifting cultivation, such as 1-, 5- and 15-year-old fallows. These regions have failed to recover the upper canopy layers (ST and T1 layers) and species composition. The study suggests that the harvested forests can naturally recover their forest height and canopy structure relatively quickly. However, valuable commercial tree species are still missing in these forest stands, necessitating enrichment planting. For 1-year-old fallow in steeper slopes, more than 12% should be applied to Slope Agriculture Land Technology (SALT). Simultaneously, 5- and 15-year-old fallows need rehabilitation with commercial tree and herb species for Timber Forest Products (TFPs) and Non-Timber Forest Products (NTFPs) in heavily degraded forest areas, using the different silvicultural treatments. The implications of this research can help conserve biodiversity and preserve degraded forestlands in various tropical areas.

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Tree species diversity, composition and structure in the tropical moist deciduous forest of Kadigarh National Park, Mymensingh, Bangladesh

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Abstract. *Das N. 2024. Tree species diversity, composition and structure in the tropical moist deciduous forest of Kadigarh National Park, Mymensingh, Bangladesh. Asian J For 8: 41-49.* The species diversity, floristic composition, and structural characteristics of tree species in Kadigarh National Park, Mymensingh, Bangladesh, where the forest is of the tropical moist deciduous type, were explored. The study was carried out by randomly sampling 20 m × 20 m plots to record and identify trees in the area, resulting in 87 species belonging to 70 genera and 34 families. Additionally, the stem density, Basal area, diversity indices, and importance value index of tree species with a Diameter at Breast Height (DBH) of ≥5 cm were assessed in this protected area. The basal area of tree species and stem density were 18.105±1.06 m^2 ha^{-1} and 1373.07±44.83 stems ha^{-1}, respectively. The diversity indices, such as the Shannon-Wiener diversity, Simpson diversity, Margalef's richness, and Pielou's evenness index, showed poor diversity compared to other protected areas in Bangladesh. The structural composition based on DBH and height indicated higher regeneration and recruitment, but the trees of large-growth classes were removed. *Sal* (*Shorea robusta* Gaertn.) was identified as the most dominant and native tree species, accounting for 72% of the tree individuals. However, some rare tree species, such as *Sidha* (*Lagerstroemia parviflora* Roxb.), *Mahua* (*Madhuca longifolia* (J.Koenig ex L.) J.F.Macbr.), and *Thona* (*Oroxylum indicum* (L.) Kurz), showed the presence of *Sal*. Therefore, this research will support future policymakers in formulating a forest resource management plan for Kadigarh National Park.

Keywords: Diversity indices, Kadigarh National Park, structural composition

INTRODUCTION

The natural forest structure of Bangladesh has been negatively changed by biotic and abiotic disturbances, which have ultimately affected the regeneration and population dynamics during the last few decades (Shaforth et al. 2002; Kwit and Platt 2003). The size distribution of trees in natural forests is a fundamental characteristic of forest structure (Lai et al. 2013). Understanding forest stand parameters, such as DBH class distribution, height class distribution, and stocking, is important for modeling future forest wood production (Das et al. 2018a). Describing the number of species, tree density, Basal area, and stock (volume) per hectare in a forest stand is important for comparing it with a desired level for balanced forest health and growth. However, the rapid loss and degradation of forests have led to an alarming rate of forest biodiversity depletion in Bangladesh (Rahman et al. 2000; Hossain 2001). The conservation of biological diversity to ensure their sustainable use, the fair and equitable sharing of benefits arising from using genetic resources, and complex ecosystem functions are major aims of the convention of biological diversity. Moreover, information on floristic composition, their quantitative structure, and diversity is vital for understanding the functioning and dynamics of forest ecosystems (Reddy et al. 2008).

Floristic and ecological studies are essential for understanding the distribution and composition of plant communities in natural forests (Haq et al. 2023). Assessing the levels, distribution, and dynamics of native tree species is crucial for a better understanding of a particular forest's distribution and species diversity dynamics. The flora of forest regeneration plays a key role in preserving biodiversity and informing conservation plans. Additionally, understanding the status and structure of biological resources is vital for achieving effective conservation and management, particularly for native tree species. Bangladesh consists of 3611 angiosperm species belonging to 198 families, of which 988 species under 41 families belong to monocotyledons and 2623 species under 158 families belong to dicotyledones (Ahmed et al. 2008).

The *Sal* (*Shorea robusta* Gaertn.) forest is a tropical, moist deciduous forest located in the Districts of Tangail, Mymensingh, Gazipur, and Dinajpur in Bangladesh (Rahman et al. 2010). *Sal* is gregarious and dominant in its stand (Troup 1986). *Sal* regenerates from seed origin or by coppicing, sprouting from root suckers, and there is no difference in the vigor of the seedlings from coppice or seed origin (Gautam and Devoe 2006; Das 2015a). The biodiversity of *Sal* forests is very wide and interesting from ecological and conservation perspectives (Alam 1995). The composition of tree species is considered a biodiversity indicator and an important attribute of forest ecosystems (Malaker et al. 2010). Furthermore, non-timber forest products of *Sal* forests are important to rural people in terms of food, fodder, medicines, and domestic requirements (Das 2014a). These forests are composed of many medicinal plants like *Arjune* (*Terminalia arjuna*

(Roxb.) Wight & Arn.), *Haritaki* (*Terminalia chebula* Retz.), *Bohera* (*Terminalia bellirica* (Gaertn.) Roxb.), and *Kurchi* (*Holarrhena antidysenterica* (L.) Wall. ex A.DC.) (Khan et al. 2001). At present, devastating anthropogenic and natural impacts, along with overexploitation of forest resources, have caused severe damage to the *Sal* forest ecosystem (Hossain et al. 2013a).

Forest biodiversity conservation is essential in Bangladesh as the forests are undergoing severe degradation countrywide due to anthropogenic disturbances inside the forest, over-extraction of forest resources, inappropriate forest management systems, and lack of proper conservation initiatives (Hassan 1995; Dutta et al. 2015). Many researchers have investigated plant species diversity and forest stand structure in Bangladesh (Rahman et al. 2011; Hossain et al. 2012; Hossain et al. 2013b; Feeroz and Uddin 2015; Hossain et al. 2015; Sarker et al. 2015; Chowdhury et al. 2018; Das et al. 2018b). The sustainability and resiliency of a forest ecosystem can be ensured if the floristic composition, structure, and diversity are known for managerial decision-making and development planning. However, the Kadigarh National Park lacks information regarding structural composition, stocking, and conservation issues. Hence, the present study was conducted in Bangladesh's Kadigarh National Park (KNP) to assess tree species composition, diversity, and structural composition based on DBH and height class distribution.

MATERIALS AND METHODS

Study area

Kadigarh National Park (KNP) is a tropical, moist deciduous forest under the jurisdiction of the Mymensingh Forest Division, Bangladesh. It is located between 24°19' to 24°21'N latitude and 90°18' to 90°20'E longitude, situated on the western side of the Dhaka-Mymensingh main road, covering an area of 344.13 ha (Figure 1). The soil is highly oxidized, reddish-brown clay containing ferruginous nodules and manganese spots, belonging to the bio-ecological zone of the Madhupur Sal Tract (Nishat et al. 2002, Das and Sarker 2015). The soils have a moderate to strong acidic reaction (Richards and Hassan 1988) and are characterized by low organic matter and fertility (Alam 1995). According to the Bangladesh Meteorological Department (BMD 2008) studies, the annual rainfall ranges from 2110 to 2310 mm, temperatures range from 11 to 35°C, and humidity falls between 61 and 87%.

Field data collection

The study was conducted from November 2021 to March 2022. Approximately 62 random sample plots, each measuring 20 m × 20 m, covered a sample intensity of 0.72% of the total area based on the QGIS geoprocessing tool in and around the KNP for the present study (Figure 1). The geographical locations of each sample plot were recorded using a Ground Positioning System (GPS) device (Transight Systems Private Limited & ICOMPASS). If randomly generated plots were unavailable, the nearest available plots were selected instead. Plants with a Diameter at Breast Height (DBH) ≥5 cm (Hossen et al. 2021) were enumerated from the quadrats. The total height (m) and DBH (in cm) of all trees inside the demarcated plots were measured using a Santo Clinometer (SUUNTO & Suunto PM-5 Clinometer) and diameter tape, respectively. For multi-stemmed trees, the bole DBH (cm) was measured below the forking if the height was 1.37 m from the ground (Sarker et al. 2013; Das 2014b, c; Das 2015b). Samples of unknown tree species were collected for the preparation of herbarium.

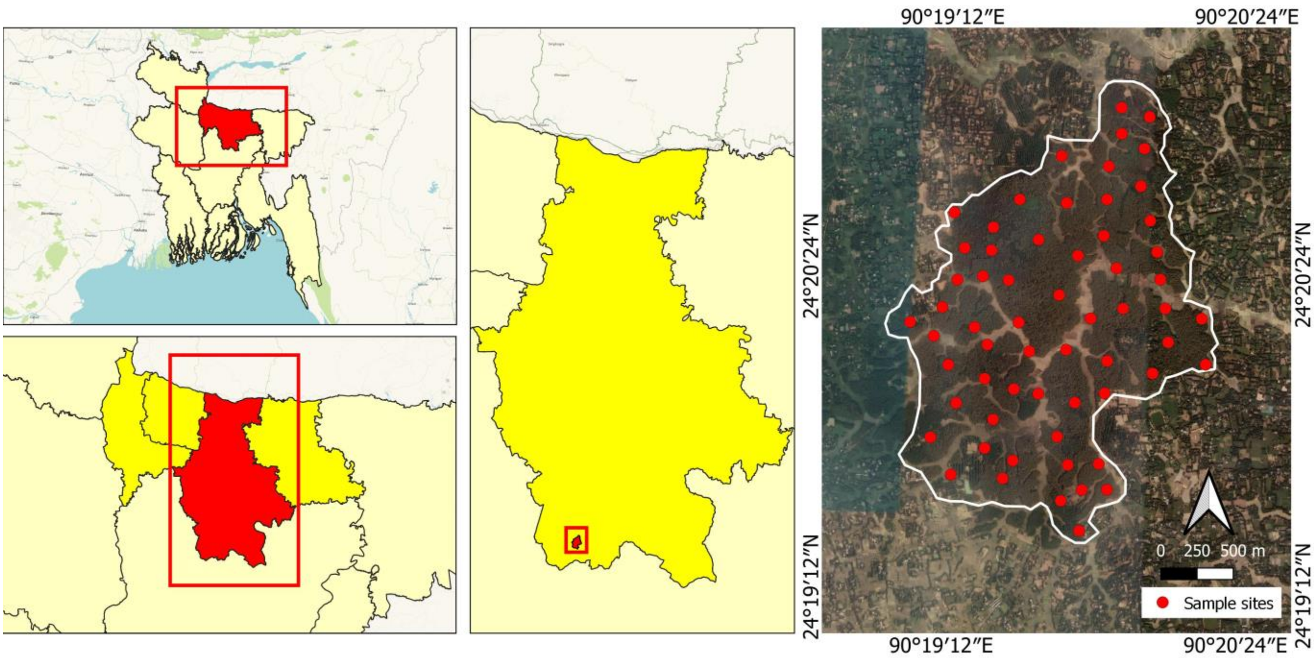

Figure 1. Location map of Kadigarh National Park in Bangladesh

Table 1. The list of phytosociological characters of the vegetation

Phytosociological Features	Formula	References
Basal Area/ha (BA)	$BA=\frac{\sum \Pi \times D2/4}{\sum \text{Area of all quadrate}}\times 10000$	Shukla and Chandel (2000), Chowdhury et al. (2019)
Density (D)	$D=\frac{a}{b}$	Shukla and Chandel (2000)
Relative Density (RD)	$RD=\frac{n}{N}\times 100$	Dallmeier et al. (1992)
Frequency (F)	$F=\frac{c}{b}$	Shukla and Chandel (2000)
Relative Frequency (RF)	$RF=\frac{Fi}{\sum_{i=1}^{s}(Fi)}$	Dallmeier et al. (1992)
Abundance (A)	$A=\frac{n}{c}$	Shukla and Chandel (2000)
Relative Abundance (RA)	$RA=\frac{Ai}{\sum_{i=1}^{s}(Ai)}$	Shukla and Chandel (2000)
Relative dominance (D)	$RD=\frac{\text{Basal area of one specis}}{\text{Total basal area}}\times 100$	Hossain et al. (2013a), Chowdhury et al. (2019)
Importance Value Index (IVI)	$IVI=RD+RF+RA$	Dallmeier et al. (1992), Shukla and Chandel (2000)

Table 2. The list of biodiversity indices of the vegetation

Biodiversity Indices	Formula	References
Shannon-Weiner's diversity index (H)	$H=-\sum_{i=1}^{n}P_i\ln P_i$	Shannon and Weaver (1963)
Simpson's diversity index (D)	$D=\sum_{i=1}^{n}P_i^2$	Simpson (1949)
Margalef's richness index (R)	$R=\frac{(S-1)}{LN(N)}$	Margalef (1958)
Pielou's evenness index (E)	$E=\frac{H}{Ln(S)}$	Pielou (1966)

Data analysis

The field data were analyzed to determine density, Relative Density (RD %), frequency, relative frequency (RF %), abundance, Relative Abundance (RA %), and Importance Value Index (IVI) (Table 1). Moreover, biodiversity indices such as Shannon's diversity index (Shannon and Weaver 1963), Simpson's diversity index (Simpson 1949), Pielou species evenness index (Pielou 1966), and Margalef species richness index (Margalef 1958) are listed in Table 2.

RESULTS AND DISCUSSION

Tree species composition

The study reveals 87 species belonging to 70 genera and 34 families in Kadigarh National Park (Table 3). Moraceae and Euphorbiaceae are represented by the highest number of species (eight species each), followed by Caesalpiniaceae, Mimosaceae, and Myrtaceae, each having five species. Some common species of the natural forest, such as *Sal* (*S. robusta*), *Bohera* (*T. bellirica*), *Haritaki* (*T. chebula*), *Neol* (*Protium serratum* (Wall. ex Colebr.) Engl.), *Sinduri* (*Mallotus philippensis* (Lam.) Müll.Arg.), and *Bheola* (*Semecarpus anacardium* L.fil.), are growing within the natural forest patch.

Diversity indices

A total of 1,373 individual stems are recorded from this park. The vacant area of the forest is now covered with more or less mixed plantations, resulting in a high stem density of 878 stems per hectare. The Shannon-Wiener diversity index (0.791±0.06), Simpson diversity index (0.583±0.04), Margalef species richness index (1.278±0.10), and Pielou species evenness index (0.429±0.01) were calculated for the study area (Table 4). The values of the Shannon-Wiener diversity, Simpson diversity, Margalef's richness, and Pielou's evenness index indicate a poor diversity of tree species in this area.

Quantitative structure of tree species

Sal (*S. robusta*) is represented by maximum stem density (1,193.72 stem ha^{-1}) followed by *T. chebula* (32.56 stem ha^{-1}). *S. robusta* is the single plant species represented by maximum (57.84%) relative density, maximum (40.76%) relative frequency, maximum (28.62%) relative abundance, and maximum (81.34%) relative dominance (Table 5). The highest relative density of this plant species was comprised of all the tree individuals, followed by *T. chebula* (3.30%), *T. bellirica* (2.89%), and *H. orixensis* (2.82%). The importance value index (IVI) of the species revealed that *S. robusta* has a maximum IVI of 185.12 out of 300, followed by *T. chebula* (8.59) and *T. bellirica* (6.42) (Table 5).

Table 3. List of tree species recorded from Kadigarh National Park, Bangladesh

Family	Scientific Name	Local Name	Use
Anacardiaceae	*Mangifera indica* L.	*Aam*	F, Fd, T
Anacardiaceae	*Semecarpus anacardium* L.fil.	*Bheula, Bhela*	Fd, N, T
Annonaceae	*Miliusa velutina* (Dunal) Hook. f. & Thom.	*Gandhi gajari*	Fd
Apocynaceae	*Alstonia scholaris* (L.) R. Br.	*Chatian*	M, N
Apocynaceae	*Holarrhena antidysenterica* (L.) Wall. ex A.DC.	*Kurchi*	M
Arecaceae	*Phoenix acaulis* Buch. –Ham. ex Roxb.	*Khudi khejur*	Fd
Bignoniaceae	*Oroxylum indicum* (L.) Kurz	*Thona*	M
Bixaceae	*Bixa orellana* L.	*Ranggula*	M, N
Bombacaceae	*Bombax ceiba* L.	*Shimul*	M, T
Burseraceae	*Garuga pinnata* Roxb.	*Sada Jiga*	Fd, M, T
Burseraceae	*Lannea coromandelica* (Houtt.) Merr.	*Jiga*	Fd, M, N, T
Burseraceae	*Protium serratum* (Wall. ex Colebr.) Engl.	*Neul, Neur*	Fd, T
Caesalpiniaceae	*Bauhinia malabarica* Roxb.	*Chokakola*	F, N
Caesalpiniaceae	*Cassia fistula* L.	*Sonalu, Banor noli*	Fd, M, N, T
Caesalpiniaceae	*Delonix regia* Rafin.	*Krisnachura*	N
Caesalpiniaceae	*Peltophorum pterocarpum* (DC.) K. Heyne	*Halud krisnachura*	Fd, N, T
Caesalpiniaceae	*Tamarindus indica* L.	*Tentul*	Fd, T
Clusiaceae	*Garcinia cowa* Roxb. ex DC.	*Cao*	Fd, M
Combretaceae	*Terminalia arjuna* (Roxb.) Wight & Arn.	*Arjun*	M, T
Combretaceae	*Terminalia bellirica* (Gaertn.) Roxb.	*Bohera*	Fd, M, T
Combretaceae	*Terminalia chebula* Retz.	*Haritaki*	Fd, M, N, T
Dilleniaceae	*Dillenia indica* L.	*Chalta*	Fd, M, T
Dilleniaceae	*Dillenia scabrella* Roxb. ex Wall.	*Ajuli, Ajugi*	Fd, T
Dipterocarpaceae	*Dipterocarpus costatus* Gaertn.	*Sada garjan*	F, N, T
Dipterocarpaceae	*Dipterocarpus turbinatus* Gaertn.	*Telia garjan*	N, T
Dipterocarpaceae	*Hopea odorata* Roxb.	*Telsur*	M, N, T
Dipterocarpaceae	*Shorea robusta* Gaertn.	*Sal*	T
Euphorbiaceae	*Antidesma acuminatum* Wall. in Wight.	*Chokoi*	Fd
Euphorbiaceae	*Aporosa* sp.	*Kharjon*	F, Fd
Euphorbiaceae	*Bischofia javanica* Bl.	*Kanjal bhadi*	M, T
Euphorbiaceae	*Bridelia tomentosa* Bl.	*Sitki*	M
Euphorbiaceae	*Croton tiglium* L.	*Bish khagor, Jamai gota*	M, N
Euphorbiaceae	*Mallotus philippensis* (Lam.) Müll.Arg.	*Sinduri*	T
Euphorbiaceae	*Phyllanthus emblica* L.	*Amloki*	Fd, M, N
Euphorbiaceae	*Ricinus communis* L.	*Varenda*	M
Fabaceae	*Gliricidia sepium* (Jacq.) Kunth ex Walp.	*Gliricidia*	M, N
Lauraceae	*Cryptocarya amygdalina* Nees.	*Ojha*	Fd, T
Lauraceae	*Litsea glutinosa* (Lour.) Robinson	*Kharajora, Menda*	M
Lecythidaceae	*Careya arborea* Roxb.	*Gadila, Kumbi*	N, T
Lythraceae	*Lagerstroemia parviflora* Roxb.	*Sidha*	N, T
Lythraceae	*Lagerstroemia speciosa* (L.) Pers.	*Jarul*	N, T
Meliaceae	*Azadirachta indica* A. Juss.	*Neem*	M, N
Meliaceae	*Melia azedarach* L.	*Ghoranim, Bokhain*	M, T
Meliaceae	*Swietenia mahagoni* Jacq.	*Mahagoni*	T
Meliaceae	*Toona ciliata* M. Roem.	*Toon, Rongi*	T
Mimosaceae	*Acacia auriculiformis* A. Cunn. ex Benth.	*Akashmoni*	F, N, T
Mimosaceae	*Albizia lebbeck* (L.) Benth.	*Kala Koroi*	Fd, M, N, T
Mimosaceae	*Albizia procera* (Roxb.) Benth.	*Shil koroi, Sada koroi*	F, M, T
Mimosaceae	*Albizia richardiana* (Voigt.) King & Prain	*Raj koroi*	N, T
Mimosaceae	*Aphanamixis polystachya* (Wall.) R.N. Parker.	*Ptiraj*	Fd, M, T
Moraceae	*Artocarpus heterophyllus* Lam.	*Kanthal*	Fd, N, T
Moraceae	*Artocarpus lacucha* Buch.-Ham.	*Borta*	Fd, M, T
Moraceae	*Ficus benghalensis* L.	*Bot*	Fd, M, N
Moraceae	*Ficus hispida* L.f.	*Dumor, Kodora*	Fd, T
Moraceae	*Ficus racemosa* L.	*Jagya dumur*	Fd, M, N
Moraceae	*Ficus religiosa* L.	*Bot*	Fd, M
Moraceae	*Ficus virens* Ait.	*Pakur, Pakar, Paikur*	Fd
Moraceae	*Streblus asper* Lour.	*Sheora*	F, Fd, M
Myrsinaceae	*Ardisia colorata* Roxb.	*Vet*	M
Myrtaceae	*Cleistocalyx nervosum* (DC.) Kosterm.	*Ludijam, Dephajam,*	M
Myrtaceae	*Psidium guajava* L.	*Payara*	F, Fd, M, N
Myrtaceae	*Syzygium cumini* (L.) Skeels	*Kalojam*	Fd, T
Myrtaceae	*Syzygium firmum* Thw.	*Dhakijam*	Fd, N

Myrtaceae	*Syzygium fruticosum* DC.	*Putijam, Titijam*	Fd, T
Oxalidaceae	*Averrhoa carambola* L.	*Kamranga*	Fd, M, N
Rhamnaceae	*Ziziphus mauritiana* Lam.	*Boroi*	Fd
Rhamnaceae	*Ziziphus rugosa* Lam.	*Anoi, Anai gota*	Fd, M
Rubiaceae	*Haldina cordifolia* (Roxb.) Ridsdale	*Kaika, haldu*	T
Rubiaceae	*Hymenodictyon orixensis* (Roxb.) Mabb.	*Bhutum*	N, M
Rubiaceae	*Neolamarckia cadamba* (Roxb.) Bosser	*Kadom*	M, N, T
Rubiaceae	*Tamilnadia uliginosa* (Retz.) Tirveng. & Sastre	*Pirilagota, Piralo*	M
Rutaceae	*Aegle marmelos* (L.) Corr.	*Bel*	Fd, M, T
Rutaceae	*Limonia acidissima* L.	*Kodbel, Koethbel*	Fd, M, T
Rutaceae	*Murraya paniculata* (L.) Jack	*Kamini*	M, T
Rutaceae	*Zanthoxylum rhetsa* (Roxb.) DC.	*Bajna*	M, N, T
Sapindaceae	*Lepisanthes rubiginosa* (Roxb.) Leenh.	*Harinagola*	Fd
Sapindaceae	*Schleichera oleosa* (Lour.) Oken.	*Joyna, Kusum*	Fd, M, N, T
Sapotaceae	*Madhuca longifolia* (J.Koenig ex L.) J.F.Macbr.	*Mahua*	M, T
Sterculiaceae	*Abroma augustum* (L.) L.f.	*Ulotkombol*	M
Sterculiaceae	*Sterculia villosa* Roxb. ex Smith	*Udal*	M, N
Thymeliaceae	*Aquilaria agallocha* Roxb.	*Agar*	N
Tiliaceae	*Grewia asiatica* L.	*Kapaia*	Fd, N
Ulmaceae	*Trema orientalis* (L.) Bl.	*Jigni*	F, Fd, N
Verbenaceae	*Callicarpa arborea* Roxb.	*Bormala*	F, Fd, M
Verbenaceae	*Gmelina arborea* Roxb.	*Gamar, Jogi*	M, T
Verbenaceae	*Tectona grandis* L.f.	*Shegun*	M, T
Verbenaceae	*Vitex glabrata* R.Br.	*Hakuni gach, Baskura*	Fd, M, T

Note: F: Fuelwood, Fd: Food and fodder, M: Medicinal, N: Miscellaneous non-timber uses (other than food, fuel, fodder and medicinal), T: Timber, Nk: Not known

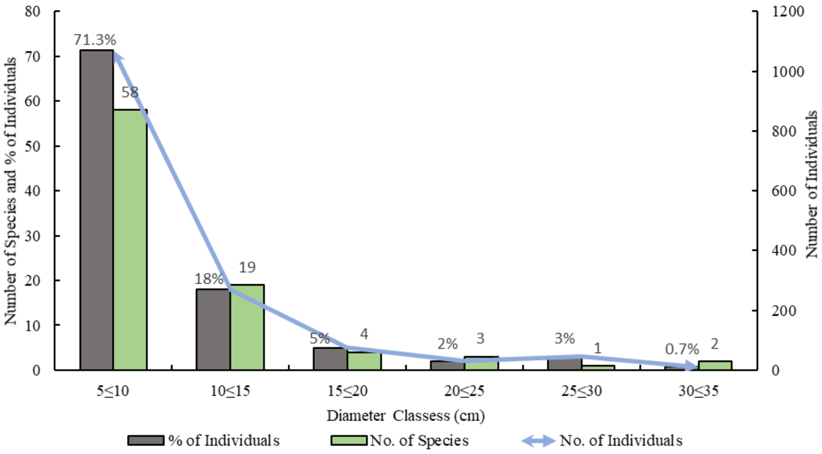

Figure 2. Tree species distribution and tree individuals into different diameter classes

Table 4. Diversity indices and Quantitative status of tree species for Kadigarh National Park, Bangladesh

Category	Value
Shannon-Wiener diversity index	0.791±0.06
Simpson diversity index	0.583±0.04
Margalef species richness index	1.278±0.10
Pielou species evenness index	0.429±0.01
Basal area (m^2) per hectare	18.105±1.06
Number of stems per hectare	1,373.07±44.83

Structural composition based on DBH class distribution

The structural composition of the tree species is assessed by dividing them into six diameter classes based on their diameter at breast height (1.37 m from the base). The diameter (cm) ranges are 5≤10, 10≤15, 15≤20, 20≤25, 25≤30, and ≥35. The lowest diameter range of 5≤10 cm is represented by the maximum (71.30%) tree individuals belonging to 58 tree species (Figure 2). Tree individuals of almost all the tree species are found in this diameter range. The *S. robusta* is the flagship plant species of the KNP forest, dominating almost all the diameter classes except the ≥35 cm class. On the other hand, a diameter range of 30≤35 cm is represented by only two *Ficus* species and a minimum number of (0.7%) tree individuals. The graph representing the number of tree species and individuals reduces gradually in the upper diameter classes, an important feature of natural forests (Figure 2).

Table 5. Density, Relative Density (RD), Relative Frequency (RF), Relative Abundance (RA), Relative Dominance (RD), and Importance Value Index (IVI) of the tree species (≥5 cm DBH) recorded from Kadigarh National Park, Bangladesh

Scientific Name	Stem ha^{-1}	RD (%)	RF (%)	RA (%)	RD (%)	IVI
Semecarpus anacardium L.fil.	1.29	0.59	0.97	0.83	0.17	0.97
Miliusa velutina (Dunal) Hook. f. & Thom.	4.31	1.45	1.79	2.58	0.75	2.19
Holarrhena antidysenterica (L.) Wall. ex A.DC.	1.29	0.59	0.97	0.83	0.17	0.97
Oroxylum indicum (L.) Kurz	0.43	0.23	0.32	0.27	0	0.25
Bixa orellana L.	0.86	0.39	0.61	0.49	0.09	0.53
Lannea coromandelica (Houtt.) Merr.	6.47	1.78	2.08	2.92	0.91	2.77
Protium serratum (Wall. ex Colebr.) Engl.	3.88	1.31	1.47	2.21	0.64	1.69
Bauhinia malabarica Roxb.	0.86	0.39	0.61	0.49	0.09	0.53
Garcinia cowa Roxb. ex DC.	1.72	0.72	1.27	1.49	0.38	1.25
Terminalia bellirica (Gaertn.) Roxb.	25.43	2.89	3.95	5.08	1.43	6.42
Terminalia chebula Retz.	32.56	3.3	4.11	6.17	1.88	8.59
Dillenia scabrella Roxb. ex Wall.	1.72	0.72	1.27	1.49	0.38	1.25
Shorea robusta Gaertn.	1,193.72	57.84	40.76	28.62	81.34	185.12
Antidesma acuminatum Wall. in Wight.	0.43	0.23	0.32	0.27	0	0.25
Aporosa sp.	0.86	0.39	0.61	0.49	0.09	0.53
Bischofia javanica Bl.	0.86	0.39	0.61	0.49	0.09	0.53
Bridelia tomentosa Bl.	0.86	0.39	0.61	0.49	0.09	0.53
Mallotus philippensis (Lam.) Müll.Arg.	4.74	1.55	1.83	2.67	0.78	2.38
Ricinus communis L.	1.29	0.59	0.97	0.83	0.17	0.97
Gliricidia sepium (Jacq.) Kunth ex Walp.	0.86	0.39	0.61	0.49	0.09	0.53
Cryptocarya amygdalina Nees.	1.72	0.72	1.27	1.49	0.38	1.25
Litsea glutinosa (Lour.) Robinson	3.88	1.31	1.47	2.21	0.64	1.69
Careya arborea Roxb.	1.72	0.72	1.27	1.49	0.38	1.25
Lagerstroemia parviflora Roxb.	0.43	0.23	0.32	0.27	0	0.25
Azadirachta indica A. Juss.	0.86	0.39	0.61	0.49	0.09	0.53
Melia azedarach L.	6.47	1.78	2.08	2.92	0.91	2.77
Toona ciliata M. Roem.	3.02	0.21	1.02	0.64	0.01	1.51
Acacia auriculiformis A. Cunn. ex Benth.	14.22	2.39	2.98	3.97	1.06	3.89
Aphanamixis polystachya (Wall.) R.N. Parker.	0.86	0.39	0.61	0.49	0.09	0.53
Artocarpus lacucha Buch.-Ham.	1.72	0.72	1.27	1.49	0.38	1.25
Ficus benghalensis L.	3.88	1.31	1.47	2.21	0.64	1.69
Ficus hispida L.f.	0.86	0.39	0.61	0.49	0.09	0.53
Ficus racemosa L.	1.72	0.72	1.27	1.49	0.38	1.25
Ficus religiosa L.	0.43	0.23	0.32	0.27	0	0.25
Streblus asper Lour.	0.86	0.39	0.61	0.49	0.09	0.53
Syzygium firmum Thw.	0.86	0.39	0.61	0.49	0.09	0.53
Ziziphus rugosa Lam.	1.72	0.72	1.27	1.49	0.38	1.25
Haldina cordifolia (Roxb.) Ridsdale	3.88	1.31	1.47	2.21	0.64	1.69
Hymenodictyon orixensis (Roxb.) Mabb.	22.41	2.82	3.77	4.81	1.35	4.27
Murraya paniculata (L.) Jack	1.72	0.72	1.27	1.49	0.38	1.25
Zanthoxylum rhetsa (Roxb.) DC.	1.29	0.59	0.97	0.83	0.17	0.97
Lepisanthes rubiginosa (Roxb.) Leenh.	4.31	1.45	1.79	2.58	0.75	2.19
Schleichera oleosa (Lour.) Oken.	1.29	0.59	0.97	0.83	0.17	0.97
Madhuca longifolia (J.Koenig ex L.) J.F.Macbr.	0.43	0.23	0.32	0.27	0	0.25
Abroma augustum (L.) L.f.	0.86	0.39	0.61	0.49	0.09	0.53
Sterculia villosa Roxb. ex Smith	4.31	1.45	1.79	2.58	0.75	2.19
Grewia asiatica L.	1.29	0.59	0.97	0.83	0.17	0.97
Trema orientalis (L.) Bl.	1.72	0.72	1.27	1.49	0.38	1.25
Total	1373.18	100	100	100	100	255.73

Structural composition based on height class distribution

The total height of the tree individuals of different species considered in six height classes with an interval of 6 m. The six height classes are 2≤7 m, 7≤12 m, 12≤17 m, 17≤22 m, 22≤27 m, and 27≤32 m. The lowest height of the tree species is recorded at 2 m for habitually small trees. The study reveals that the number of species is maximum (49 species) in the height range of 2≤7 m, followed by 7≤12 m (36) and 12≤17 m (13) in Figure 3. The relative number of individuals is high in the first height class (2≤7 m), then gradually reduced with the increase in height growth. The tree species and individuals are very few in the higher height ranges of 22≤27 m and 27≤32 m. The relative distribution of both tree individuals and species indicates that tree species of KNP are distributed mainly in 3 strata, i.e., 2≤7 m, 7≤12 m, and 12≤17 m (Figure 3). Tree species distribution within the different height classes reveals that *S. robusta* (26.73%) and *T. chebula* (3.82%) are common in the lowest height ranges. In the 7≤12 m height range, *S. robusta* (39.16%) is very common, and *T. bellirica* (2.45%) and *Hymenodictyon orixensis* (Roxb.) Mabb. (2.72%) are found in comparatively higher numbers.

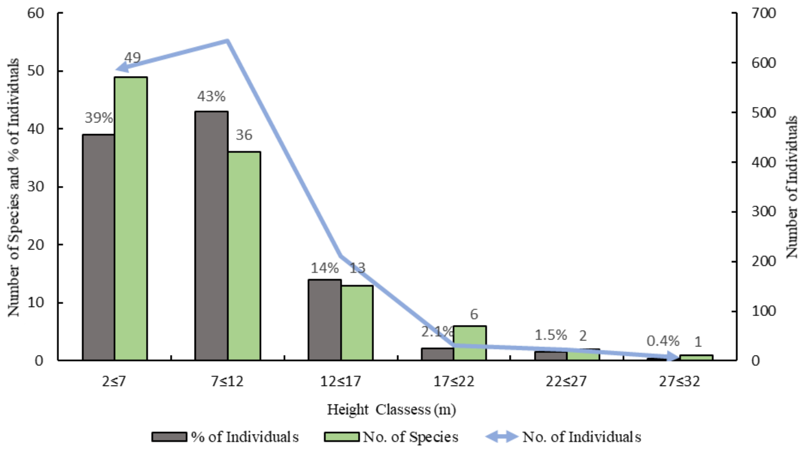

Figure 3. Tree species distribution and tree individuals into different height classes

Discussion

The tree species composition of the KNP is naturally homogeneous. The present study in the Mymensingh Forest Division reveals a lower tree species composition than in other tropical forests. Rahman et al. (2019a) found 139 tree species belonging to 100 genera and 40 families in the Madhupur National Park. Hossain et al. (2015) reported the presence of 107 tree species belonging to 72 genera and 37 families in the sample plots of the Kamalachari Natural Forest of Chittagong South Forest Division. Naidu et al. (2018) found 135 species and 105 genera belonging to 45 families in India's tropical deciduous forests of North-Central Eastern Ghats. Moreover, other studies found 93 tree species in Chunati Wildlife Sanctuary (Nath et al. 2016), 151 tree species in the Inani Protected Forest (Nath et al. 2000), 150 tree species in Teknaf Wildlife Sanctuary (Uddin et al. 2013), and 400 tree species in the forests of Sylhet (Alam 2008) in Bangladesh. However, the tree species diversity of this park is comparatively higher than that of 56 tree species belonging to 50 genera and 29 families in Durgapur Hill Forest (Rahman et al. 2019b), 50 tree species belonging to 28 families in Rampahar Natural Forest (Malaker et al. 2010), 52 tree species in Kaptai National Park (Rahman et al. 2016), 62 tree species in the Tankawati Natural Forest (Motaleb and Hossain 2011), 77 species in the Dudhpukuria natural forest (Hossain et al. 2012), and 78 tree species in Lawachara forest (Malaker et al. 2010).

The diversity index value indicates that tree species diversity is relatively poor in the natural forest. The Shannon-Wiener diversity index (0.791±0.06) of KNP is significantly lower than other natural forests, such as 3.762 of Chunati Wildlife Sanctuary, 3.25 of Tankawati natural forest of Chittagong South Forest Division, 4.45 of Dudhpukuria-Dhopachori WS, 2.98 of Sitapahar reserve forest of Chittagong South Forest Division, 4.27 in Garo Hills of India and 4.37 in Tropical Moist Forests of Mizoram, Northeast India (Nath et al. 2000; Kumar et al. 2006; Motaleb and Hossain 2011; Hossain et al. 2013b; Hossain and Hossain 2014; Devi et al. 2018). Similarly, the Simpson diversity index (0.583±0.04), Margalef species richness index (1.278±0.10), and Pielou species evenness index (0.429±0.01) also suggest poor diversity in comparison to Chunati Wildlife Sanctuary and Dudhpukuria-Dophachari Wildlife Sanctuary (Hossain et al. 2013b; Hossain and Hossain 2014). This poor diversity is due to factors such as the higher occurrence of *Sal* than associated tree species, habitat degradation, human interference, or natural disturbances. The homogeneous topography and climatic and edaphic conditions over the KNP area also contribute to the poor diversity and almost homogeneous distribution of the different tree species.

The Importance Value Index (IVI) indicates a comprehensive understanding of the phytosociological characteristics of a species within the forest. The study reveals that 72% of tree individuals in KNP are *Sal* (*S. robusta*), making it the most dominant tree species and highlighting its crucial ecological functions, such as providing habitat for wildlife, carbon sequestration, and soil stabilization. This dominance contributes to the structural complexity of the forest and supports a diverse range of plant species. Furthermore, the Basal area of KNP is greater than that of the Kaptai Deer Breeding Centre (14.36 m^2 ha^{-1}) in the Rangamati South Forest Division (Mohajan et al. 2016). Additionally, the density in KNP is higher than the 555 stems ha^{-1} in the Chunati Wildlife Sanctuary (Hossain and Hossain 2014), 855 stems ha^{-1} in the Durgapur hill forest (Rahman et al. 2019b), and 709 stems ha^{-1} in the Tropical Forest of Eastern Ghats, India (Reddy et al. 2011). Hossain et al. (2013b) reported a tree species (≥10 cm DBH) density of 468 stems ha^{-1} in the Dudhpukuria-Dhopachari Wildlife Sanctuary. The study by Malaker et al. (2008) in the Jaus beat of Madhupur *Sal* forest revealed that *S. robusta* was represented by maximum density (226.67 trees ha^{-1}), total Basal cover (99.11 m), IVI (72.60), and species diversity (0.145), which is lesser than the current result. Hossain et al. (2013b) also reported that *D. turbinatus* showed the highest IVI (13.74), followed by *L. acuminata* (10.81). Chowdhury et al. (2018) found *P. serratum* to be a dominant regenerating tree species with the highest relative density (15.24%), relative frequency (16.30%), and IVI (50.09) in the Rampahar natural forest reserve in Rangamati, where the values are lower in comparison with the present findings.

Regarding the DBH class distribution, Nath et al. (2016) recorded that 90% of trees belonged to the 5-to-15-cm DBH class in the Chunati Wildlife Sanctuary, which is similar to the present study. However, Hossain et al. (2017) reported that the maximum number of species (169 species) was found to occur within the DBH range of 10≤24.5 cm in the Dudhpukuria Dhopachori Wildlife Sanctuary, Chittagong, Bangladesh. Bhuju and Yonzon (2001) revealed that the majority of species were most frequently found within the 4-10 m height range. In contrast, Hossain et al. (2015) demonstrated a higher number of tree species and a greater percentage of tree individuals, except for a lower number (97 species, 77.99%, 404 individuals, respectively) within the 4.5-14.4 m height range. This suggests that KNP is a comparatively more or less well-vertically stratified forest. Species such as *S. robusta*, *T. bellirica*, *A. carambola*, *D. turbinatus*, and *N. cadamba* dominate the upper canopy of KNP.

The structural composition of the study indicates potential regeneration status but also highlights threats from human disturbances. The severe encroachment and deforestation by surrounding communities over the past few decades pose a significant threat to the ecosystem and biodiversity of the area. Expansion of agricultural land, settlements, and infrastructure development has led to the loss of forest cover, disrupting the natural habitat of numerous plant and animal species. Illegal felling of mature trees in the park area further exacerbates the problem, leading to a decline in forest health and ecological balance. However, the Forest Department has enhanced the protection status of the KNP by involving some local people as community forest workers in the last 10 years. Collaborative efforts to protect and conserve the forests and forest resources have resulted in partial recovery of the forest coverage, indicating progress in restoring and preserving the forest. Overall, a combination of law enforcement, community involvement, habitat restoration, sustainable land use planning, collaboration, and research can help address the threats of encroachment and deforestation and conserve the *Sal* Forest ecosystems. Therefore, maintaining biodiversity conservation as the primary purpose for establishing this protected area as a National Park is essential.

In conclusion, the study reveals a land characterized by poorly diverse tree species and stratified tree populations. The IVI values reveal the most important tree species in the forest economically and ecologically and those to be prioritized for conservation. The height class distribution indicates occurrences of illegal removal of trees from the forest. Moreover, the DBH class distribution shows a poor regeneration status in some species, which may be due to human disturbance and livestock grazing. Firing and encroachment have caused extensive loss of regenerated seedlings of important native tree species in the last decades. Therefore, such detrimental intrusion must be stopped immediately, which makes the area more fragmented and reduces the natural forest restoration capacity in Kadigarh National Park of Bangladesh. Both ex-situ and in-situ conservation measures could be initiated to conserve the rare native plant species in the forest.

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Woody vegetation and soil composition of tropical forest along an altitudinal gradient in Western Ghats, India

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Abstract. *Bhatt H, Gopakumar S, Bhindhu PS, Vishnu BR, Jugran HP. 2024. Woody vegetation and soil composition of tropical forest along an altitudinal gradient in Western Ghats, India. Asian J For 8: 51-62.* The altitudinal gradient significantly influences the diversity and spatial distribution of biodiversity in mountainous areas. Exploring tree species diversity patterns provides valuable insights into the factors influencing woody community structures in unexplored areas within the Western Ghats, India, a biodiversity hotspot. This study examined the floristic attributes of woody vegetation and soil composition along an altitudinal gradient (350-1450 m asl) in the tropical evergreen forest in Mankulam Forest Division, Western Ghats, Kerala, India. Along this gradient, the vegetation survey recorded 199 individuals, encompassing 88 tree species from 34 families. Species composition, tree abundance, diversity, and frequency increased with elevation while basal area decreased. *Clausena anisata* (Willd.) Hook.fil. and *Memecylon talbotianum* Brandis were dominant in the lower zone (350-900 m asl), while *Actinodaphne bourdillonii* Gamble and *Litsea keralana* Kosterm. were dominant in the higher zone (900-1450 m asl). Canonical Correspondence Analysis (CCA) revealed intricate interrelationships amongst species clustering, altitudinal spans, and soil properties. A gradual increase in species abundance was observed as the soil compositions increased along the altitude. A marked change in tree vegetation and soil concentrations was observed along this gradient, implying the distribution pattern difference across the altitudinal gradient. It is observed that under prevailing climate change conditions, any significant changes could disrupt this biodiversity hotspot and jeopardize the distinctive fauna and flora that rely on it. The study highlights the cruciality of policy development and its implementation through the forest department and policymakers to conserve and manage this rich biodiversity region.

Keywords: Altitudinal gradient, biodiversity hotspot, canonical correspondence analysis, Kerala, tree diversity, Western Ghats

INTRODUCTION

Altitudinal gradients can be addressed as the most powerful natural drivers for ecological and evolutionary responses of organisms in apect to various environmental changes (Körner 2007; Sharma et al. 2018). Similarly, the adaptive and evolutionary reactions of diverse organisms, including vegetation diversity, composition and structure, are also influenced by altitudinal gradients (Cirimwami et al. 2019; Sahu et al. 2019). Globally, tropical forests cover 7% of the Earth's land area, yet they are home to over 50% of the total species of the planet (Gallery 2014). These ecosystems harbor exceptionally rich species diversity, positioning them as prime biodiversity hotspots (Admassu et al. 2016). They are often called significant carbon sinks due to their higher-standing biomass and greater productivity.

Additionally, they provide numerous ecosystem services, including prevention of soil erosion, preservation of habitat or flora and fauna, and species conservation (Armenteras et al. 2009). However, despite their importance, tropical forests are vanishing at an alarming rate, between 0.8 and 2% per annum (Sagar et al. 2003). This rapid conversion and depletion of tropical forests have resulted in an unparalleled reduction in biodiversity and the disturbance of vital ecosystem functions (Dierick and Holscher 2009).

The ecology of tropical forests is still being explored to understand their ecological systems, patterns, processes and dynamics (Anitha et al. 2010). In tropical forest ecosystems, trees are the major structural and functional components that act as vigorous indicators at the environmental scale (Brockerhoff et al. 2017). Within tropical forests, the richness of tree species exhibits variations attributable to geographic factors, habitat conditions, and degrees of disruption (Jayakumar and Nair 2013). However, the driving mechanisms influencing such high tree diversity in the tropical forest are still poorly understood.

Meanwhile, assessing species diversity encompasses a range of biota, making considering parameters of species diversity indices collectively essential. Such studies are valuable in comprehending ecosystem health and the impact of human activities and natural disruptions (Fedor and Zvaríková 2019). Given that altitude is a pivotal influencer of various life forms, it not only dictates the presence and adaptability of plant species but also provides insights into forest community structures (Körner 2007).

In India, consistent monitoring, analysis, and assessment of ecosystem components offer a potential avenue for well-informed planning and policy interventions to ensure the sustainable future of forests, including those in tropical settings. In the context of the Western Ghats, aside from factors like aspect and slope inclination, altitude also holds a significant role in molding the composition of diverse forest ecosystems and the array of woody plant species they host (USAID 2012; Rao et al. 2013).

The Western Ghats mountainous region is identified as a ‘biodiversity hotspot’ (Myers 1988) along the western coast of India (Bose et al. 2019), and around 27% of India’s overall major plant species have been documented within this region (WGEP 2011). A recorded count of 1,500 plant species endemic to this region has been documented (Ramesh 1997; Narayanan et al. 2018), though explorations are continuing. Among the evergreen tree species present, 56% are endemic (Irwin and Narsimhan 2011; Gaikwad et al. 2014).

While numerous studies on vegetation and soil change along altitude gradient have been reported for the Himalayan ecosystem (Sharma et al. 2009; Maletha et al. 2022), only very few studies are related to tree species diversity and soil compositions using multivariate analysis in tropical forests of Western Ghats (Sundrapandian and Swamy 2000; Joseph et al. 2008; Neikha and Nagaraja 2019) and Eastern ghats (Sahu et al. 2019) have been reported. Focusing on this research gap, an attempt was made to assess and describe the changes in woody vegetation and soil along an altitudinal gradient in the Mankulam Forest Division (MFD) of Western Ghats, Kerala, India. The objectives comprised (i) Phyto-sociology of woody vegetation, (ii) Assessment of the physicochemical properties of soil, and (iii) Linkages between woody vegetation diversity and soil attributes. We expect this study's results will offer pivotal insights into the status of forest tree composition along an altitudinal gradient. This information will also be instrumental in addressing the implications for managing and conserving threatened species in the Western Ghats. Additionally, the findings may guide the formulation of further policy interventions.

MATERIALS AND METHODS

Study area

This study was conducted in Mankulam Forest Division, Kerala, India (a forest division is an administrative entity that covers the primary forest area of the region), located between 10°0' N to 10°10' N latitude and 76°50' E to 77°0' E longitude with an altitudinal variation from 350-1,740 m asl (Figure 1). According to Champion and Seth (1968), the forest is classified as West Coast semi-evergreen forests (2A/C2) and West Coast tropical evergreen forests (1A/C4). The average yearly temperature ranges from 5.4°C to 8.0°C at minimum temperature and 22.8°C to 24.5°C at maximum temperature, with rainfall ranging between 153-232 mm in the study region (IMD 2019). This temperature variation is attributed to the varying altitudes (KFD 2014). The enhancement in rainfall along altitude depends on the windward side's specific topography, a specific feature in the Western Ghats (Muralidharan et al. 1985; Harikumar 2016). Soil rests upon Archean igneous rocks predominantly composed of gneisses and granites (Koshy 1970). This soil type is classified and reported as humic acrisol, according to FAO-UNESCO (1977) and Jose et al. (1996).

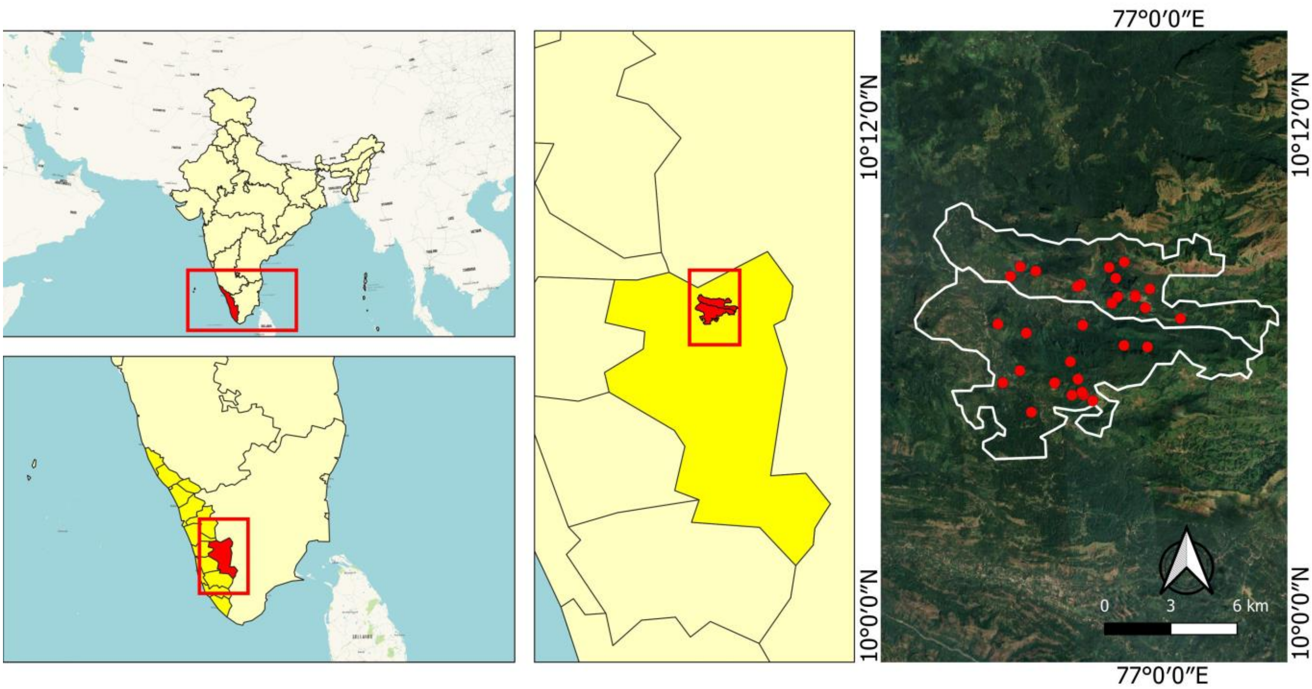

Figure 1. Map of the study area and sampling points in Mankulam Forest Division, Kerala, India

Vegetation analysis

Based on preliminary and reconnaissance surveys in MFD, a suitable primary forest for vegetation sampling was selected. Forest maps and topographic sheets were utilized to validate altitude variations within the region. The study area's altitudinal range facilitated its classification into two distinct zones, i.e., (i). Zone I (350-900 masl) is the lower zone. (ii). Zone II (900-1,450 masl) is the higher zone.

A lower and higher zone primary forests were identified for detailed analysis. Fifteen sample plots measuring 10 × 10 m (100 m^2) located roughly 10 m apart were randomly placed along a 250 m-long transect parallel to the slope (Mota et al. 2018). The limitation of adequacy in data collection is due to the topographic limitation of the study area due to high slopes (>80°) and certain inaccessibility to the high slope areas. All the tree species (>10cm DBH) were measured at a height of 1.37 m above the ground using standard equipment, and tree height (m) was recorded using Vertex IV Hypsometer (Roby 2018).

Sampled standing tree species were individually counted and identified by referencing Sasidharan (2012) and Flora of Peninsular India (CES 2019). Relative Abundance (RA), Relative Frequency (RF), Relative Density (RD), Basal Area (BA and Importance value index (IVI) were subsequently derived from the above measurements following Phillips (1959). Species Evenness (Pielou 1966), Shannon–Wiener Diversity Index (Shannon and Weaver 1963), and the Concentration of Dominance (Simpson 1949) were also derived.

Soil analysis

Soil samples were collected from individual 100 m^2 plots at two distinct depths: (i) upper (0-20 cm) and (ii) lower (20-40 cm) and then combined into composite samples. The core sampling method was used to estimate the soil bulk density (BD g cm^{-3}) (Abu-Hamdeh and Al-Jalil 1999). Soil pH was determined using an aqueous suspension (Jackson 1968) and a digital pH meter (model APX 175E/C). Electrical conductivity (EC d Sm^{-1}) was assessed using an electrical conductivity meter. Soil organic carbon (OC%) was calculated employing a titration technique developed by Walkley (1947). The content of Total nitrogen (N%) was ascertained through the Kjeldahl method (Bremner and Mulvaney 1982). Available phosphorus (P Kg ha^{-1}) was deduced from the soil following Olsen et al. (1954). Available Potassium content (K kg ha^{-1}) was determined through the neutral normal ammonium acetate method (Merwin and Peech 1951) and quantified using a flame photometer. Available soil calcium (Ca mg kg^{-1}) was estimated by complex metric titration using EDTA following Schwarzenbach et al. (1946).

Statistical analysis

Employing an independent t-test and Karl Pearson correlation test, the significance of each environmental (soil) parameter with various zones was calculated. A two-tailed Pearson correlation coefficient was computed to analyze the connections among various phytosociological and soil chemical parameters using the SPSS version 25.0 software (SPSS Inc., Chicago, IL, USA) package. Canonical Correspondence Analysis (CCA) was done using R version 3.6.2 (R Core Team 2019) to establish associations between species and soil variables.

RESULTS AND DISCUSSION

Woody species composition and diameter distribution

This study revealed the presence of 199 individuals of 88 tree species in the lower and higher zones (Tables 1 and 2). These species were spread across 88 genera and 34 plant families. In the higher zone, there were 50 species recorded (Table 2), with Lauraceae (12 species) as the dominant family (Table 3). In the lower zone, species richness was lower (38 species) (Table 1). The higher species richness in the higher zone is due to the greater number of tropical wet evergreen species in the zone, as in these forests, tropical moist deciduous and semi-evergreen species are more numerous.

Throughout the altitudinal gradient, tree abundance and tree density were higher (67.09 and 694.23 trees ha^{-1}) in the higher zone compared to the lower zone (49.11 and 613.34 trees ha^{-1}) (Tables 1 and 2). Conversely, the lower zone had a higher tree basal area (20.3 m^2 ha^{-1}) than the higher zone (12.32 m^2 ha^{-1}; Tables 1 and 2). In the higher zone, *Vateria indica* L. had the higher Importance Value Index (24.09), whereas in the lower zone, the dominant species was *Dysoxylum malabaricum* Bedd. ex C.DC. (IVI= 34.85) (Tables 1 and 2).

The diameter distribution was in three diameter classes of 30-40, 40-50, and >100cm, with the highest contribution to vegetation composition in the lower altitudinal zone (Figure 2). While in the higher altitudinal zone, the maximum tree species were in diameter classes of 50-60, 60-80, and 80-100 cm, which significantly impacted vegetation composition.

Dominance and diversity

The dependent relationship of dominance and diversity with altitude on tree diversity was examined (Figure 3). The Simpson Index, i.e., the concentration of dominance (Cd) and Shannon-Wiener index of tree diversity, increases with increasing altitude. The maximum values were recorded as (3.74 and 0.97) in the higher zone, followed by (3.47 and 0.96) in the lower zone. Pielou's index of Evenness was also slightly lower (0.953) in the lower zone compared to the higher zone (0.957).

Table 1. List of family and tree species (>10 cm DBH) and their ecological attributes in the lower zone in the Mankulam Forest Division, Western Ghats, India

Family	Species	No. of individuals	A	D	RD	F	PF	RF	BA	RBA	IVI	RIVI
Lauraceae	*Actinodaphne malabarica* N.P.Balakr.	3	1.5	20	3.26	0.13	13.33	2.86	0.11	0.54	6.65	2.22
Meliaceae	*Aglaia simplicifolia* (Bedd.) Harms	2	1	13.33	2.17	0.13	13.33	2.86	0.04	0.22	5.25	1.75
Lauraceae	*Alseodaphne semecarpifolia* Nees	2	1	13.33	2.17	0.13	13.33	2.86	0.03	0.15	5.18	1.73
Apocynaceae	*Alstonia scholaris* (L.) R. Br.	3	1	20	3.26	0.2	20	4.28	0.03	0.17	7.72	2.57
Phyllanthaceae	*Aporosa cardiosperma* (Gaertn.) Merr.	2	2	13.33	2.17	0.06	6.67	1.42	0.05	0.25	3.85	1.28
Moraceae	*Artocarpus hirsutus* Lam.	3	1	20	3.26	0.13	13.33	2.86	0.15	0.71	6.83	2.28
Centroplacaceae	*Bhesa indica* (Bedd.) Ding Hou	2	1	13.33	2.17	0.13	13.33	2.86	0.62	3.07	8.10	2.70
Bombacaceae	*Bombax ceiba* L.	1	1	6.67	1.09	0.06	6.67	1.42	2.11	10.40	12.91	4.30
Lauraceae	*Cinnamomum camphora* (L.) J.Presl	1	1	6.67	1.09	0.06	6.67	1.42	0.03	0.16	2.68	0.89
Lauraceae	*Cinnamomum malabatrum* (Burm. f.) Presl	1	1	6.67	1.09	0.06	6.67	1.428	0.01	0.06	2.58	0.86
Rutaceae	*Clausena anisata* (Willd.) Hook.fil.	1	1	6.67	1.09	0.06	6.67	1.42	0.01	0.04	2.56	0.85
Meliaceae	*Dysoxylum malabarirum* Bedd. ex C.DC.	7	1.4	46.67	7.61	0.33	33.33	7.14	4.08	20.10	34.85	11.63
Elaeocarpaceae	*Elaeocarpus tuberculatus* Roxb.	3	1.5	20	3.26	0.13	13.33	2.86	0.34	1.70	7.881	2.60
Moraceae	*Ficus hispida* L. f.	2	1	13.33	2.17	0.13	13.33	2.86	0.06	0.28	5.31	1.77
Moraceae	*Ficus tsjahela* Burm.f	1	1	6.67	1.09	0.06	6.67	1.42	0.04	0.22	2.74	0.91
Clusiaceae	*Garcinia rubroechinata* Kosterm.	1	1	6.67	1.09	0.06	6.67	1.42	0.03	0.17	2.68	0.89
Sapindaceae	*Harpullia arborea* (Blanco) Radlk.	1	1	6.67	1.09	0.06	6.67	1.42	0.02	0.10	2.62	0.87
Dipterocarpaceae	*Hopea parviflora* Bedd.	3	1.5	20	3.26	0.13	13.33	2.85	0.11	0.52	6.64	2.21
Sapotaceae	*Isonandra perrottetiana* A.DC.	1	1	6.67	1.09	0.06	6.67	1.42	0.17	0.84	3.35	1.12
Myristicaceae	*Knema attenuata* (Hook.fil. & Thomson) Warb.	3	1.5	20	3.26	0.13	13.33	2.86	0.22	1.07	7.19	2.40
Lauraceae	*Litsea bourdillonii* Gamble	2	2	13.33	2.17	0.06	6.67	1.42	1.27	6.27	9.87	3.29
Lauraceae	*Litsea floribunda* (Blume) Gamble	1	1	6.67	1.09	0.06	6.67	1.42	0.01	0.06	2.58	0.86
Lauraceae	*Litsea wightiana* (Nees) Benth. & Hook. fil.	2	1	13.33	2.17	0.13	13.33	2.86	0.11	0.53	5.56	1.85
Euphorbiaceae	*Macaranga peltata* (Roxb.) Müll.Arg.	6	1.2	40	6.52	0.33	33.33	7.14	0.61	2.99	16.65	5.55
Sapotaceae	*Madhuca neriifolia* (Moon) H.J. Lam	3	3	20	3.26	0.06	6.67	1.42	0.75	3.69	8.38	2.79
Magnoliaceae	*Magnolia nilagirica* (Zenker) Figlar	4	1.34	26.67	4.34	0.2	20	4.28	2.33	11.47	20.11	6.70
Euphorbiaceae	*Mallotus philippensis* (Lam.) Müll.Arg.	4	1.34	26.67	4.34	0.2	20	4.28	1.39	6.85	15.48	5.16
Rutaceae	*Melicope lunu-ankenda* (Gaertn.) T.G. Hartley	2	2	13.33	2.17	0.06	6.67	1.42	0.26	1.28	4.89	1.63
Sabiaceae	*Meliosma simplicifolia* (Roxb.) Walp.	2	1	13.33	2.17	0.13	13.33	2.86	0.02	0.08	5.11	1.70
Melastomataceae	*Memecylon talbotianum* Brandis	1	1	6.67	1.09	0.06	6.67	1.42	1.36	6.69	9.20	3.07
Calophyllaceae	*Mesua ferrea* L.	1	1	6.67	1.09	0.06	6.67	1.42	0.01	0.06	2.54	0.86
Myristicaceae	*Myristica dactyloides* Gaertn.	7	2.33	46.67	7.61	0.2	20	4.28	0.60	2.93	14.80	4.95
Sapotaceae	*Palaquium ellipticum* (Dalzell) Baill.	2	2	13.33	2.17	0.06	6.67	1.42	0.89	4.40	8	2.67
Clusiaceae	*Poeciloneuron indicum* Bedd.	2	1	13.33	2.17	0.13	13.33	2.86	0.71	3.48	8.51	2.84
Sapindaceae	*Schleichera oleosa* (Lour.) Oken	2	1	13.33	2.17	0.13	13.33	2.86	0.22	1.07	6.10	2.03
Bignoniaceae	*Spathodea companulata* Beauverd	3	1.5	20	3.26	0.13	13.33	2.86	0.55	2.73	8.85	2.95
Staphyleaceae	*Turpenia cochinchinensis* (Lour.) Merr.	3	1	20	3.26	0.13	13.33	2.86	0.16	0.78	6.90	2.30
Dipterocarpaceae	*Vateria indica* L.	2	1	13.33	2.17	0.13	13.33	2.86	0.79	3.87	8.90	2.97
	Total	92	49.11	613.34	99.95		466.66	99.9	20.3	100	300	100

Note: A: Abundance, D: Density (trees ha^{-1}), F: Frequency (%), RD: Relative Density (%), PF: Percent Frequency (%), BA: Basal Area (m^2 ha^{-1}), RBA: Relative Basal Area (%), RF: Relative frequency (%), IVI: Importance Value Index, RIVI: Relative Importance Value Index

Table 2. List of family and tree species (>10 cm DBH) and their ecological attributes in the higher zone in the Mankulam Forest Division, Western Ghats, India

Family	Species	No. of individuals	A	D	RD	F	PF	RF	BA	RBA	IVI	RIVI
Rutaceae	*Acronychia pedunculata* (L.) Miq.	1	1	6.67	0.93	0.06	6.67	1.22	0.1	0.84	2.99	1.00
Lauraceae	*Actinodaphne bourdillonii* Gamble	3	1.5	20	2.80	0.13	13.33	2.44	0.11	0.87	6.11	2.04
Lauraceae	*Actinodaphne hookeri* Meisn.	3	1.5	20	2.80	0.13	13.33	2.44	0.10	0.83	6.07	2.02
Lauraceae	*Alseodaphne semecarpifolia* Nees	1	1	6.67	0.93	0.06	6.67	1.22	0.03	0.23	2.38	0.79
Euphorbiaceae	*Antidesma montanum* Blume	2	2	12.37	1.87	0.06	6.67	1.22	0.06	0.46	3.55	1.18
Phyllanthaceae	*Aporosa lindeliyana* (Wight) Baill.	2	1	12.37	1.86	0.13	13.33	2.44	0.07	0.56	4.87	1.62
Lauraceae	*Apollonias arnotii* Nees	1	1	6.67	0.934	0.06	6.67	1.22	0.04	0.36	2.52	0.84
Callophylaceae	*Calophyllum polyanthum* Wall. ex Choisy	1	1	6.67	0.93	0.06	6.67	1.22	0.02	0.20	2.35	0.78
Burseraceae	*Canarium strictum* Roxb.	4	1.34	26.67	3.73	0.2	20	3.66	0.42	3.45	10.85	3.62
Lauraceae	*Cinnamomum malabatrum* (Burm. f.) Presl	2	1	12.37	1.86	0.13	13.33	2.44	0.07	0.55	4.86	1.62
Verbenaceae	*Clerodendron infortunatum* L.	3	1.5	20	2.80	0.13	13.33	2.44	0.07	0.57	5.81	1.94
Malvaceae	*Cullenia exarillata* A. Robyns	4	2	26.67	3.74	0.13	13.33	2.44	0.32	2.59	8.76	2.92
Dilleniaceae	*Dillenia pentagyna* Roxb.	1	1	6.67	0.93	0.06	6.67	1.22	0.03	0.24	2.39	0.80
Sapindaceae	*Dimocarpus longan* Lour.	1	1	6.67	0.93	0.06	6.67	1.22	0.11	0.93	3.09	1.03
Meliaceae	*Dysoxylum ficiforme* (Wight) Gamble	1	1	6.67	0.93	0.06	6.67	1.22	0.35	2.85	5.01	1.67
Elaecarpaceae	*Elaeocarpus tuberculatus* Roxb.	3	1.25	20	2.80	0.26	26.66	4.88	0.52	4.24	11.92	3.97
Elaecarpaceae	*Elaeocarpus serratus* L.	2	1	13.33	1.86	0.13	13.33	2.44	0.22	1.80	6.11	2.04
Moraceae	*Ficus hispida* L.fil.	1	1	6.67	0.93	0.06	6.67	1.22	0.02	0.13	2.29	0.76
Theaceae	*Gordonia obtusa* Wall.	7	1.75	46.67	6.54	0.26	26.66	4.88	0.98	7.97	19.39	6.46
Anacardiaceae	*Holigarna beddomei* Wall. ex Hook. f.	1	1	6.67	0.93	0.06	6.67	1.22	0.02	0.19	2.34	0.78
Anacardiaceae	*Holigarna grahamii* (Wight) Kurz	1	1	6.67	0.93	0.06	6.67	1.22	0.02	0.17	2.33	0.78
Dipterocarpaceae	*Hopea parviflora* Bedd.	2	1	12.37	1.87	0.13	13.33	2.44	0.02	0.16	4.46	1.49
Achariaceae	*Hydnocarpus pentandrus* (Buch.-Ham.) Oken	2	2	12.37	1.87	0.06	6.67	1.22	0.09	0.70	3.79	1.26
Myristicaceae	*Knema attenuata* (Hook.fil. & Thomson) Warb.	2	1	6.67	0.93	0.06	6.67	1.22	0.07	0.55	3.64	1.21
Lauraceae	*Litsea bourdillonii* Gamble	1	1	6.67	0.93	0.06	6.67	1.22	0.29	2.38	4.54	1.51
Lauraceae	*Litsea coriacea* (Nees) Hook.f.	1	1	6.67	0.93	0.06	6.67	1.22	0.03	0.21	2.37	0.79
Lauraceae	*Litsea floribunda* (Blume) Gamble	4	2	26.67	3.73	0.13	13.33	2.44	0.32	2.59	8.76	2.92
Lauraceae	*Litsea keralana* Kosterm.	2	1	13.33	1.86	0.13	13.33	2.44	0.07	0.61	4.92	1.64
Lauraceae	*Litsea laevigata* (Nees) Gamble	1	1	6.67	0.93	0.06	6.67	1.22	0.03	0.24	2.39	0.8
Lauraceae	*Litsea wightiana* (Ness) Benth. & Hook.fil.	2	2	13.33	1.86	0.06	6.67	1.22	0.09	0.74	3.83	1.28
Euphorbiaceae	*Macaranga peltata* (Roxb.) Müll.Arg.	1	1	6.67	0.93	0.06	6.67	1.22	0.20	1.66	3.81	1.27
Sapotaceae	*Madhuca longifolia* (J. Koenig ex L.) J.F. Macbr.	2	2	12.37	1.86	0.06	6.67	1.22	0.15	1.23	4.32	1.24
Myrsinceae	*Maesa indica* (Roxb.) Sweet	2	2	12.37	1.86	0.06	6.67	1.22	0.58	4.68	7.77	2.58
Sabiaceae	*Meliosma pinnata* (Roxb.) Maxim.	1	1	6.67	0.93	0.06	6.67	1.22	0.03	0.26	2.41	0.80
Sabiaceae	*Meliosma simplicifolia* subsp. *pungens* (Walp.) van Beusekom	4	1.33	26.67	3.73	0.2	20	3.66	1.09	8.85	16.25	5.40
Clusiaceae	*Mesua ferrea* L.	2	1	12.37	1.86	0.13	13.33	2.44	0.19	1.55	5.86	1.25
Icacinaceae	*Nothapodytes nimmoniana* (J.Graham) Mabb.	4	2	26.67	3.73	0.13	13.33	2.43	0.07	0.58	6.76	2.25
Sapotaceae	*Palaquium ellipticum* (Dalzell) Baill.	1	1	6.67	0.93	0.06	6.67	1.22	0.54	4.37	6.53	2.18
Lauraceae	*Persea macrantha* (Nees) Kosterm.	2	1	13.33	1.86	0.13	13.33	2.43	0.08	0.66	4.97	1.66
Rosaceae	*Photinia integrifolia* Lindl.	2	2	13.33	1.86	0.06	6.67	1.22	0.15	1.18	4.27	1.42
Rosaceae	*Prunus ceylanica* (Wight) Miq	1	1	6.67	0.93	0.06	6.67	1.22	0.02	0.20	2.40	2.35

Rubiaceae	*Psychotria nigra* (Gaertn.) Alston	1	1	6.67	0.93	0.06	6.67	1.22	0.03	0.25	2.40	0.80
Rubiaceae	*Psydrax dicoccos* Gaertn.	2	1	12.37	1.87	0.13	13.33	2.43	0.19	1.23	5.54	1.65
Sapindaceae	*Schleichera oleosa* (Lour.) Merr.	5	1.25	33.33	4.67	0.26	26.66	4.88	0.64	5.22	14.77	4.7
Anacardiaceae	*Solenocarpus indicus* Wight & Arn.	1	1	6.67	0.93	0.06	6.67	1.22	0.03	0.28	2.41	0.81
Sterculiaceae	*Sterculia guttata* Roxb.	4	1.33	26.67	3.74	0.2	20	3.66	0.5	4.07	11.47	3.62
Myrtaceae	*Syzigium mundagam* (Bourd.) Chithra	1	1	6.67	0.93	0.06	6.67	1.21	0.05	0.39	2.55	0.85
Meliaceae	*Trichilia connaroides* (Wight & Arn.) Bentv.	2	2	13.33	1.87	0.13	13.33	2.43	0.82	6.62	10.90	3.64
Staphylaceae	*Turpinia cochinchinensis* (Lour.) Merr.	3	3	20	2.80	0.06	6.67	1.22	0.22	1.8	5.83	1.94
Dipterocarpaceae	*Vateria indica* L.	4	1.33	26.67	3.74	0.2	20	3.66	2.05	16.69	24.09	8.03
	Total	107	67.09	694.23	99.914		546.69	99.99	12.32	99.98	300	100

Note: A: Abundance, D: Density (trees ha^{-1}), F: Frequency (%), RD: Relative Density (%), PF: Percent Frequency (%), BA: Basal Area (m^2 ha^{-1}), RBA: Relative Basal Area (%), RF: Relative Frequency (%), IVI: Importance Value Index, RIVI: Relative Importance Value Index

Impact of altitude on vegetation

Canonical Correspondence Analysis (CCA) also confirmed the significant impact of altitude on vegetation in the two altitudinal zones (Figures 4 and 5). The eigenvalues associated with CCA Axis 1 and 2 within the lower zone were 0.71 and 0.67, respectively. For the initial two axes of CCA, the collective percentage variance of the species-environment relationship was 34.63% (Figure 4). Axis 1 indicates a strong positive correlation, which is statistically significant, with total N (0.778), while displaying a noteworthy negative correlation with Bulk Density (BD) (-0.571), which means that the total N values showed an increasing trend with the change in altitudinal variation. In contrast, the bulk density declined with the change in altitudinal variation. Axis 2 correlated positive-significantly and strongly with soil pH (0.629) and negative-significantly correlated with Bulk Density (BD) (-0.558) (Table 6). This indicates that the soil pH values increased with elevation while bulk density declined, impacting the soil quality.

In the higher zone, the eigenvalues associated with CCA Axis 1 and 2 were 0.74 and 0.71, respectively. For the initial two CCA axes, the collective percentage variance in the species-environment relationship is 34.1 % (Figure 5). Axis 1 exhibits a robust positive correlation with N (0.764) and a negative correlation with BD (-0.679). Axis 2 correlated more positively with soil pH (0.685) and negatively with EC (-0.485) (Table 7). It shows that the edaphic factors play a significant role in delineating the species-environmental relationship.

Soil compositions

All the soil physicochemical properties exhibited large variations along the altitudinal gradient (Tables 4 and 5). Soil pH, OC, N, P, K, and Ca values increased along the gradient, while soil bulk density values decreased (Table 4). In the higher zone, soil depth significantly influenced soil EC values, probably due to the leaching of soluble salts and their accumulation in deeper layers (Tables 4 and 5). In the lower zone, available K exhibited a notably positive correlation with organic C (0.695), perhaps due to the abundance of species like *D. malabaricum* and *Myristica dactyloides* Gaertn. attributing better litter decomposition and humus formation. Total N negatively correlated with bulk density with the increase in soil depth and declined with an increase in soil depth, while BD increased with a decrease in soil depth (-0.551) (Table 6). In the higher zone, available K positively correlated with total N (0.700) due to well-rooted tree species that bind the soil and release N in the forest floor, while total N negatively correlated with bulk density (-0.667) (Table 7).

Table 3. Number of species of the ten most diverse families from two altitudinal zones in the Mankulam Forest Division, Western Ghats, India

Lower Zone		Higher Zone	
Family	**S**	**Family**	**S**
Lauraceae	7	Lauraceae	12
Moraceae	3	Euphorbiaceae	3
Sapotaceae	3	Anacardiaceae	3
Meliaceae	2	Rubiaceae	2
Dipterocarpaceae	2	Dipterocarpaceae	2
Myristicacae	2	Sapindaceae	2
Sapindaceae	2	Elaeocarpaceae	2
Rutaceae	2	Sabiaceae	2
Euphorbiacae	2	Rosaceae	2
Clusiacae	2	Callophylaceae	1

Note: S-species richness represents the number of species within the respective families

Table 4. Independent t-test to investigate the influence of soil depth on soil variables at each altitudinal zone

Altitudinal zone	Soil variables	Soil- depth 0-20 cm	Soil- depth 20-40 cm	t- value	p-value
Lower zone	pH	4.53±0.138	4.61±0.183	-0.321	0.751
	EC	0.91±0.08	0.63±0.05	2.56	0.016**
	BD	0.97±0.03	1.05±0.04	-1.942	0.147
	C	3.84±0.34	3.23±0.39	1.175	0.25
	N	0.13±0.018	0.11±0.01	0.874	0.389
	P	97.93±23.17	65.31±19.38	1.08	0.289
	K	854.93±38.8	778.84±37.53	1.409	0.17
	Ca	424±51.46	325.33±45.45	1.437	0.162
Higher zone	pH	4.78±0.147	4.63±0.107	0.795	0.433
	EC	0.68±0.06	0.53±0.05	1.85	0.075
	BD	0.92±0.03	0.98±0.04	-1.152	0.259
	C	5.09±0.63	4.18±0.62	1.033	0.311
	N	0.22±0.02	0.18±0.02	1.141	0.264
	P	320.43±88.09	202.48±65.89	1.072	0.293
	K	990.48±84.15	799.71±81.22	1.631	0.114
	Ca	700±84.04	520±50.67	1.834	0.077

Note: BD: Bulk Density, pH: Soil pH, N: Total nitrogen, C: Soil organic carbon, K: Available potassium, EC: Electrical Conductivity, P: Available phosphorus, Ca: Available calcium. ** The correlation is significant at the 0.01 level with a two-tailed test

Table 5. Independent t-test to investigate the influence of two altitudinal zones on various soil variables at each depth

Soil depth	Soil variables	Altitudinal zone		t- value	p-value
		Lower zone	Higher zone		
0-20	pH	4.53±0.138	4.78±0.147	-1.235	0.227
	EC	0.91±0.08	0.68±0.06	-2.061	**0.049
	BD	0.97±0.03	0.92±0.03	1.138	0.265
	C	3.84±0.34	5.09±0.63	-1.755	0.93
	N	0.13±0.02	0.22±0.02	-3.074	**0.005
	P	97.93±23.17	320.43±88.09	-2.443	**0.027
	K	854.93±38.8	990.48±84.15	-1.463	0.159
	Ca	424±51.46	700±84.04	-2.801	**0.009
20-40	pH	4.61±0.183	4.63±0.107	-0.145	0.886
	EC	0.63±0.05	0.53±0.05	-1.293	0.207
	BD	1.05±0.04	0.98±0.04	1.166	0.254
	C	3.23±0.39	4.18±0.62	-1.297	0.207
	N	0.11±0.01	0.18±0.02	-2.968	**0.006
	P	65.31±19.38	202.48±65.89	-1.997	0.063
	K	778.84±37.53	799.71±81.22	-0.233	0.818
	Ca	325.33±45.45	520±50.67	-2.86	**0.008

Note: BD: Bulk Density, pH: Soil pH, N: Total nitrogen, C: Soil organic carbon, K: Available potassium, EC: Electrical Conductivity, P: Available phosphorus, Ca: Available calcium. **: The correlation is significant at the 0.01 level with a two-tailed test

Table 6. Correlations among soil-related environmental variables and the CCA axis were examined in the lower zone

Environmental variables	Axis 1	Axis 2	pH	EC	BD	OC	N	P	K	Ca
pH	0.163	0.629								
EC	0.322	-0.253	0.081							
BD	-0.571	-0.416	-0.177	-0.343						
OC	0.390	-0.558	-0.384	0.281	-.0.249					
N	0.778	-0.340	0.091	0.542*	-0.551*	0.658**				
P	0.437	-0.042	0.348	0.214	-0.164	0.353	0.498			
K	0.638	0.114	0.134	0.161	-0.453	0.695**	0.591*	0.465		
Ca	0.580	-0.356	0.134	0.139	-0.094	0.566	0.590*	0.171	0.512	

Note: **: Significant at 0.01 levels (2-tailed), *: Significant at 0.05 levels, others are non-significant (2-tailed). K: Available Potassium, BD: Bulk Density, N: Total Nitrogen, EC: Electrical Conductivity, OC: Organic Carbon, P: Available Phosphorus, Ca: Available Calcium

Table 7. Correlations among soil-related environmental variables and the CCA axis were examined in the higher zone

Environmental variables	Axis 1	Axis 2	pH	EC	BD	OC	N	P	K	Ca
pH	0.1809	0.685								
EC	0.0284	-0.485	-0.379							
BD	-0.6794	0.016	0.001	0.288						
OC	0.6776	0.116	0.040	0.098	-0.285					
N	0.7635	-0.013	-0.210	-0.105	-0.667**	0.677**				
P	-0.2850	-0.118	0.087	-0.092	0.244	-0.394	-0.198			
K	0.4339	0.320	0.075	-0.278	-0.628*	0.311	0.700**	-0.106		
Ca	0.4644	0.032	0.333	0.092	-0.351	0.132	0.235	-0.163	0.548*	

Note: **: Statistically significant at the 0.01 levels (two-tailed), *: Statistically significant at 0.05 levels, others are non-significant (two-tailed). K: Available Potassium, BD: Bulk Density, N: Total Nitrogen, EC: Electrical Conductivity, OC: Organic Carbon, P: Available Phosphorus, Ca: Available Calcium

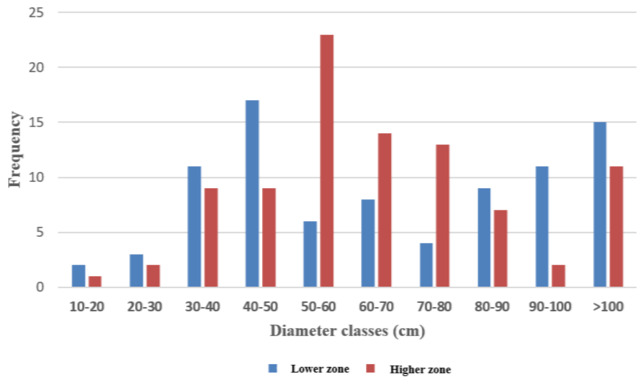

Figure 2. Diameter-frequency distribution in two altitudinal zones in the Mankulam Forest Division, Western Ghats, India

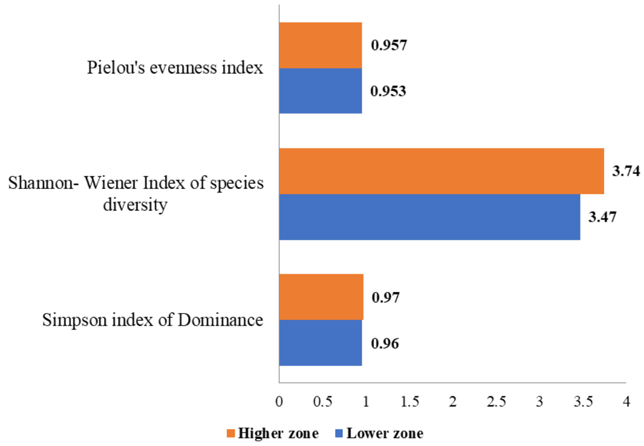

Figure 3. Floristic diversity indices of tree vegetation in two altitudinal zones in the Mankulam Forest Division, Western Ghats, India

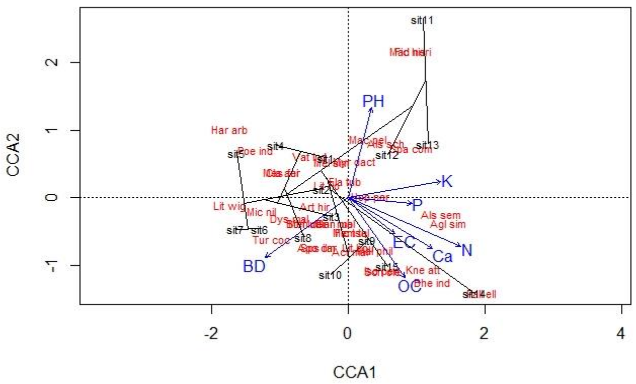

Figure 4. Ordination plot illustrating Canonical Correspondence Analysis (CCA) for trees in the lower zone. Variables: Bulk Density (BD), soil pH (pH), total nitrogen (N), soil organic carbon (OC), available potassium (K), electrical conductivity (EC), available phosphorus (P), and available calcium (Ca)

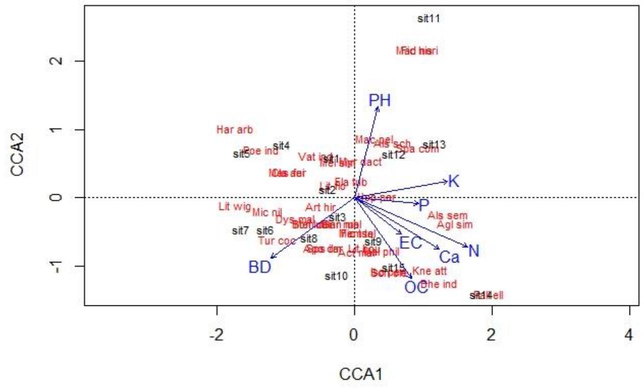

Figure 5. Ordination plot illustrating Canonical Correspondence Analysis (CCA) for trees in the higher zone. Variables: Bulk Density (BD), soil pH (pH), total nitrogen (N), soil organic carbon (OC), available potassium (K), electrical conductivity (EC), available phosphorus (P), and available calcium (Ca)

Discussion

The study's findings underscore that the altitudinal gradient has a pivotal function in shaping forest communities and species richness and existence in humid tropical forests. This observation aligns with the conclusions drawn by Bacaro et al. (2008), who noted that elevation, functioning as a significant regional and local environmental factor, is a prime predictor for the diversity and spatial distribution of woody species within specific regions.

Species diversity pattern

The previous investigations in diverse regions within the Western Ghats of India indicated varying levels of woody vegetation diversity (H'= 0.45-3.37) throughout different temperate forests. In this study, the significant differences in vegetation composition, diversity, and structure were discerned across the altitudinal gradient. Species richness stands out as a prominent characteristic of tropical forests. As anticipated, the higher zone exhibited elevated species richness and diversity, which aligns with the study by Singh (2016). In line with expectations, the higher zone had higher tree density (713.33 trees ha^{-1}) when contrasted with the lower zone (613.33 trees ha^{-1}), which is found to be different from the previous studies findings of 850 trees ha^{-1} in Makutta Wildlife Range, Western Ghats (Neikha and Nagaraja 2019), 748 trees ha^{-1} in Kodayar, Agasthyamalai hills of Western Ghats (Sundrapandian and Swamy 2000) and also in Mudumalai Wildlife Sanctuary with 232-370 trees ha^{-1} (Joseph et al. 2008).

Some tree species documented in this study include dominants of higher altitudinal zones, viz., the evergreen trees *Gordonia obtusa* Wall., *Litsea floribunda* (Blume) Gamble, and *V. indica* L. (Table 2). Conversely, in the lower zones, the presence of dominant trees like *D. malabaricum*, *Macaranga peltata* (Roxb.) Müll.Arg., *M. dactyloides* were the dominant species (Table 1), possibly due to the suitable climatic factors reported by Mota et al. (2018). Invasive species like *Spathodea companulata* Beauverd and *M. peltata* were also reported in the lower zone.

In total, 88 tree species in 34 families (Tables 1 and 2) were documented in both altitudinal zones. This study recorded lower species richness compared to the studies reported in the Singara range, Nilgiri Biosphere Reserve, Western Ghats, with 181 species belonging to 115 genera and 56 families (Singh 2016), 106 tree species in 78 genera with 31 families in Nilgiri Biosphere reserve, Western Ghats (Anitha et al. 2010) and 68 tree species comprising 604 individuals of 55 genera and spanning 30 families in Makutta wildlife range, Western Ghats (Neikha and Nagaraja 2019). The lower tree species diversity in this study could be ascribed to (a) restriction of enumerations to the adult tree (>10cm DBH) following (Sundrapandian and Swamy 2000) and (b) lower sampling intensity (Sukumar et al. 1992). These species are also represented in earlier studies of forest composition and floristic studies of the Western Ghats across similar elevation ranges (Mohandass and Davidar 2009; Magesh and Menon 2011; Subashree et al. 2021).

Basel area pattern

The basal area of trees (20.31 m^2 ha^{-1}) was greater in the lower zone as opposed to the higher zone (12.31 m^2 ha^{-1}) (Tables 1 and 2). Nevertheless, these values were below the range reported in Mudumulai Wildlife Sanctuary with 22.3- 53 m^2 ha^{-1} (Joseph et al. 2008) and in the Nilgiri Mountains of Southern Western Ghats with 53.33m^2 ha^{-1} (Mohandass and Davidar 2009). Variations in the lower basal area can be ascribed to factors such as the composition of species, altitudinal variation, successional stage of a forest stand, tree age, and the extent of disturbances (Sundrapandian and Swamy 2000). The tree (>10 cm DBH) diversity index (Shannon index) was in the range of (3.47-3.74) for both altitudinal zones, which was comparatively higher (2.64 for Malayatoor Forest division near Mankulam, Western Ghats) as reported by Magesh and Menon (2011) and recorded lower (3.00-3.62) than in Amoro forest, Ethiopia (Liyew et al. 2018) and 3.9-5.26 in Mudumalai Wildlife Sanctuary, Western Ghats as noted by Joseph et al. (2008).

Meanwhile, the dominance index for the tree layer of both zones (0.96-0.97) in this study fell within the range of 0.94 recorded by Singh et al. (2016) in the Singara range of Western Ghats, India. The higher values could be attributed to largely undisturbed forests contributing to a large amount of humus and litter fall formation, resulting in higher carbon return to the ground (Gairola et al. 2012), which increases the SOC content. Pielou's index of evenness values is comparatively higher. Therefore, there is an urgent need for the sustainable management of these forest resources, which should encompass initiatives such as replenishing and restocking the forest within the Western Ghats.

Relationship of vegetation with altitude

Canonical Correspondence Analysis (CCA) revealed that the distribution of woody species was positively associated with various soil variables (pH, BD, EC, OC, N, P, K, and Ca). It has also revealed distinctions in soil conditions across altitudes, as reported by Mota et al. (2018). A noteworthy positive correlation between total N and Axis 1 suggests that this soil attribute significantly impacts the vegetation in lower and higher zones. Total N is an important decisive factor with increasing concentration and altitude (Shedayi et al. 2016), indicating a noteworthy positive correlation with soil pH in the present study. Present results of the soil's acidic nature are similar to those reported by Fujii (2014), who reported that organic, nitric, and carbonic acid formed by microbial activities and root favors more acidic soil in Bornean humid tropical forest Indonesia. The highest value of OC, N, P, K, and Ca was recorded in a (0-20 cm) layer in the higher zone (Table 4) with significant influence on soil EC, N, P, and Ca (0-20 cm) and in (20-40 cm) in N and Ca (Table 5). The higher soil values could be attributed to the higher abundance and density of evergreen tree species (Table 2) whose leaves and litter fall contain a higher proportion of N: P (Menéndez et al. 1988; Herna'ndez 1999; Campo et al. 2014) with leaf fall throughout the year and deeper root biomass (Osman 2013; KFD 2014) as evergreen tree species favors higher organic matter mineralization enhancing the availability of base cations in soil (McNabb et al. 1997). The lower values were observed in the lower zone with a significant influence on soil EC (Table 4) can be ascribed to the presence of a mixture of moist deciduous, semi-evergreen, and evergreen species with lower abundance and density of tree species (Table 1) as a higher proportion of moist deciduous and semi-evergreen leads to seasonal leaf fall (Osman 2013) with a lower proportion of N: P and favoring less mineralization.

This study showed variance with the prominent tree diversity pattern along the altitudes in the Western Ghats, i.e., hump-shaped patterns reported in earlier studies. It was revealed that higher zones of the Mankulam Forest Division have richer forest vegetation and better soil parameters than its lower forest zones. The higher abundance of evergreen tree species with an undisturbed forest ecosystem in the higher altitude zones shows good diversity, while the presence of invasive species due to increasing anthropogenic disturbances threatens this fragile ecosystem. The variation among altitudinal gradients also showed significant changes in vegetation dynamics. The significant properties of these forests are changing rapidly because of the multitude of influencing factors, such as climatic variations, increased demand for forest-based products, and anthropogenic disturbances. Therefore, there is an urgent need to ensure the sustainable working and management of this forest ecosystem and to conduct a detailed analysis of these coupled relationships.

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Estimation of carbon sequestration in pine forest and agroforestry in Bategede Village, Jepara, Central Java, Indonesia

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Abstract. *Nur AAI, Setyawan AD, Kusumaningrum L. 2024. Estimation of carbon sequestration in pine forest and agroforestry in Bategede Village, Jepara, Central Java, Indonesia. Asian J For 8: 63-71.* The escalating rise in atmospheric carbon dioxide levels catalyzes accelerated global warming, profoundly impacting Earth's life. Within this context, forests emerge as crucial guardians of environmental equilibrium by actively absorbing atmospheric carbon dioxide. This process serves as a strategic mitigation measure against the perils of global warming. This study aims to determine the inherent potential of biomass, carbon stock, and carbon sequestration within tree stands and poles existing within pine forests and agroforestry landscapes in Bategede Village, Jepara, Central Java, Indonesia. Additionally, the study undertakes a comparative assessment of the biomass, carbon stock, and carbon sequestration attributes between two distinct forest types: homogeneous pine forests and heterogeneous forests represented by agroforestry systems within Bategede Village. The study was conducted in March in Bategede Village, Nalumsari District. Data was collected through non-destructive methods, focusing on tree stands with a diameter (at breast height) exceeding 20 cm and poles with a diameter (at breast height) ranging from 10 to 20 cm. Robust biomass calculations were computed through predetermined allometric equations. The results of this study show that the biomass, carbon stock, and carbon sequestration were recorded at 407.83 tons/ha, 191.68 tons/ha, and 703.46 tons/ha, respectively, in pine forests. Meanwhile, the biomass, carbon stock, and carbon sequestration values recorded in agroforestry landscapes in Bategede Village were 120.64 tons/ha, 56.41 tons/ha, and 207.01 tons/ha, respectively. The comparative analysis revealed that homogeneous forests, particularly in the tree category, have carbon sequestration values that are sixfold greater than their heterogeneous counterparts. A parallel evaluation within the pole category demonstrated a twofold rise in carbon sequestration within heterogeneous forests compared to their homogeneous counterparts. This difference may be due to the interplay of factors, including variations in stem diameter, species composition, and number of individuals, all cumulatively influencing carbon sequestration within the homogeneous and heterogeneous forest ecosystems.

Keywords: Allometric equation, carbon stock, environmental services, heterogeneous forest, homogenous forest

INTRODUCTION

Anthropogenic activities across various sectors can have a detrimental impact on the environment. Anthropogenic activities originate from various human actions such as industrial processes, transportation, etc., which can serve as sources of pollution to the environment (Sepriani et al. 2014). According to Singh and Purohit (2014), various anthropogenic activities, especially after the Industrial Revolution, have increased greenhouse gas levels in the atmosphere, including carbon dioxide (CO_2). Pirkko and Nyronen (1990) affirm that carbon dioxide emissions contribute more significantly to the greenhouse effect, accounting for approximately 48%. This high concentration of carbon dioxide is attributed to emissions from multiple anthropogenic sources, including industry, transportation, and deforestation. If proper controls are not implemented to curb carbon dioxide emissions, the acceleration of global warming could be exacerbated.

Global warming denotes the rise in the Earth's temperature brought about by the entrapment of solar heat by greenhouse gases in the atmosphere (Sulkam 2020). It has evolved into a pressing environmental concern due to its profound impact on Earth's biota. The ramifications of global warming include climate changes, which can lead to catastrophes such as coastal erosion, melting of ice and glaciers, altered rainfall patterns, and increased disease prevalence. A range of strategies can be adopted to mitigate the consequences of global warming, including measures to regulate atmospheric carbon concentrations through forest conservation.

Forests are paramount natural resources, endowing numerous environmental services that benefit human life. In mitigating accelerated global warming, forests play a crucial role in providing environmental services by helping absorb carbon dioxide from the atmosphere (Anggraeni et al. 2021). Plants facilitate this absorption of carbon dioxide through photosynthesis, whereby carbon is converted into organic carbon within the biomass (Nurfansyah et al. 2019). According to Rizki et al. (2016), trees exhibit the highest growth phase regarding carbon absorption and storage. The diversity of tree species within a forest community inherently influences the extent of carbon absorption capacity (Yastori et al. 2016).

Jepara District in Central Java Province, Indonesia, has witnessed recent industrial development, prompting escalated anthropogenic activities contributing to global warming. A pertinent example is the furniture and carving industry, which entails deforestation for sourcing wood for production. Additionally, the machinery used in the production process generates emissions that further elevate the presence of greenhouse gases in the atmosphere. Bategede Village in Jepara District is characterized by diverse forest areas, offering the potential to contribute to global warming mitigation through carbon sequestration. The biomass quantity and capacity to absorb atmospheric carbon within a specific area are crucial in climate change mitigation (Munir 2017).

The literature presented substantiates the forests' pivotal role in attenuating global warming's acceleration. No published scientific work currently provides a comprehensive report on vegetation inventory and carbon sequestration potential across various forest land covers, particularly in Bategede Village, Nalumsari Sub-district, Jepara District, Indonesia. Information on vegetation's carbon-absorbing capacity is essential for effective area management and conservation efforts. Therefore, this study aims to estimate the carbon sequestration potential of homogeneous pine forests and heterogeneous agroforestry systems within Bategede Village, Nalumsari Sub-district, Jepara District.

MATERIALS AND METHODS

Study area

The study was conducted in Bategede Village, Nalumsari Sub-district, Jepara District, Central Java Province, Indonesia. Bategede Village is geographically located at 6°40'59"S and 110°49'12"E (Figure 1). This study is centered within a pine forest area located in the Wana Sreni Indah, which serves as a representative example of a homogeneous vegetation type. The study also encompasses a forest area with an agroforestry system, serving as a representative instance of heterogeneous vegetation type.

Data collection

Data collection was conducted in March 2023. Estimating carbon sequestration in pine forests and agroforestry areas in Bategede Village involved the calculation of Aboveground Biomass (AGB) and Belowground Biomass (BGB). Biomass calculations were performed using allometric equations, using a non-destructive sampling method. The sampling process involved both tree-level Diameter at Breast Height (DBH) > 20 cm and pole-level (DBH 10 to 20 cm) divisions. The sampling plots were divided into 20 × 20 m^2 for tree vegetation and 10 × 10 m^2 for pole vegetation. A total of 150 plots were used for the research purpose. Essential data, including the names of plant species and the corresponding diameters at breast height, were recorded in the datasheet. Complementary secondary data, such as pertinent allometric equations and specific gravity, were integrated into this study (Table 1).

Data analysis

The data analysis was conducted using a quantitative descriptive approach, where the field data acquired were subjected to calculations from several allometric equations. Subsequently, each species' total aboveground and belowground biomass was multiplied by 0.47 to obtain its carbon stock value (SNI 2011). Therefore, the derived carbon stock outcomes were further multiplied by a constant factor of 3.67 to derive the respective carbon sequestration values. The following are the allometric formulas used to calculate the aboveground biomass:

Conversely, the quantification of belowground biomass was done by applying the root-to-shoot ratio methodology. This approach involves evaluating the relationship between belowground biomass and aboveground biomass. The equation for estimating root biomass, proposed by Cairns et al. (1997), is as follows:

$$RDB = \exp(-1.0587 + 0.8836 \times \ln AGB)$$

Where RDB stands for root biomass or Belowground Biomass (BGB), and AGB represents aboveground biomass.

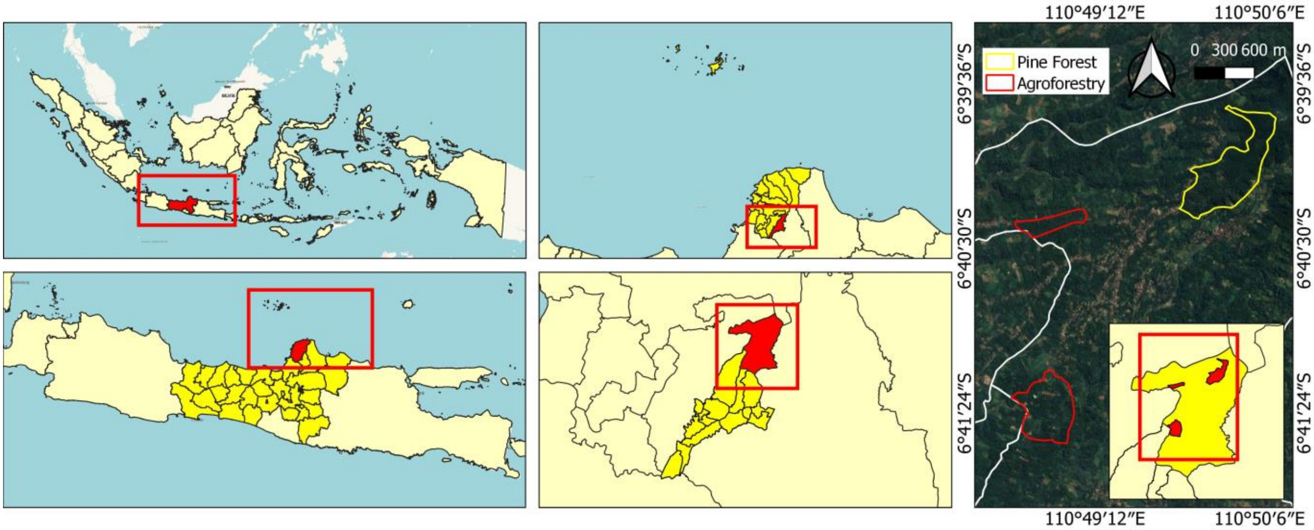

Figure 1. Location of the study area in Bategede Village, Jepara District, Central Java, Indonesia

Table 1. Allometric equations used for calculating Aboveground Biomass (AGB)

Species	Equation	References
Arecaceae	$\exp\{-2.134 + 2.530 \times \ln(D)\}$	Brown (1997)
Artocarpus heterophyllus Lam.	$0.179 \times D^{2.25112}$	Samsu (2019)
Branched tree	$0.11 \times \rho \times D^{2.62}$	Ketterings et al. (2001)
Gmelina arborea Roxb.	$0.153 \times D^{2.217}$	Banaticla et al. (2007)
Leucaena leucocephala (Lam.) de Wit	$0.206 \times D^{2.305}$	Banaticla et al. (2007)
Paraserianthes falcataria (L.) I.C.Nielsen	$0.049 \times D^{2.591}$	Banaticla et al. (2007)
Pinus merkusii Jungh. & de Vriese	$0.0936 \times D^{2.4323}$	Siregar (2007)
Swietenia macrophylla King in Hook.	$0.048 \times D^{2.68}$	Adinugroho and Sidiyasa (2006)
Tectona grandis L.f.	$0.290091 \times D^{2.3}$	Hendri (2001)
Theobroma cacao L.	$0.012088 \times D^{1.98}$	Yuliasmara et al. (2009)

Note: D stands for diameter, and ρ refers to wood density (World Agroforestry 2023)

RESULTS AND DISCUSSION

Pine forest

Pine, a prominent species within plantation forests, plays a crucial role in sustainably rehabilitating land. Apart from their utility in timber and sap production, pine forests also contribute to environmental services by absorbing one of the significant greenhouse gases, viz. carbon dioxide (CO_2) (Polosakan et al. 2014). Based on the findings of this study, the pine forest of Bategede Village was found to harbor a diverse array of tree species, namely pinus (*P. merkusii*), *sengon laut* (*P. faltacaria*), *mahoni* (*S. macrophylla*), *jati* (*T. grandis*), and *salam* (*S. polyanthum*). Meanwhile, at the pole level, the study identified two predominant species, namely *P. merkusii* and *P. faltacaria*.

The pine forests exhibited a tree density of 482 individuals/ha, with an average diameter measuring 35.52 cm. Notably, *P. merkusii* emerged as the prevalent species, with a density of 465 individuals/ha, constituting approximately 96% of the species' populace (Figure 2). This substantial figure highlights the dominance of *P. merkusii* within that area. Therefore, the pine forest qualifies as a homogeneous forest ecosystem, primarily due to the dominance of *P. merkusii*. This is in line with the delineation of a homogeneous forest by Agesti (2018), where a single species constitutes around 80% of the entire population. In this study, the *P. merkusii* species accounted for a remarkable 96% of all the species encountered at the tree level.

The results show that *P. merkusii* had the highest biomass value, including aboveground and belowground biomass, in carbon stock and sequestration values, among other species. This can be attributed to the significantly higher number of *P. merkusii* species than other species. As the predominant species within pine forests, *P. merkusii* demonstrates a higher rate of carbon absorption than other species. This follows the study of Komiyama et al. (2007), who elucidated how dominant species influence the quantum of biomass and carbon storage in an area. The values for aboveground and belowground biomass of *P. merkusii*, carbon stock, and carbon sequestration were 322.29 tons/ha, 50.26 tons/ha, 175.14 tons/ha, and 642.77 tons/ha, respectively (Table 2).

Moreover, at the pole level, the total species density within the pine forest reached 232 ind/ha, where *P. merkusii* was found at 200 ind/ha and 32 ind/ha was *P. falcataria* (Figure 3). The average diameter was about 17.45 cm. This value highlights the prevalence of tree stands compared to pole stands. Notably, *P. merkusii* was also dominant at the pole stands with a species density of *P. merkusii*, which is 200 ind/ha, accounting for 86% of the total species count. In contrast, the density of *P. falcataria* was only 32 ind/ha.

The *P. merkusii* maintained its dominance in the pole category in the study area. This shows the higher value of *P. merkusii* than *sengon laut* or *P. falcataria*. Specifically, the carbon sequestration value achieved by *P. merkusii* in the pole category was 44.2 tons/ha, whereas *P. falcataria* only absorbed carbon dioxide at a rate of 3.59 tons/ha. However, it's noteworthy that the value of carbon sequestration of *P. falcataria* at the pole level exceeded that of the tree level (Table 3). This may be attributed to the greater number of individuals at the pole level than the tree level (Figures 2 and 3).

Table 2. Biomass, carbon stock, and carbon sequestration for tree category in the pine forest

Local name	Scientific name	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
		Above ground	Below ground		
Pinus	*Pinus merkusii* Jungh. & de Vriese	322.29±156.01	50.26±20.76	175.14±83.1	642.77±304.96
Mahoni	*Swietenia macrophylla* King in Hook.	3.95±7.73	0.67±1.29	2.17±2.98	7.97±15.55
Jati	*Tectona grandis* L.f.	0.93±4.47	0.15±0.70	0.51±2.53	1.85±9.27
Sengon Laut	*Paraserianthes falcataria* (L.) I.C.Nielsen	0.78±2.36	0.15±0.44	0.43±1.31	1.59±4.82
Salam	*Syzygium polyanthum* (Wight) Walp.	0.73±2.66	0.13±0.46	0.40±1.47	1.48±5.38

Table 3. Biomass, carbon stock, and carbon sequestration for pole category in the pine forest

Local name	Scientific name	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
		Above ground	Below ground		
Pinus	*Pinus merkusii* Jungh. & de Vriese	21.34±19.30	4.29±3.88	12.04±10.89	44.2±39.98
Sengon Laut	*Paraserianthes falcataria* (L.) I.C.Nielsen	1.71±4.44	0.37±0.95	0.98±2.54	3.59±9.31

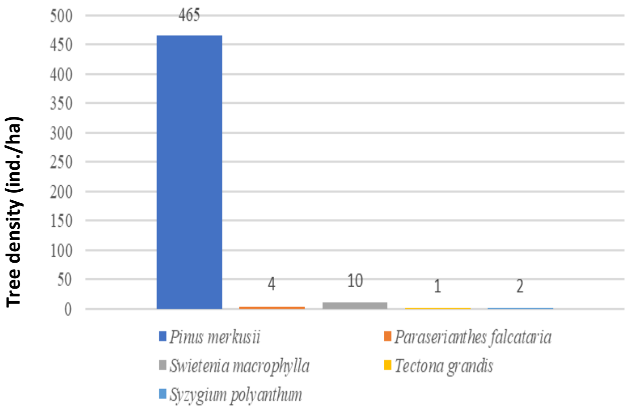

Figure 2. The density of tree species in pine forest

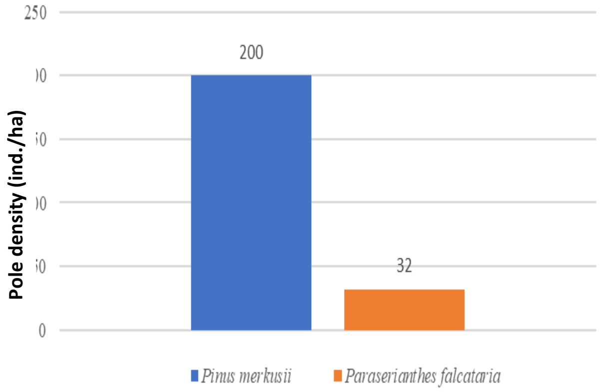

Figure 3. Density of pole species in pine forest

Table 4. Total biomass, carbon stock, and carbon sequestration in the pine forest

Category	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
	Above ground	Below ground		
Tree	328.68	51.44	178.66	655.67
Pole	23.05	4.66	13.02	47.79
Total	407.83		191.68	703.46

Based on the calculations, the tree species in the pine forest had an aboveground and belowground biomass of 328.68 tons/ha and 51.44 tons/ha (Table 4). Therefore, using these biomass values, the carbon stock and carbon dioxide absorption in the pine forest in the tree category was estimated at 655.67 tons/ha. Meanwhile, the pole category had smaller aboveground and belowground biomass values than the tree category. The low value of pole-level biomass compared to trees may be ascribed to the larger tree diameter than the pole. This is in line with the study of (Yamani 2013), who reported an increase in diameter with the increase in the tree's biomass.

The total biomass within the pine forest, as assessed across both tree and pole categories, amounted to 407.83 tons/ha. This biomass value was determined by calculating the total biomass above and below ground or root biomass. Notably, this value surpasses that of the study of Ramadhan et al. (2014), wherein the biomass within Pine Forest Taman Hutan Raya (Tahura) Pocut Meurah Intan across the tree, pole and root categories stood at 117.92 ton/ha. The carbon stock value attributed to the pine forest in Bategede Village was 191.68 tons/ha. According to Table 4, the pine forest in this study demonstrates the capacity to absorb 703.46 tons/ha of carbon. This quantity notably exceeds the study by Syabana et al. (2015) conducted in the pine forest composition of Taman Wisata Alam (TWA) Punti Kayu, where carbon reserves at the tree level were measured at 103.21 tons/ha, and carbon dioxide absorption amounted to 378.79 tons/ha. These differences may arise from variations in diameter and the presence of diverse species. Furthermore, it's important to note that the study by Syabana et al. (2015), exclusively focused on carbon reserves and carbon dioxide absorption within the tree category.

Agroforestry

From an ecological standpoint, agroforestry contributes to the quality of the local ecological conditions (Adinugroho et al. 2013). This contribution is attributed crucial role of vegetation present within agroforestry systems in effectively sequestering carbon within an area. This highlights the vital contribution of agroforestry in mitigating climate change through the absorption of atmospheric CO_2 (Lorenz and Lal 2014). According to Pandey (2002), agroforestry stands out as a superior climate change mitigation option compared to marine and other terrestrial alternatives, given its manifold advantages such as bolstering food security, augmenting income in the agricultural sector, conservation of biological diversity, maintenance of watershed hydrology, and safeguarding soil integrity.

In the Bategede Village, agroforestry emerged as a potent contributor to the absorption of carbon dioxide through its diverse constituent plants. According to Asmi et al. (2013), agroforestry's plant composition usually consists of crops, timber plants, and fruit plants. Noteworthy crops in the Bategede Village agroforestry include *kencur*, galangal, and cassava, besides timber plants like *T. grandis, C. pentandra, P. falcataria,* among others. The fruit-bearing plants, including *A. heterophyllus, M. indica,* and *C. nucifera*, further enrich the agroforestry landscape.

In the context of agroforestry, the tree level density was 158.5 ind/ha, with an average diameter of 30.3 cm. The species with the highest density was *P. falcataria*, 36 ind/ha, followed by *S. macrophylla*, 34 ind/ha. Meanwhile, the species with the lowest density were *A. procera*, *M. foetida*, *M. indica*, *T. indica*, and *S. polyanthum*, each with a 0.5 ind/ha density (Figure 4). The higher the density value, the greater the number of species found. Conversely, the lower the density value, the rarer the species was found in the research location.

Based on Table 5, *C. pentandra* exhibited the highest biomass values above and below ground, surpassing the values of other species, with measurements of 19.56 tons/ha and 3.14 tons/ha, respectively. Furthermore, the findings also indicate that *C. pentandra* had larger carbon stock and carbon sequestration values than other species, specifically 10.67 tons/ha and 39.15 tons/ha, respectively. This was because of the direct influence of biomass values on carbon stock and carbon sequestration metrics. A direct correlation emerged between greater biomass values and augmented carbon stock and sequestration values compared to other species, corroborating prior research findings (Chanan 2012; Manafe et al. 2016). This trend also aligns with the insights shared by Pambudi (2019), who highlighted a positive relationship between biomass and carbon stock values.

The density of poles within the agroforestry system stands at 634 ind/ha, with an average diameter of 14.43 cm. Remarkably, this density exceeded that observed at the tree level within the agroforestry. Compared to trees, the abundant presence of pole-level species suggests an ongoing ecological evolution, as these poles are poised to develop into trees and reshape the agroforestry structure. Among the species, *sengon laut* (*P. falcataria*) has the highest density, reaching 222 ind/ha, accounting for 35% of the total species composition. Sengon laut has a significantly higher value than other species, thus reinstating its prominence at the study site. On the other hand, species such as *mindi* (*M. azedarach*), *pakel* (*M. foetida*), *alpukat* (*P. americana*), *salam* (*Syzygium aromaticum*), and *jambu air* (*Syzygium aqueum*) had the lowest density at 2 ind/ha, indicating their relatively lower prevalence within the studied ecosystem (Figure 5).

According to Suwardi et al. (2013), trees characterized by small diameters, such as poles, are anticipated to contribute to future carbon stocks substantially. This study shows that the pole category, *P. falcataria*, had the highest carbon sequestration value, surpassing other species at 25.92 tons/ha (Table 6). Interestingly, this value is also higher at the tree level (Table 5). This can be attributed to the notably higher number of individuals at the pole level than the tree level. This follows the study by Widyasari and Saharjo (2010); it is evident that poles' density and growth rate play crucial roles in augmenting the potential for carbon sequestration.

Table 5. Estimation of biomass, carbon stock, and carbon sequestration for tree category in agroforestry

Local name	Scientific name	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
		Above ground	Below ground		
Randu	*Ceiba pentandra* (L.) Gaertn.	19.56±25.04	3.14±3.83	10.67±13.57	39.15±49.78
Mahoni	*Swietenia macrophylla* King in Hook.	11.83±15.90	1.93±2.49	6.21±8.64	22.81±31.69
Sengon Laut	*Paraserianthes falcataria* (L.) I.C.Nielsen	6.63±6.17	1.24±1.14	3.70±3.43	13.60±12.60
Jati	*Tectona grandis* L.f.	8.43±18.27	1.33±2.67	4.59±9.84	16.84±36.11
Petai Cina	*Leucaena leucocephala* (Lam.) de Wit	1.99±5.24	0.34±0.89	1.09±2.88	4.02±10.58
Nangka	*Artocarpus heterophyllus* Lam.	1.69±4.23	0.31±0.76	0.94±2.34	3.44±8.60
Waru	*Hibiscus tiliaceus* L.	1.43±3.77	0.26±0.68	0.79±2.09	2.91±7.67
Mindi	*Melia azedarach* L.	1.34±3.01	0.25±0.54	0.75±1.67	2.74±6.13
Durian	*Durio zibethinus* L.	1.28±3.15	0.23±0.56	0.71±1.75	2.61±6.41
Gmelina	*Gmelina arborea* Roxb.	0.95±2.87	0.18±0.54	0.53±1.60	1.95±5.88
Petai	*Parkia speciosa* Hassk.	0.79±2.70	0.14±0.48	0.44±1.94	1.60±5.48
Kelapa	*Cocos nucifera* L.	0.77±2.67	0.13±0.46	0.43±1.47	1.57±5.41
Mangga	*Mangifera indica* L.	0.44±3.11	0.07±0.49	0.24±1.69	0.88±6.21
Jati Londo	*Guazuma ulmifolia* Lam.	0.41±1.69	0.07±0.30	0.23±0.93	0.83±3.43
Weru	*Albizia procera* (Roxb.) Benth.	0.40±2.83	0.06±0.45	0.22±1.54	0.80±5.66
Jengkol	*Archidendron pauciflorum* (Benth.) I.C.Nielsen	0.19±0.94	0.04±0.18	0.11±0.53	0.39±1.93
Salam	*Syzygium polyanthum* (Wight) Walp.	0.12±0.86	0.02±0.16	0.07±0.48	0.25±1.75
Pakel	*Mangifera foetida* Lour.	0.09±0.62	0.02±0.12	0.05±0.35	0.18±1.27
Asam Jawa	*Tamarindus indica* L.	0.003±0.02	0.001±0.01	0.002±0.01	0.01±0.05

Table 6. Biomass estimation, carbon stock, and carbon sequestration for poles category in agroforestry

Local name	Scientific name	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
		Above ground	Below ground		
Sengon Laut	*Paraserianthes falcataria* (L.) I.C.Nielsen	12.19±8.93	2.84±2.61	7.06±5.23	25.92±19.19
Jati	*Tectona grandis* L.f.	6.98±14.30	1.33±2.72	3.91±8.00	14.33±29.35
Nangka	*Artocarpus heterophyllus* Lam.	4.81±6.91	0.99±1.40	2.73±3.91	10.00±14.33
Mahoni	*Swietenia macrophylla* King in Hook.	4.22±5.45	0.89±1.13	2.40±3.09	8.81±11.34
Mangga	*Mangifera indica* L.	3.67±5.56	0.76±1.11	2.08±3.09	7.65±11.33
Jengkol	*Archidendron pauciflorum* (Benth.) I.C.Nielsen	3.40±5.29	0.76±1.10	1.94±3.00	7.13±11.03
Waru	*Hibiscus tiliaceus* L.	1.57±3.54	0.34±0.75	0.90±2.02	3.29±7.40
Petai	*Parkia speciosa* Hassk.	1.36±4.30	0.28±0.87	0.77±2.43	2.84±8.93
Gmelina	*Gmelina arborea* Roxb.	1.07±2.72	0.23±0.57	0.61±1.55	2.24±5.68
Petai Cina	*Leucaena leucocephala* (Lam.) de Wit	0.81±6.39	0.16±0.64	0.45±1.84	1.66±6.75
Rambutan	*Nephelium lappaceum* L.	0.75±2.18	0.16±0.46	0.43±1.24	1.57±4.54
Durian	*Durio zibethinus* L.	0.74±2.21	0.16±0.46	0.42±1.25	1.54±4.61
Jati Londo	*Guazuma ulmifolia* Lam.	0.04±2.28	0.08±0.45	0.23±1.28	0.85±4.70
Sirsak	*Annona muricata* L.	0.29±1.26	0.06±0.27	0.17±0.72	0.62±2.64
Randu	*Ceiba pentandra* (L.) Gaertn.	0.19±0.72	0.04±0.16	0.11±0.42	0.40±1.53
Alpukat	*Persea americana* Mill.	0.17±1.07	0.03±0.22	0.09±0.61	0.34±2.22
Salam	*Syzygium polyanthum* (Wight) Walp.	0.13±0.62	0.03±0.14	0.07±0.36	0.27±1.32
Mindi	*Melia azedarach* L.	0.07±0.53	0.02±0.01	0.04±0.31	0.16±1.12
Pakel	*Mangifera foetida* Lour.	0.07±0.49	0.02±0.11	0.04±0.29	0.15±1.05

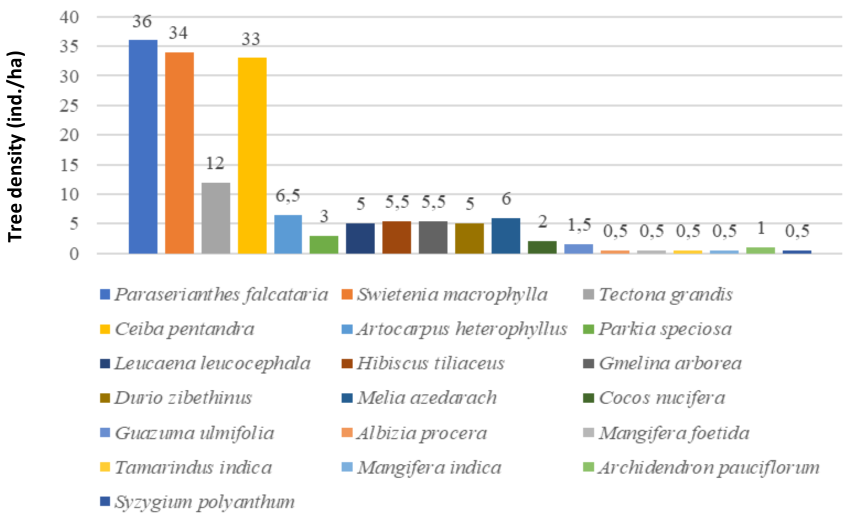

Figure 4. Density of tree species in agroforestry

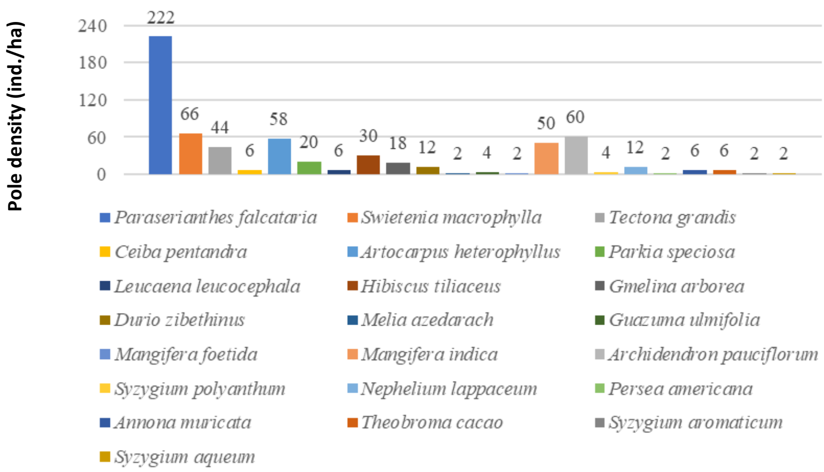

Figure 5. Density of pole species in agroforestry

Table 7. Estimation of biomass, carbon stock, and carbon sequestration in agroforestry

Category	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
	Above ground	Below ground		
Tree	58.34	9.85	31.76	116.07
Pole	43.23	9.22	24.65	90.46
Total	120.64		56.41	207.01

In the agroforestry within Bategede Village, the combined biomass value for trees and pole categories amounts to 120.64 tons/ha. Correspondingly, the carbon stock had a value of 56.41 tons/ha. This value is consistent with the findings of Murthy et al. (2013), who asserted that Southeast Asian agroforestry systems have the potential to sequester carbon within the range of 12 to 228 MgC/ha. Moreover, the established carbon stock value in the agroforestry framework of West Java is documented to span from 37 to 108Mg/ha, as indicated by Siarudin et al. (2021). Notably, the carbon stock value in the agroforestry system of Bategede Village is also comparable to the study by Malau et al. (2013), which identified carbon stock values of 58.438 tons/ha, 63.005 tons/ha, and 56.76 tons/ha in agroforestry stands within Sei Binga Sub-district, Bahorok Sub-district, and Wampu Sub-district, respectively. The dynamic spectrum of carbon stock across agroforestry landscapes was further evidenced by Paembonan et al. (2019) observations in Toraja, South Sulawesi, where a carbon stock value of 79.246 tons/ha was recorded. Moreover, the projected potential of agroforestry at the tree and pole level in Bategede Village to absorb carbon could be established at 207.01 tons/ha (Table 7).

Pine forest (homogenous forest) vs agroforestry (heterogenous forest)

Forests offer invaluable environmental services, including their role as carbon sinks. Within this intricate ecosystem, the vegetation takes part in sequestering atmospheric CO_2 through the process of photosynthesis. Acknowledging that the carbon-absorbing potential varies among distinct plant species is important. As a result, the mosaic of plant diversity within a forest ecosystem increases the divergent capacities for carbon dioxide assimilation. Azzahra et al. (2020) findings show that the carbon content variations are intricately linked to specific plant species. That study explored the carbon dioxide absorption capabilities at both tree and pole levels, comparing these dynamics within homogeneous and heterogeneous forests.

Figure 6.A. illustrates a clear distinction between tree-level metrics within homogeneous forests, primarily pine forests, and their counterparts in heterogeneous or agroforestry forests; homogeneous forests exhibited significantly higher values in comparison. Biomass, carbon stock, and CO_2 absorption values in homogeneous forests stand at 380.12 tons/ha, 178.66 tons/ha, and 655.67 tons/ha, respectively. On the contrary, within heterogeneous forests, the corresponding values for carbon stock biomass and carbon sequestration were 68.19 tons/ha, 31.76 tons/ha, and 116.55 tons/ha, respectively. Notably, a conspicuous sixfold difference surfaced in carbon absorption, favoring homogeneous forests. This disparity increases due to the higher number of individual trees present in pine forests, resulting in a larger diameter distribution compared to the agroforestry system.

At the pole level (Figure 6.B), pine forests exhibited comparatively lower biomass, carbon stock, and carbon dioxide absorption values than agroforestry, quantified at 27.71 tons/ha, 13.02 tons/ha, and 47.79 tons/ha, respectively. Meanwhile, agroforestry had a biomass value of 52.45 tons/ha, a carbon stock of 24.65 tons/ha, and a carbon dioxide absorption of 90.46 tons/ha. This value notably surged to nearly twice that of biomass, carbon stock, and carbon dioxide absorption observed at the pole level within pine forests. The variance in carbon sequestration values can be attributed to several factors, including stem diameter, species type, and population density. A greater stem diameter corresponds to a greater biomass value within a stand (Hairiah and Rahayu 2007; Yamani 2013; Manafe et al. 2016; Azizah et al. 2019).

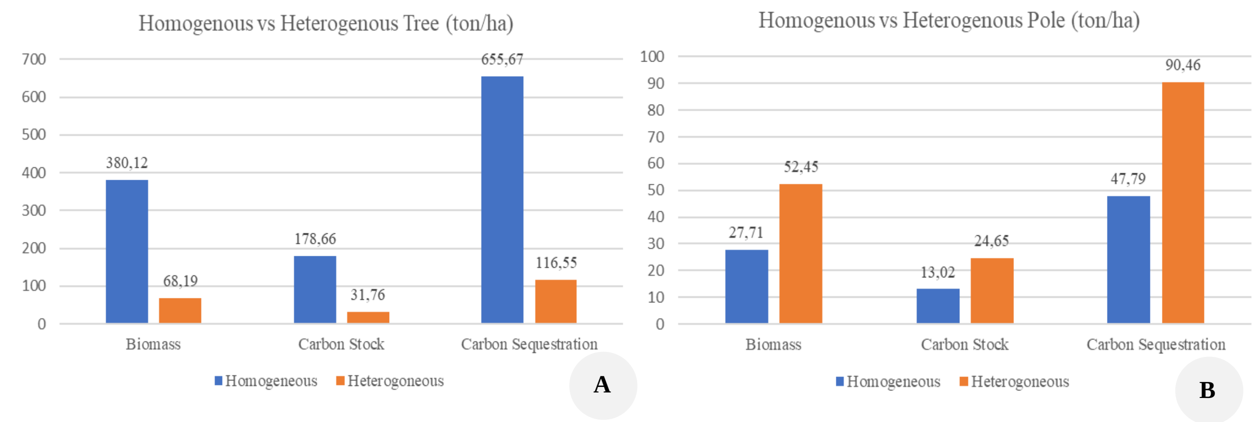

Figure 6. Comparison of biomass, carbon stock and carbon sequestration at: A. The tree level, and B. The pole level

Besides diameter, the species type also significantly contributes to carbon absorption potential (Suwardi et al. 2013; Zulkarnaen 2020). Each species exhibits distinct specific gravity or allometric formulas, resulting in distinct biomass values for each species, thereby influencing the total carbon absorption estimate. According to the study by Adinugroho et al. (2013), the plant's categorization shapes carbon reserves within a stand due to the variations of wood-specific gravity values inherent to each plant species. Furthermore, the number of individuals further impacts the biomass value within a designated area. This is in line with the findings of Hartoyo et al. (2022), which highlight the significant influence of species population on the carbon reserves quantification.

In conclusion, the present study has yielded notable findings regarding biomass, carbon stock, and carbon sequestration values within the pine forests, amounting to 407.83 tons/ha, 191.68 tons/ha, and 703.46 tons/ha, respectively. Conversely, the agroforestry system in Bategede Village showed distinct figures within biomass, carbon stock, and carbon sequestration, reaching 120.64 tons/ha, 56.41 tons/ha, and 207.01 tons/ha, respectively. The comparisons highlight that the carbon sequestration value within the homogeneous forest, specifically within the tree category of Bategede Village, significantly surpasses its heterogeneous counterparts, exhibiting a remarkable sixfold increment. Notably, the pole category in the heterogeneous forest demonstrates a twofold augmentation in carbon sequestration compared to the homogeneous forest. This difference may be attributed to variations in stem diameter, species composition and population density, factors that influence the carbon sequestration dynamics within these forests.

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Avenue tree diversity in the urban area of Coimbatore District, Tamil Nadu, India

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Abstract. *Aravindhan V, Jeevith S, Aruna R, Ramachandran VS, Gopal G. 2024. Avenue tree diversity in the urban area of Coimbatore District, Tamil Nadu, India. Asian J For 8: 72-80.* The flowering plant is the major natural source of human companion with biodiversity in the whole plant kingdom. The present study aimed to determine the arborescent plant species of an urban stretch in selected highway routes of Coimbatore District, Tamil Nadu, India. The present investigation is based on the plant's flowering type, economic uses, and their role in the ecosystem. The current survey recorded the arboreal species and found that 107 species belonging to 83 genera and 35 families are listed. The dominant families are the Fabaceae, Bignoniaceae, Meliaceae, Moraceae, Rutaceae, Malvaceae, Myrtaceae, and Sapindaceae. Among the 107 taxa, 62 are found to be native species, and 45 are introduced. The general use category of avenue trees was analyzed as ornamental plants (23%), medicinal plants (21%), timber plants (14%), pollution-reducing plants (14%), pollen/nectar-providing plants (10%), edible plants (8%), frugivory (6%) and toxic (4%). Considering the rapidly changing urban land use in Coimbatore, a sub-urban area, much attention should be paid towards creating tree islands by planting more native trees, which would help reduce dust pollution and air pollution, produce oxygen and consume carbon dioxide-free of cost, and improve wildlife. Also, this study presented an updated checklist of avenue trees in the Coimbatore urban area.

Keywords: Air pollution, remnant biodiversity, tree islands, urban greening

INTRODUCTION

Vegetation plays an aesthetic link between man and the environment. Plants enhance the quality of the environment by influencing life-supporting systems (Shukla and Chandel 1972). The trees are considered nature's air conditioners and reduce annual cooling energy by 10% to 50 % and electricity by 23% in California (Simpson and Pherson 1996). Vegetation plays an effective role in the urban environment, supporting many fundamental issues, viz., hydrological cycles, nutrient cycles, and gas balance. So, the above all play an essential role in function as a whole.

In recent days, most of the vegetation covers have been severely affected by various human-induced activities. This increased CO_2 accumulation in the atmosphere, ultimately increasing global warming worldwide. This kind of change severely altered many plant species distribution, composition, genetic structure and even extinction of many useful plants (Chandra and Joshi 2002). Species diversity is an important criterion for any vegetation study (Dattaraja 1992). Species diversity is the number and variety of species found in an urban area in a region (Sharma 1975).

The tree, present along the roadside, is known as the avenue tree, including the city and highway. These trees maintain a healthy environment, reduce pollution levels, and increase the greenery and beauty of the place. Avenue trees are directly connected with biodiversity. It plays a dynamic role in maintaining the ecological equilibrium (Nazaneen et al. 2015; Jeevith and Manjunath 2023). These trees play a vital role in the maintenance of the ecosystem and provide natural, social, and physiological services while balancing nature compositions and enhancing air quality (Smith 1981). Presently, the world faces high environmental problems that ultimately disturb the ecosystem. The unornamented reasons behind global warming are floods, droughts, toxic gases, etc.

Every tree plays multiple biodiversity functions (Kohli et al. 1998). In recent years, carbon dioxide acceleration in urban cities has been directly connected with population and amplifies vehicular traffic followed by industrial pollution. Avenue trees protect the environment from climate change, water conservation, attracting biodiversity, reducing carbon levels and other pollutants. The reason behind planting avenue trees in cities and along the roadsides is that we believe that no road or street is dressed or furnished until it has been planted to furnish shade, frame vistas of outlying beauty, and prevent natural calamities.

India is witnessing towering levels of air pollution and a considerable population of tree species were felled due to construction, industrialization, and urbanization development (Tejashri and Nandikar 2012; Prakash et al. 2020). The purposes of avenue trees in the cities are mainly ornamental, shade, aesthetic, and medicinally valuable. Planting wild and exotic trees in urban landscapes has succeeded in many parts of the world. The homogenous stand of the plants never fulfils the functions mentioned above in a given area, and species diverseness not only renders the above needs as well as to withstand for the long run. Therefore, species diversity and their proportion availability in a given area are highly needed to manage urban greening better.

Although vast bio-geographical areas are effectively preserved by various levels of policies and intensive research studies, microenvironments such as avenue trees and social forestry were less attempted for research. But these micro-environment's role in high carbon polluted cities is remarkable. Recent plant explorations in the Coimbatore district revealed plant diversity changes in various urban and forest landscapes. In this context, the present study attempted to exhibit the need to establish avenue trees in the urban area in selected highway routes of Coimbatore City, where the avenue trees are highly warranted to absorb the pollution. Hence, the present study aimed to provide information about avenue tree diversity in the region.

MATERIALS AND METHODS

Study area

Coimbatore is an inland district of the southern part of the Indian Peninsula, elongates from north to south between longitude 76° 39' and 77°56' E, latitude 10°12' and 11°57' N (Figure 1). Coimbatore region played a prominent role in the Second Poligar War in 1801; it was later established as the capital of the newly formed Coimbatore District in 1804. In 1866, the district was accorded municipality status with the first chairman, Mr. Robert Stanes. The district takes pride in abundant varieties of industrialization, once ruled by the Sangam Cheras. After several decades, the district was developed with textiles, industrial and commercial sectors, educational and research institutions, information technology, healthcare, eco-parks, etc. In recent years, the Coimbatore City extent of the area around 15,602 sq km. The urban area has many shopping complexes, residential areas, hospitals, etc. The population of Coimbatore urban has nearly growth rate of 46.25% with 274.04 sq km. The district's soil is chiefly red sand and gravel with a moderate area of red loam, black loam, or sometimes black clay. During the study period, the temperature was maximum (31°C) in September and minimum (17°C) in December.

Data collection

The extensive survey was carried out from 2018 to 2022 and was performed on four different highway routes in the urban environment of the Coimbatore District (Figure 1). The data on avenue trees along the highways of Narasimanayakanpalayam to Kavundapalayam (10 km), Thudiyalur, Coimbatore (North) was selected, which is a small portion and developing urban area of Coimbatore city, followed by Gandhipuram to Saravanampatti (8 km), Lakshmi Mills to Neelambur (12 km), and Ukkadam to Sulur (19 km). The data on avenue plants, mainly tree species, were collected from road/transect surveys through selected routes. Only observation and field notes were taken during the study, and some typical trees with phenology flowering and fruiting were photographed for identification and future reference.

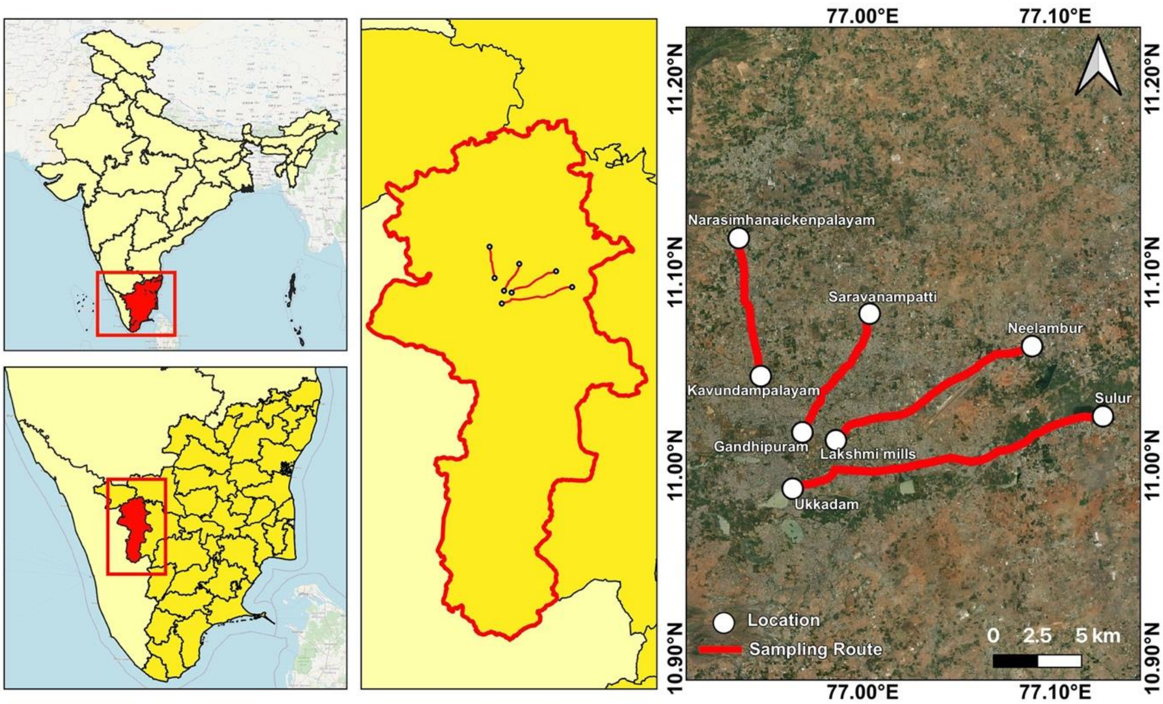

Figure 1. Map showing the selected routes in Coimbatore District, Tamil Nadu, India

Data analysis

With the help of the collected samples (twigs of the plant with flowers and fruits) along with periodic documentation, the avenue trees of the study area were identified for their taxonomic position following Gamble and Fischer (1956), Mathew (1983), and Chandrabose and Nair (1988). Botanical nomenclature and classification systems were used according to APG-IV and WFO (https://www.worldfloraonline.org/). A total number of tree species was noted, and of these, three dominant tree species were recorded based on their occurrence. Habitat preference, status, and trend of each tree species were categorized and tabulated.

RESULTS AND DISCUSSION

The avenue trees were recorded in the present study and documented about 107 plant species belonging to 83 genera and 35 families. The complete list of the documented avenue trees is shown in Table 1. The most represented families were Fabaceae, Bignoniaceae, Meliaceae, Moraceae, Rutaceae, Malvaceae, Myrtaceae, Sapindaceae, Apocynaceae Arecaceae, Rubiaceae, and Sapotaceae. The dominant family, Fabaceae, listed 17 genera and 25 species, followed by Bignoniaceae, recorded 7 genera and 8 species; Meliaceae, 5 genera and 7 species, Moraceae 2 genera and 5 species; Rutaceae with 4 genera and 4 species; Malvaceae, Myrtaceae, and Sapindaceae with 3 genera and 4 species each. Family Apocynaceae, Arecaceae, Rubiaceae, and Sapotaceae with 3 genera and 3 species, respectively. Annonaceae, Capparaceae, and Simaroubaceae reported 2 genera and 3 species, respectively, and the family Combretaceae listed one genus and 3 species; one species represented sixteen families.

Information on the plant families with a high number of genera and species is presented in Table 1. These avenue trees can be planted/cultivated in the home or backyard gardens, growing along urban roads or irrigation canals and on lakes, ponds, etc. Based on the utilization, the avenue trees are categorised under Timber Plants (TP), Medicinal Plants (MP), Edible Plants (EP), Pollen/Nectar Providing plants (PP), pollution-reducing plants (PR), Ornamental Plants (OP), Frugivory (Fr) and Toxic (Tc) were given in Figure 2. Selected avenue trees of flowers and fruits were given as plates (Figures 3 and 4).

The most important timber-yielding plants are *Albizia amara*, *Azadirachta indica*, *Ficus recemosa*, *Gmelina arborea*, *Mangifera indica*, *Morinda pubescens*, *Peltophorum pterocarpum*, *Pithocellobium dulce*, *Swietenia macrophylla*, *Terminalia arjuna*, *T. bellirica* and *Tamarindus indica*. *Melia dubia* and *Pterocarpus indicus* are used in plywood industries, whereas *G. arborea* is used in making pulp in paper industries. Some of the important medicinal plants are *Aegle marmelos*, *Annona muricata*, *A. indica*, *Calophyllum inophyllum*, *Cassia fistula*, *Ficus racemosa*, *M. indica*, *Mimusops elengi*, *Oroxylum indicum*, *Pongamia pinnata*, *P. indicus*, *Syzygium cumini*, *T. arjuna*, *T. bellirica* and *Thespesia populnea*.

It is interesting to know that some plants are edible and birds utilize them widely. They are *A. indica*, *C. inophyllum*, *Ficus benghalensis*, *F. recemosa*, *F. religiosa*, *M. indica*, *M. elengi*, *Muntingia calabura*, *P. dulce*, *S. cumini* and *Terminalia catappa*. These fruits and value-added products like dry materials of flowers, fruits, leaves, barks, seeds, and roots are commercially sold in traditional shops and by herbal medical practitioners. Some of the plants provide nectar/pollen to the insects, and some of them are *A. amara*, *C. inophyllum*, *C. fistula*, *G. arborea*, *Melaleuca citrine*, *Millingtonia hortensis*, *M. elengi*, *P. pinnata*, *Morinda citrifolia*, *M. calabura*, *P. pterocarpum*, *P. dulce*, *S. cumini* and *T. catappa*.

Moreover, plants bearing tannins and latex are capable of absorbing more carbon dioxide and helping reduce pollution. They are *C. inophyllum*, *Cascabela thevetia*, *F. benghalensis*, *Ficus benjamina*, *F. racemosa*, *F. religiosa*, *M. indica*, *Monoon longifolium*, *P. indicus*, *S. cumini*, *Simarouba glauca*, and *T. catappa*. Although many trees are planted as avenue trees, they provide shelter and aesthetic value and serve as ornamental trees. They are: *C. fistula*, *Cordia sebestena*, *Callistemon lanceolatus*, *Adenanthera pavonina*, *Bauhinia purpurea*, *Filicipium descipiens*, *F. benjamina*, *Delonix regia*, *Jacaranda mimosifolia*, *P. pterocarpum*, *Pisonia grandis*, *Plumeria rubra*, *M. longifolium* and *Tecoma stans*.

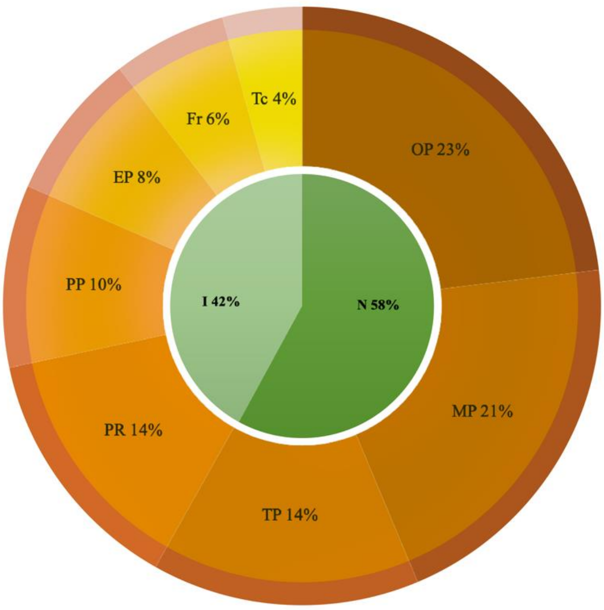

Figure 2. A general use of avenue trees (N-Native, I-Introduced). TP: Timber Plant, MP: Medicinal Plant, EP: Edible Plant, PP: Pollen Producing Plant, PR: Pollen Reducing Plant, OP: Ornamental Plant, Fr: Frugivory, Tc: Toxic

Table 1. List of avenue trees in the urban area, Coimbatore district, Tamil Nadu, India

Scientific name	**N/I**	**Family**	**TP**	**MP**	**EP**	**PP**	**PR**	**OP**	**Fr**	**Tc**
Adenanthera pavonina L.	🌳	Fabaceae						✢		
Aegle marmelos (L.) Corrêa	🌳	Rutaceae		✢	✢			✢		✢
Ailanthus excelsa Roxb.	🌳	Simaroubaceae	✢	✢				✢		
Ailanthus triphysa (Dennst.) Alston	🌳	Simaroubaceae	✢	✢				✢		
Alangium salviifolium (L.f.) Wangerin	🌳	Cornaceae		✢			✢	✢	✢	
Albizia amara (Roxb.) Boivin	🌳	Fabaceae		✢		✢		✢		✢
Alstonia scholaris (L.) R.Br.	🌳	Apocynaceae		✢		✢	✢	✢		✢
Annona muricata L.	🌲	Annonaceae		✢	✢		✢	✢		
Annona squamosa L.	🌲	Annonaceae		✢	✢		✢	✢		
Araucaria heterophylla (Salisb.) Franco	🌲	Araucariaceae					✢	✢		
Areca catechu L.	🌲	Arecaceae	✢	✢	✢		✢	✢		
Artocarpus altilis (Parkinson) Fosberg	🌲	Moraceae		✢	✢			✢		
Azadirachta indica A.Juss.	🌲	Meliaceae	✢	✢	✢				✢	
Bauhinia purpurea L.	🌳	Fabaceae						✢		
Bauhinia racemosa Lam.	🌳	Fabaceae		✢				✢		
Bauhinia tomentosa L.	🌲	Fabaceae		✢				✢		
Bauhinia variegata L.	🌳	Fabaceae		✢				✢		
Bergera koenigii L.	🌳	Rutaceae		✢	✢	✢	✢	✢	✢	
Borassus flabellifer L.	🌳	Arecaceae	✢	✢	✢		✢	✢		
Calophyllum inophyllum L.	🌳	Clusiaceae	✢	✢		✢	✢		✢	
Capparis divaricata L.f.	🌳	Capparaceae		✢			✢	✢		
Carica papaya L.	🌲	Caricaceae		✢	✢		✢	✢	✢	
Cascabela thevetia (L.) Lippold	🌳	Apocynaceae					✢			✢
Cassia fistula L.	🌳	Fabaceae		✢	✢	✢		✢		✢
Cassia grandis L.f.	🌲	Fabaceae				✢				
Casuarina equisetifolia L.	🌳	Casuarinaceae	✢					✢		
Chukrasia tabularis A.Juss.	🌳	Meliaceae	✢	✢				✢		
Cocos nucifera L.	🌲	Arecaceae	✢	✢	✢			✢		
Cordia dichotoma G.Forst.	🌳	Boraginaceae						✢		
Cordia sebestena L.	🌲	Boraginaceae						✢		
Couroupita guianensis Aubl.	🌲	Lecythidaceae	✢	✢			✢	✢		
Crateva adansonii DC.	🌳	Capparaceae		✢						
Crateva religiosa G.Forst.	🌳	Capparaceae		✢						
Dalbergia lanceolaria L.f.	🌳	Fabaceae	✢	✢		✢				
Dalbergia latifolia Roxb.	🌳	Fabaceae	✢			✢				
Dalbergia sissoo Roxb. ex DC.	🌳	Fabaceae						✢		
Delonix elata (L.) Gamble	🌲	Fabaceae	✢			✢		✢		
Delonix regia (Bojer ex Hook.) Raf.	🌲	Fabaceae		✢	✢			✢		
Dichrostachys cinerea (L.) Wight & Arn.	🌳	Fabaceae		✢		✢				
Erythrina variegata L.	🌳	Fabaceae		✢		✢	✢	✢		
Eucalyptus tereticornis Sm.	🌲	Myrtaceae	✢	✢				✢		✢
Ficus benghalensis L.	🌳	Moraceae	✢		✢		✢		✢	
Ficus benjamina L.	🌲	Moraceae					✢	✢		
Ficus racemosa L.	🌳	Moraceae	✢	✢	✢		✢		✢	
Ficus religiosa L.	🌳	Moraceae					✢		✢	
Filicium decipiens (Wight. & Arn.) Thw.	🌳	Sapindaceae						✢		
Gmelina arborea Roxb. ex Sm.	🌳	Lamiaceae	✢			✢			✢	
Hibiscus tiliaceus L.	🌳	Malvaceae						✢		
Holoptelea integrifolia (Roxb.) Planch.	🌳	Ulmaceae	✢		✢		✢			✢
Jacaranda mimosifolia D.Don	🌲	Bignoniaceae		✢				✢		
Kigelia africana (Lam.) Benth.	🌲	Bignoniaceae					✢	✢		
Lagerstroemia speciosa (L.) Pers.	🌲	Lythraceae						✢		
Leucaena leucocephala (Lam.) de Wit	🌲	Fabaceae	✢	✢		✢				
Limonia acidissima L.	🌳	Rutaceae		✢	✢		✢	✢		

Madhuca longifolia (L.) J.F.Macbr.	N	Sapotaceae	✢	✢				✢		
Magnolia champaca (L.) Baill. ex Pierre	N	Magnoliaceae	✢	✢			✢	✢	✢	
Majidea zanguebarica Kirk ex Oliv.	I	Sapindaceae						✢		
Mangifera indica L.	I	Anacardiaceae	✢					✢		
Manilkara zapota (L.) P.Royen	I	Sapotaceae		✢	✢		✢	✢	✢	✢
Melaleuca citrina (Curtis) Dum.Cours.	I	Myrtaceae				✢		✢		
Melia azedarach L.	N	Meliaceae	✢			✢		✢		✢
Melia dubia Cav.	N	Meliaceae		✢		✢		✢	✢	
Millingtonia hortensis L.f.	I	Bignoniaceae	✢	✢		✢		✢		
Mimusops elengi L.	N	Sapotaceae				✢			✢	
Mitragyna parvifolia (Roxb.) Korth.	N	Rubiaceae	✢	✢						
Monoon longifolium (Sonn.) B.Xue & R.M.K.Saunders	N	Annonaceae	✢				✢	✢		
Morinda citrifolia L.	N	Rubiaceae		✢				✢		
Moringa oleifera Lam.	N	Moringaceae	✢	✢	✢			✢		✢
Muntingia calabura L.	I	Tiliaceae		✢				✢		
Murraya paniculata (L.) Jack	N	Rutaceae		✢		✢	✢	✢	✢	✢
Neolamarckia cadamba (Roxb.) Bosser	N	Rubiaceae	✢	✢			✢	✢		
Oroxylum indicum (L.) Kurz	N	Bignoniaceae	✢	✢			✢			
Parkinsonia aculeata L.	I	Fabaceae					✢	✢		
Peltophorum pterocarpum (DC.) Backer ex K.Heyne	I	Fabaceae	✢			✢		✢		
Phyllanthus acidus (L.) Skeels	I	Phyllanthaceae		✢	✢					
Phyllanthus emblica L.	N	Phyllanthaceae		✢	✢			✢		
Pisonia grandis R.Br.	N	Nyctaginaceae		✢		✢				
Pithecellobium dulce (Roxb.) Benth.	I	Mimosaceae	✢	✢			✢		✢	
Plumeria rubra L.	I	Apocynaceae						✢		
Pongamia pinnata (L.) Pierre	N	Fabaceae					✢	✢		
Pterocarpus indicus Willd.	I	Fabaceae						✢	✢	
Pterocarpus marsupium Roxb.	I	Fabaceae	✢	✢		✢	✢	✢		
Samanea saman (Jacq.) Merr.	I	Fabaceae	✢			✢				
Santalum album L.	I	Santalaceae	✢	✢			✢	✢	✢	
Sapindus emarginatus Vahl	N	Sapindaceae	✢					✢	✢	
Sapindus trifoliatus L.	N	Sapindaceae	✢				✢			
Saraca asoca (Roxb.) W.J.de Wilde	N	Fabaceae		✢		✢	✢	✢		
Simarouba glauca DC.	I	Simaroubaceae	✢	✢				✢		
Spathodea campanulata P.Beauv.	I	Bignoniaceae	✢	✢	✢	✢	✢	✢		
Sterculia foetida L.	N	Malvaceae		✢						✢
Sterculia guttata Roxb.	N	Malvaceae		✢						
Swietenia macrophylla King	I	Meliaceae	✢	✢						
Swietenia mahagoni (L.) Jacq.	I	Meliaceae	✢				✢	✢		
Syzygium cumini (L.) Skeels	I	Myrtaceae	✢	✢	✢	✢	✢		✢	
Syzygium jambos (L.) Alston	I	Myrtaceae	✢	✢	✢	✢	✢	✢	✢	
Tabebuia aurea (Silva Manso) Benth. & Hook.f. ex S.Moore	I	Bignoniaceae				✢	✢	✢		
Tabebuia rosea (Bertol.) DC.	I	Bignoniaceae				✢	✢	✢		
Tabernaemontana divaricata (L.) R.Br. ex Roem. & Schult.	N	Apocynaceae		✢		✢		✢		
Tamarindus indica L.	I	Fabaceae	✢	✢	✢		✢	✢		
Tecoma stans (L.) Juss. ex Kunth	I	Bignoniaceae		✢		✢	✢	✢		
Tectona grandis L.f.	N	Lamiaceae	✢			✢	✢	✢		
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	N	Combretaceae		✢	✢					
Terminalia bellirica (Gaertn.) Roxb.	N	Combretaceae	✢	✢						✢
Terminalia catappa L.	N	Combretaceae	✢	✢	✢					
Thespesia populnea (L.) Sol. ex Corrêa	N	Malvaceae					✢			
Toona ciliata M.Roem.	N	Meliaceae	✢					✢		
Vachellia leucophloea (Roxb.) Maslin, Seigler & Ebinger	N	Fabaceae		✢						✢

Note: N: Native tree (N), I: Introduced (I). TP: Timber Plant, MP: Medicinal Plant, EP: Edible Plant, PP: Pollen Producing Plant, PR: Pollen Reducing Plant, OP: Ornamental Plant, Fr: Frugivory, Tc: Toxic (Thothathri et al. 1985)

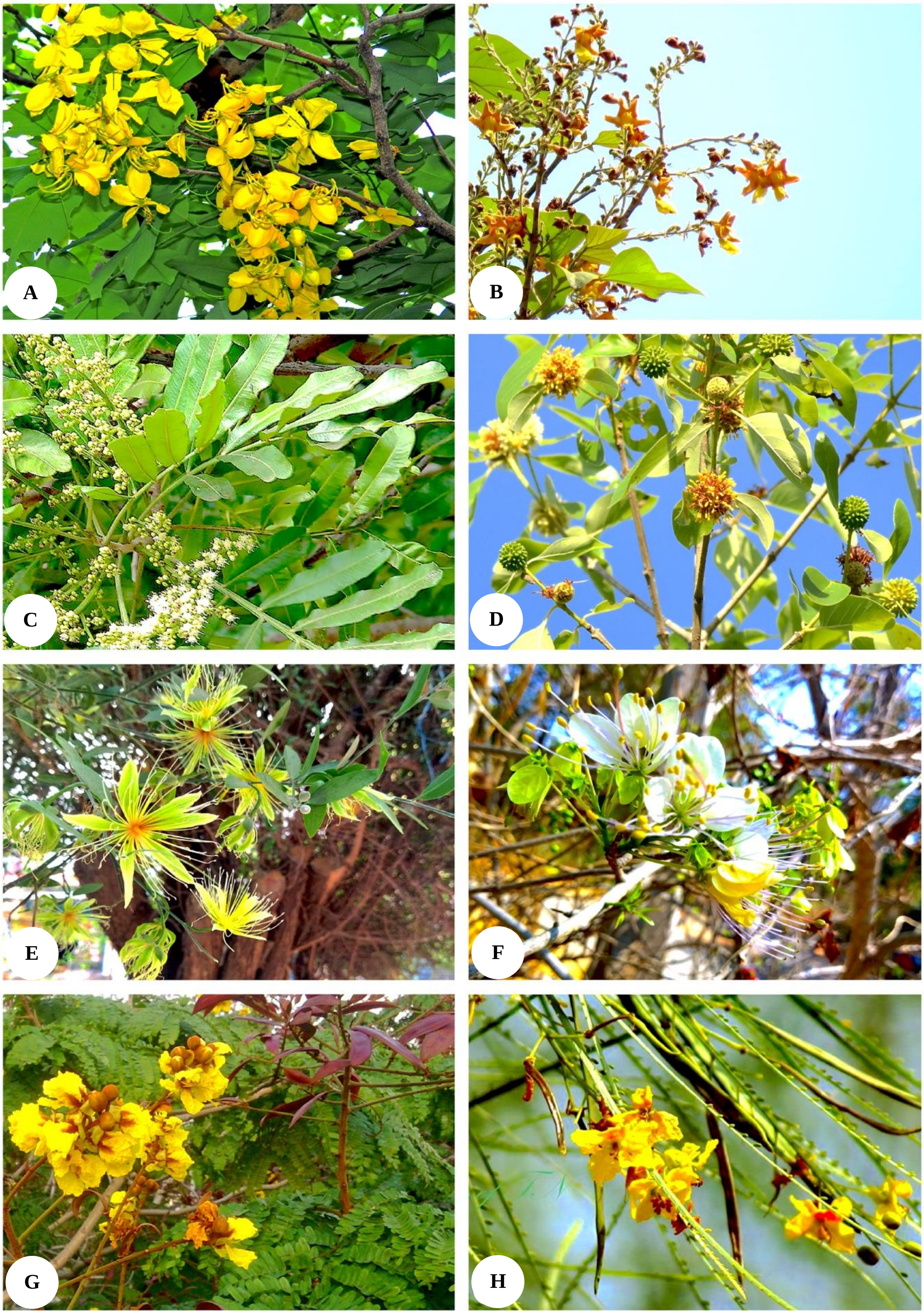

Figure 3. Selected flowers of avenue trees from the study area: A. *Cassia fistula* L. B. *Gmelina arborea* Roxb. ex Sm. C. *Filicium decipiens* (Wight. & Arn.) Thw. D. *Mitragyna parvifolia* (Roxb.) Korth. E. *Capparis divaricata* L.f. F. *Crateva adansonii* DC. G. *Peltophorum pterocarpum* (DC.) Backer ex K.Heyne H. *Parkinsonia aculeata* L.

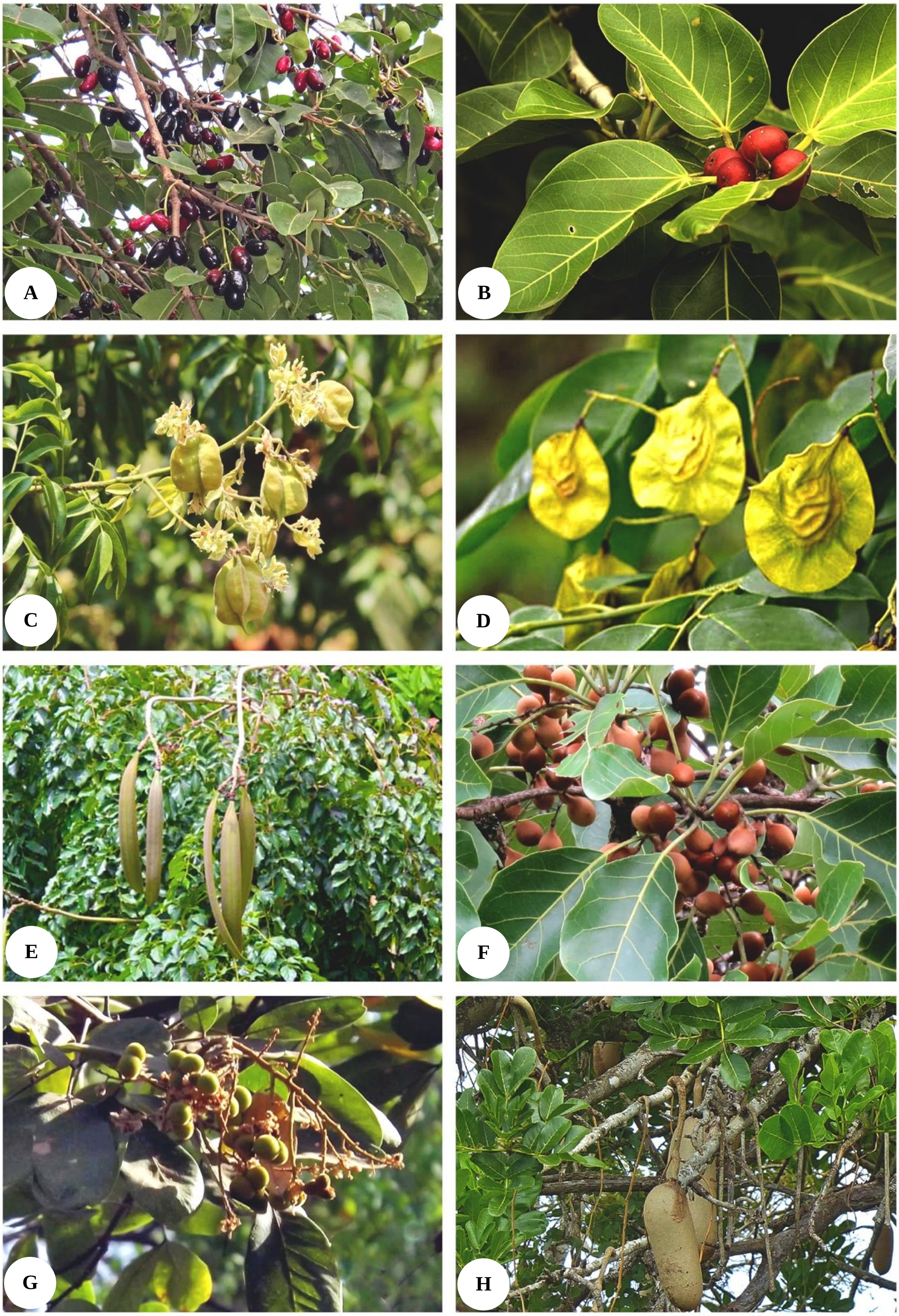

Figure 4. Selected fruits of avenue trees from the study area: A. *Syzygium cumini* (L.) Skeels B. *Ficus benghalensis* L. C. *Majidea zanguebarica* Kirk ex Oliv. D. *Pterocarpus indicus* Willd. E. *Oroxylum indicum* (L.) Kurz F. *Terminalia bellirica* (Gaertn.) Roxb. G. *Sapindus trifoliatus* L. H. *Kigelia africana* (Lam.) Benth.

Some of the trees yield fruits such as *A. indica*, *C. inophyllum, F. benghalensis, F. religiosa, F. racemosa, M. dubia, M. elengi, P. dulce, P. indicus* and *S. cumini*. Various birds like Asian Koel, Red-vented Bulbul, Common Myna, Rose-ringed Parakeet, and House Crow feed on them whenever available. Tree species with large canopies were used for nesting and roosting purposes by bats and urban birds mainly Black Kites, followed by Brahminy Kite, Cattle Egret, Pond Heron, Crows, Mynas, Bulbuls, Parakeets, Pigeons and passerines. Some of the native trees are *A. marmelos, A. indica, B. purpurea, C. inophyllum, C. fistula, F. benghalensis, F. benjamiana, F. religiosa, F. descipiens, G. arborea, M. indica, M. dubia, M. elengi, M. citrifolia, P. pinnata, P. grandis, P. indicus, S. cumini, T. arjuna, T. bellirica*, *T. indica* and *T. populnea*.

The exotic trees were introduced due to their quick growth, dense foliage, attractive flowers, etc. Along with native trees, the following exotic plants are planted: *A. pavonina, A. amara, C. thevetia, C. sebestena, D. regia, J. mimosifolia, Melia azedarach, Melaleuca citrina, M. hortensis, M. calabura, P. dulce, M. longifolium, S. glauca, Spathodea campanulata, S. macrophylla* and *S. mahagoni.*

Discussion

With the increase in urbanization, studies on urban ecology focus have developed rapidly in recent years (Celesti-Grapow et al. 2006). Floristically, cities have been observed to be richer than adjoining areas owing to high habitat heterogeneity and the presence of exotic species (Pysek et al. 2006; Primack and Miller-Rushing 2009; Kitha and Lyth 2011). Urban forestry includes the management of individual and group trees and incorporates arboriculture along with landscapes as one important component of their subject.

Urban forestry is also not restricted to planted trees. Many urban trees may have been established naturally, but in an environment where competition for land is high, they are unlikely to survive long unless actively cultivated and managed. Thus, as noted above, urban forestry also included the management of forests at the urban fringe. Urbanization constitutes one of the most significant drivers of global environmental change today, with more than 50% of the world's population living in urban areas (United Nations 2011).

Recent urbanization rapidly accelerated with unauthorized developments, and land use changes for agriculture in rural and urban areas in many districts of the region were reported (Harini and Divya 2011; Divakara et al. 2022; Jeevith and Manjunath 2023). The creation and expansion of cities put transformative pressure on the surrounding landscapes, leading to drastically increasing population densities. There will be cleaner and cooler air by planting more trees in the urban areas; in exchange for giving oxygen, trees absorb carbon dioxide produced from the combustion of various fuels. Balasubramanian et al. (2018) reported the air pollution tolerance index of urban trees in selected areas of Coimbatore. They revealed that *T. populnea* and *P. pinnata* were excellent performers in urban forests. Trees remove or freak, decreasing dust, ash, pollen, and smoke from the air, providing shade for people, and conserving soil carbon energy.

Trees provide numerous benefits to urban forests, especially in mitigating air pollution in urban areas and positively impacting human health. Similarly, Shanmugam et al. (2020) reported 54 urban trees in the Madurai District to treat 35 ailments regarding ethnomedicinal uses. The common trees were *Azadiracta indica*, *M. elengi*, *Morinda tinctoria, Parkinsonia aculeata, Alstonia scholaris, M. indica*, *M. hortensis*, *P. pinnata* were utilized in multiple disorders. Urban noise is reduced by trees' sound waves absorbent. Trees also provide wildlife habitats for many species, especially for birds. Many of the trees planted on the roadsides are exotic, i.e., from other countries. Most of the trees have bright and colourful flowers and different trees flower in different seasons. Some striking are *D. regia* with red flowers, *Albizia saman* with pink flowers, *P. pterocarpum* with yellow flowers *S. campanulata* with bright scarlet red flowers during summer months. Indian cork tree *M. hortensis* with long white flowering from August to September, and *J. mimosifolia* with brilliant bluish violet flowers.

Along with exotics, we also have native (originating from India) trees: about 26 species are of Indian origin, for example, Indian Laburnum (*C. fistula*) dangling yellow flowers, *M. dubia* with white flowers, *M. azedarach* with white with violet tinge flowers, *P. indicus* with yellow flowers, *M. elengi* with fragrant white flowers. The most common species of trees planted are *C. sebestena*, *T. stans*, *B. purpurea*, *F. benghalensis*, *F. benjamina*, and *M. calabura* (Jamaican cherry). Some of the tree species are very few, for example, *Filicium decipiens* (Fern tree) besides *M. indica*, *A. marmelos* (Indian Bael tree) and *Swietenia mahagoni* (American Mahogany).

Recently, several authors reported avenue trees from the country. Kohli et al. (1998) reported 66 tree species along the roadsides of Chandigarh, which provides multiple benefits; Harini and Divya (2010) studied the tree diversity in urban parks of Bangalore and reported 80 tree species. The common ornamental tree *Polyalthia longifolia* was largely planted in most urban areas due to its attractive drooping foliage. Pandey and Kumar (2018) recorded 64 plant species in urban green spaces of Allahabad city, Uttar Pradesh. Prakash et al. (2020) reported 113 avenue tree species in Tiruppur City with species-rich genera *Ficus, Terminalia, Acacia, Plumeria, Albizia*, and *Bauhinia.*

Several native and indigenous tree species were planted in urban scapes in different regions of the country. These wild and ornamental potential trees play a different role in the environment and benefit local communities. The knowledge of avenue plants and their potential value strongly relates to the urban community people for multiple purposes. Avenue plants, mainly in botanical gardens, parks, institutions, hospitals, home gardens, industrial areas, and highways, are essential sites for plant diversity conservation. The present study indicates that exploring urban plants and their ornamental potential value in different microhabitats of the city should be designed for country urban conservation.

In conclusion, due to rapid urbanization, there is a drastic reduction in urban biodiversity in and around the cities. Therefore, to mitigate atmospheric pollution, there is an urgent need to plant more trees on the roadsides that will help us to reduce the CO_2 level in the air; at the same time, the avenue trees also provide shade, habitat for birds, and other economic benefits derived from these trees. Recently, carbon credits have been promoted by commercials and corporate companies for the restoration of degraded invasive forests, landfills, abundant mimes, and monoculture plantations to natural forests.

The overall result suggests that urban trees are unique carbon biomass producers. In this paper, we have developed a catalog of avenue trees of the Coimbatore district, which can help the urban eco-gardens, planters, and restoration ecologists to select the high ornamental potential value tree species for planting urban and rural biodiversity development. Hence, it is advocated that planting more trees in urban areas will benefit humanity. In general, this study strongly suggests to urban management action plan for developing long-term management plans and stewardship agreements to ensure the maintenance and monitoring of restoring native trees for green development. Encouraging landowners and local stakeholders to adopt sustainable agro-farming and land management practices that support the country in a long-term healthy and productive native forest ecosystem.

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Plant species diversity along altitudinal gradient of Chamkhar River Basin, Central Bhutan

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Abstract. *Thukten K. 2024. Plant species diversity along altitudinal gradient of Chamkhar River Basin, Central Bhutan. Asian J For 8: 81-87.* Chamkhar River Basin in Bumthang District, Bhutan, plays an important role in water discharge due to the presence of forest vegetation at elevation range between 2,000-6,800 masl. This study was carried out between June-October 2023 to assess the plant species diversity, composition and abundance of vegetation along the Chamkhar River Basin representing different forest types and altitudes. In this study, 13 grids comprising 38 plots (one grid had 3 sampling plots) were established along Chamkhar River Basin through systematic sampling. The plots within the grid were selected to include tri-confluence formed by tributaries joining the Chamkhar River for the water discharge assessment. As many as 108 species and 1,294 individuals of trees, 154 species and 1,959 individuals of shrubs, and 101 species and 1,136 individuals of herbs, totaling of 363 species, 233 genera and 100 families were enumerated from different altitudes and across 4 different forest types (Blue Pine, Mixed Conifer, Cool and Warm Broadleaved forest) across the 38 sampling plots. Mixed Conifer and Blue Pine forests form the major forest type in the upstream ecosystem, while Cool Broadleaved and Warm Broadleaved forests form the major downstream ecosystem. The species richness and diversity were found higher in the Broadleaved forests at a lower altitude than in Blue Pine and Mixed Conifer forests at a higher altitude. However, species abundance did not show any definite pattern. The results of this study might be useful to better manage Chamkhar River basin and also serve as a baseline data for any future research along the Chamkhar River.

Keywords: Bhutan, Chamkhar River Basin, relative abundance, species diversity, species richness

INTRODUCTION

Chamkhar River Basin is located in the Bumthang District in the North-Central part of Bhutan, with an elevation range between 2,000-6,800 masl and consisting of 51.79% of mainly Blue pine forest (Tshering et al. 2020). Chamkhar River Basin is fed mainly by the snowfields and glaciers of the eastern Himalayas, draining into the Manas River and eventually feeding into the Brahmaputra River in India (Hill et al. 2020).

Of the 36 biodiversity hotspots, the Eastern Himalayan Range is among the richest, with Bhutan constituting 7.60% of its total area. Bhutan, a biodiversity hotspot, is a part of 23 important birding sites, 8 ecoregions, and wetlands with 2 RAMSAR sites (Banerjee and Bandopadhyay 2016) and is home to 5,603 higher plant species, of which over 600 species are considered to have medicinal uses (Lakey and Dorji 2016). Besides being rich in biological diversity, the country is endowed with a rich network of riverine systems, generating 70,572 million m^3 of water annually (Tshewang et al. 2018), while (Rizal 2020) states that on average, 75 billion tons of freshwater flows out of the country every year.

Over the last few decades, ecologists have highlighted the intricate linkages between the riparian zone and surface streams and the need to incorporate riparian zones in the stream-catchment ecosystem. Riparian zones provide numerous ecosystem services, such as nutrient modification, erosion control, temperature regulation, and water quality improvements in adjacent ecosystems (Saklaurs et al. 2022). As an area of transition between two biological communities, ecological processes in riparian zone are directly integrated between the aquatic and terrestrial ecosystems (Gregory et al. 1991). The riparian ecotone possesses a high diversity of flora and fauna with a multi-layered structure due to variable flow above and below the surface.

The vegetation along the stream is an integral component of a stable riparian ecosystem (Medina 2012), playing a critical role in regulating the quality and quantity of water in the waterbodies by acting as a filter and storehouse by improving infiltration. A healthy streamside vegetation can reduce the stream's nitrogen and phosphorus load, reducing the risk of algal blooms (Frazer 2005). In addition, many wildlife species use vegetation zones along streams and rivers for foraging and breeding (Tucker Schulz and Leininger 1990).

Many factors dictate certain species composition, abundance, and diversity along the streams and rivers, like the environmental factors, stream size and hydrological conditions. There was a positive relationship between stream size and the number of plant community types in Danish riparian areas, with different community types being influenced by nutrient and moisture preferences (Dybkjær et al. 2012). Decreased nutrient content due to increased erosion resulting from flood raises species richness and uniqueness at the river level (Bornette et al. 2001). Elevation, flooding duration, and water chemistry influenced plant community composition, distribution, and diversity along a hydrological gradient in a complex wetland (Gaberščik et al. 2018). However, any disturbances to the riparian vegetation can severely affect the nutrient exchange, population of aquatic organisms, water temperatures, quality and quantity of flow in the streams and rivers (Knight and Bottorff 1981), and a moderate degree of disturbance in a plant community can give rise to a highly diverse species composition (Vasilevich 2009).

Since no previous vegetation studies were conducted along the entire stretch of Chamkhar River Basin, we carried out a vegetation survey as part of the Bhutan for life project across different forest types and altitudes. This study aimed to assess species composition, richness, abundance, frequency, and diversity and analyze contributing factors that explain such occurrences. We expect the results of this study might assist concerned protected area managers in better managing the river and riparine resources and also serve as a baseline data for any future research along Chamkhar River Basin.

MATERIALS AND METHODS

Study area

The study area is along the Chamkhar River (27º46'13.6" to 27º01'5.724" N and 90º39'42.1" to 90º50'24.312"E) which covers surface area of 3170.16 km^2 and stretches over 119.33 km from the base of Gangkarpuensum and Moenlakarchung peaks to Rendibi-confluence where Chamkhar River meets Mangde river of Bhutan (Figure 1). The forest type changes from Alpine scrubs at the sources to Bluepine forest in the middle belt and cool broadleaved forest at lower altitudes.

Data collection procedures

As part of rapid biodiversity assessment, 13 grids (Table 1) were laid systematically along Chamkhar River Basin using GIS software. The survey sites within the grid were selected in such a way as to include tri-confluence formed by tributaries joining the Chamkhar River for the water discharge assessment. A vegetation study was also done at the water discharge sampling points.

From the tri-confluence of the river, we took 100 meters upstream for both the right and left tributaries and 100 meters downstream of Chamkhar River while maintaining a buffer of 100 meters from the banks on either side for vegetation sampling. In each grid, we laid three 20×20m square sample plots through simple random sampling to enumerate trees and within this plot, we laid 4×4m square plots to enumerate shrubs and 2×2m for herbs in accordance to the Biodiversity Monitoring and Social Surveying Protocol of Bhutan (DoFPS 2020). Sampling plots were laid on the right side of the river and tributaries in the starting grid and then alternated in the following grids to avoid selection biases. Therefore, 38 sampling plots were laid in 13 grids, with one sampling plot falling in an inaccessible area.

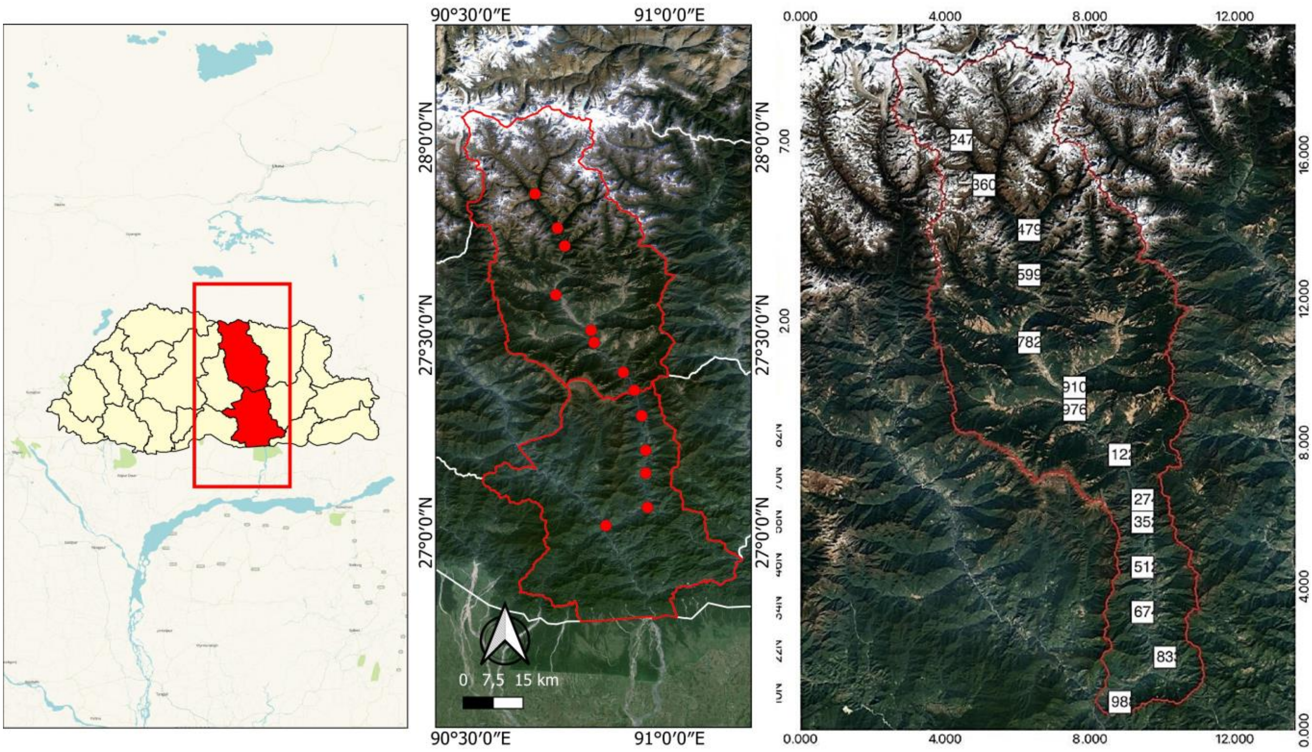

Figure 1. Map of study area in Chamkhar River Basin, Bumthang District, Bhutan and the survey grids

Table 1. Summary of grids along Chamkhar River Basin, Bhutan

Grid no.	Place Name	GPS Coordinates	Altitude (m asl.)	Forest/Habitat Type	Vegetation Type
1	Tshampa	27º51'25.9" N, 90º39'42.1"E	3700	Forest, thicket/pole stage, shrubland	Mixed conifer
2	Zampa Nyipa	27º46'13.6" N, 90º43'05.5"E	3071	Forest	Mixed conifer
3	Zampa Dangpa	27º43'30.8" N, 90º44'12.2"E	2942	Forest, thicket/pole stage, shrubland	Mixed conifer
4	Thangbi	27º36'06.4" N, 90º42'50.1"E	2591	Forest	Blue pine
5	Kurkurbithang	27º30'42.9" N, 90º48'09.7"E	2512	Forest	Blue pine
6	Gektong Zam	27º28'51.6" N, 90º48'37"E	2467	Forest	Blue pine
7	Ura-Chamkhar chhu confluence	27º24'20.2" N, 90º53'00.5"E	2165	Forest	Cool broad leaved
8	Murgang	27º21'37.4" N, 90º54'41.0"E	1840	Forest	Cool broad leaved
9	Doptaru	27º17'44.904" N, 90º55'48.642"E	1241.1	Forest/shrubland	Warm broad leaved
10	Radi chhu	27º12'30.342" N, 90º56'23.358"E	918.5	Forest	Warm broad leaved
11	Khomshar chhu	27º09'3.624" N, 90º56'23.910"E	730.1	Forest/shrubland	Warm broad leaved
12	Langdurbi-Murgang chhu	27º03'50.210" N, 90º56'40.413"E	425.6	Forest/pole stage	Warm broad leaved
13	Ringdribi	27º01'5.724" N, 90º50'24.312"E	213.9	Forest	Warm broad leaved

Data analysis

Species richness and abundance

Different species of trees, shrubs and herbs occurring within the three sampling plots of the grid were enumerated and filled in their respective survey forms. For species richness, we recorded several species found in the sampling plots of the grid and used MS Excel to compute the total species richness of that grid. For species abundance, the study recorded the total number of individuals of the species found in the sampling plot of the grid and computed the species abundance of that grid. The study arranged species occurrences for species frequency according to their respective forest types and calculated frequency by dividing individual species count by total species count in that particular forest type.

Shannon & Simpson diversity index

To calculate species diversity, we used both Shannon and Simpson indices. We combined the tally of trees, shrubs, and herbs of the three sampling plots to calculate a combined diversity index. Then, diversity indices of trees, shrubs and herbs were averaged to find a common diversity index of the vegetation. The Shannon and Simpson indices were calculated using the equation below:

$$\text{Shannon Index (H)} = -\sum_{i=1}^{s} p_i \ln p_i$$

$$\text{Simpson Index (D)} = \frac{1}{\sum_{i=1}^{s} p_i^2}$$

Where p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations, and s is the number of species.

Statistical analysis

The Pearson correlation test was used to observe the correlation between altitude and species abundance to investigate how the altitude impacted species abundance. The significance of diversity differences between grids was calculated using the one-way Analysis of Variance (ANOVA).

RESULTS AND DISCUSSION

Total plant species

A total of 1,294 individuals of trees (108 species), 1,959 individuals of shrubs (154 species.), and 1,136 individuals of herbs (101 species) belonging to 363 species, 233 genera and 100 families were enumerated from different altitude gradients and across 4 different forest types, i.e., Blue Pine, Mixed Conifer, Cool and Warm Broadleaved forest. Asteraceae (n=18) and Poaceae (n=14) were the most dominant family (Table 2) while *Rhododendron* (tree), *Pteridium* (shrub) and *Potentilla* (herb) were the most represented genera in their respective vegetation types (Table 3) in the Chamkhar River Basin.

Table 2. Top 10 families in the Chamkhar River Basin, Bhutan

Family	Number of species
Asteraceae	18
Poaceae	14
Fabaceae	10
Urticaceae	8
Rosaceae	7
Lamiaceae	7
Ericaceae	6
Araliaceae	6
Lauraceae	5
Rutaceae	5

Table 3. Top 10 representative genera in each vegetation type in Chamkhar River Basin, Bhutan

Tree	No. of Ind.	No. of occurrences	Shrub	No. of ind.	No. of occurrences	Herb	No. of Ind.	No. of occurrences
Rhododendron	53	17	*Pteridium*	131	13	*Potentilla*	130	12
Acer	71	16	*Berberis*	19	11	*Poa*	145	11
Pinus	212	9	*Artemisia*	54	10	*Pilea*	125	10
Tsuga	49	9	*Rubus*	25	10	*Ainsliaea*	58	9
Macaranga	38	9	*Rosa*	38	9	*Digitaria*	84	7
Alnus	44	8	*Tetrastigma*	37	9	*Anaphalis*	38	6
Betula	36	8	*Strobilanthes*	107	8	*Ageratum*	41	4
Ostodes	22	7	*Pteris*	23	7	*Synotis*	35	4
Ficus	18	7	*Piper*	102	6	*Selaginella*	28	4
Duabanga	42	6	*Elsholtzia*	23	6	*Equisetum*	11	4

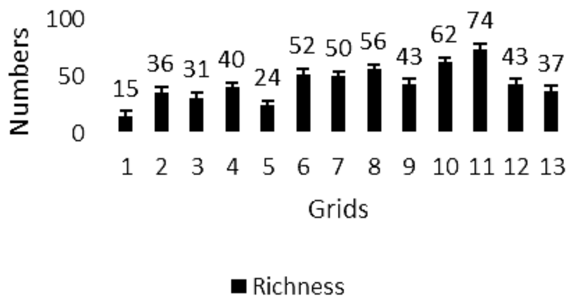

Figure 2. Comparison of species richness among the grids in Chamkhar River Basin, Bumthang District, Bhutan

Species richness

Grid 1 (Tshampa region, alt:3,700 masl, forest type: Mixed Conifer) had the least species richness (n=15) as the area falls in the sub-alpine region, where the harsh environment supports the growth of only a few cold hardy species like the *Abies densa*, *Juniperus* sp., *Rhododendron* shrubs, *Betula utilis*, *Bamboo* and *Acer* sp.

Grid 11 (Khomshar region, alt: 730.1 masl, forest type: Warm Broadleaf) had the most species richness (n=74), followed by Grid 10 (Radi region, alt: 918.5 masl forest type: Warm Broadleaf n=62). The predominant trees that grow in these regions included *Erythrina arborescens, Altingia excelsa, Lithocarpus* sp., *Terminalia tomentosa, Pterospermum acerifolium, Tetrameles nudiflora, Pandanus furcatus* and *Macaranga denticulata.*

Grids 6, 7, 8, 10 and 11 had similar species richness and were higher than other grids with more or less similar species richness (Figure 2)

Shrubs had a higher richness compared to other vegetation types along Chamkhar River Basin. Shrub richness were more prounounced in the altitude range of 730.1 m to 2467 masl comprising Bluepine, Cool-broadleaved and Warm-broadleaved forests (Table 4)

Species abundance

While most grids showed equal number of individuals, Grid 1 (Tshampa region) showed the most abundance per grid (n=653) (Table 5 and Figure 3). *Acer campbellii* was the most abundant tree in Grid 1, while *Rhododendron lepidotum* and *Arundinaria racemosa* dominate the shrub type and *Sphagnum* moss, *Aster himalaicus, Astragalus* sp., *Agrostis* sp. at the herb type.

Grid 13 (Rindribi, alt: 213.9 masl, forest type: Warm Broadleaf) had the least species abundance (n=194) among the grids. *Phoebe hainesiana* was the dominant tree species, *Strobilanthes multidens* the shrub species, and *Potentilla indica* the dominant herb species in this grid.

Table 4. Richness of each vegetation type along Chamkhar River Basin, Bhutan

Grids	Richness (number of species)		
	Trees	Shrubs	Herbs
1	7	4	4
2	11	15	10
3	7	14	10
4	6	14	20
5	7	13	4
6	13	19	20
7	16	24	10
8	9	34	13
9	17	19	7
10	17	31	14
11	29	26	19
12	21	17	5
13	18	17	2
Total	178	247	138

Table 5. Abundance of each vegetation type in Chamkhar River Basin, Bhutan

Grids	Abundance		
	Trees	Shrubs	Herbs
1	68	525	60
2	109	110	82
3	64	73	148
4	67	122	195
5	177	86	10
6	109	73	126
7	85	158	70
8	23	153	107
9	58	147	84
10	136	220	94
11	94	115	110
12	193	106	38
13	111	71	12
Total	1294	1959	1136

Table 6. Pearson correlation between species abundance and altitude in Chamkhar River Basin, Bumthang District, Bhutan

Coefficient (r)	N	T statistics	DF	P value
0.422756	13	1.547182	11	0.15009

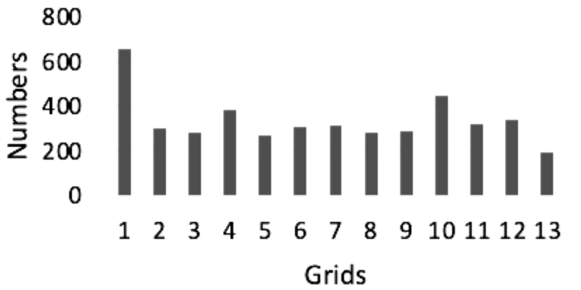

Figure 3. Comparison of species abundance among the grids in Chamkhar River Basin, Bumthang District, Bhutan

Grid 5 had the most trees (n=177) while Grid 1 had the most shrubs (n=525) and Grid 4 had the most herbs (n=195). In general, shrubs were more abundant than the two other vegetation types in the Chamkhar River Basin.

The result of Pearson correlation test indicated that species abundance showed a moderate positive correlation (Table 6), suggesting that species abundance is affected by altitude.

Diversity indices

The Shannon diversity index ranged from 1.15-2.86 and Simpson diversity index ranged from 0.58-0.93. According to Shannon and Weiner, a diversity index of 2.5 and above is considered "high diversity," while a diversity index of 1.5 and below is considered "low diversity." As per these indices, two grids (Grid 1: Tshampa region, alt:3,700 masl, forest type: Mixed Conifer and Grid 5: Kurkurbithang region, alt: 2,512 masl, forest type: Blue Pine) fall under low diversity while only one grid (Grid 11: Khomshar region, alt: 730.1 masl, forest type: Warm Broadleaf) fall under high diversity and rest of the 10 grids under medium diversity (Figure 4). Simpson's Diversity Index also yields the same result, with Grid 11 showing the highest diversity (SDI-0.93) and Grid 1 showing the least diversity (SDI-0.58).

Grid 11 consisted of major tree species, including *P. furcatus*, *Toona ciliata*, *Schima wallichii*, *T. tomentosa*, *Quercus lamellosa*, *E. arborescens*, *A. excelsa*, *Lithocarpus* sp., *P. acerifolium*, *T. nudiflora*, and *M. denticulata*. While major shrubs in this grid included *Tetrastigma rumucispermum*, *Eupatorium* sp., *Piper mullesua*, *Cynoglossum* sp., *Artemisia* sp. and *Thysanolaena latifolia*; and major herbs: *Pilea symmeria*, *Drymaria cordata*, *Setaria palmifolia*, *Ageratum conyzoides*, *Acmella repens*, *Pollia hasskarlii* and *Plantago erosa*.

To evaluate the diversity significance between the grids ($p=0.05$), we ran a one-way Analysis of Variance (ANOVA) test. The study revealed the diversity difference was significant ($p=0.000108$, $p<0.05$) between the grids, indicating that species diversity decreased with the increase in altitude (Table 7).

Species Relative Frequency (RF)

In the Mixed Conifer Forest type, *Acer* sp. (RF=0.245) was the most frequent tree species, followed by *Tsuga* sp. (RF=0.170), while *R. lepidotum* (RF=0.182) was the most frequent shrub species, followed by *R. setosum* (RF=0.121). With almost 60% representation, *A. racemosa* (RF=0.598) was the most frequent herb species, followed by *P. indica* (RF=0.075) (Table 8).

Table 7. The results of ANOVA to evaluate the diversity between the grids in Chamkhar River Basin, Bumthang District, Bhutan

Source of Variation	SS	df	MS	F	P-Value	F Crit
Between Groups	164.2044	1	164.2044	21.38579	0.000108	4.259677
Within Groups	184.2769	24	7.678204			
Total	348.4814	25				

Table 8. Species relative frequency in each forest type in Chamkhar River Basin, Bumthang District, Bhutan

Forest Type	Habit					
	Tree	RF	Shrub	RF	Herb	RF
Mixed Conifer	*Acer* sp.	0.245	*Rhododendron lepidotum*	0.182	*Arundinaria racemosa*	0.598
	Tsuga sp.	0.17	*R. setosum*	0.121	*Potentilla indica*	0.075
Blue Pine	*Pinus wallichiana*	0.589	*Pteridium aquilinum*	0.26	*Poa* sp.	0.284
	Populus sp.	0.272	*Artemisia* sp.	0.139	*Potentilla indica*	0.157
Cool Broadleaved	*Symplocos* sp.	0.389	*Cocculus* sp.	0.148	*Pilea* sp.	0.243
	Alnus nepalensis	0.176	*Strobilanthes* sp.	0.071	*Poa* sp.	0.147
	Duabanga grandiflora	0.1	*Piper mullesua*	0.135	*Digitaria cruciata*	0.152
	Alnus nepalensis	0.1	*Strobilanthes multidens*	0.121	*Bambusa* sp.	0.134
Warm Broadleaved	*Macaranga denticulata*	0.087				

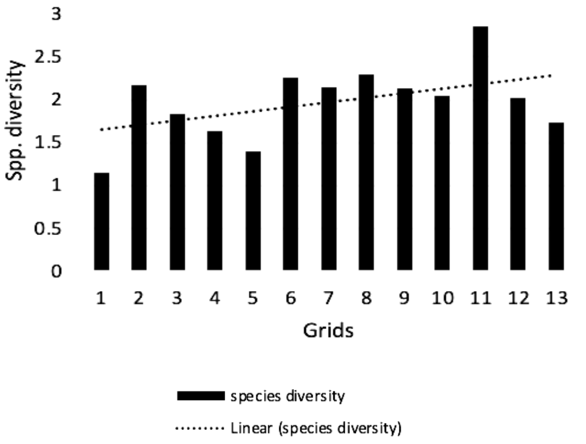

Figure 4. Comparison of species diversity among the grids in Chamkhar River Basin, Bumthang District, Bhutan

Pinus wallichiana (RF=0.589) was the most frequent tree species in the Blue Pine Forest type, followed by *Populus* sp. (RF=0.272). *Pteridium aquilinum* (RF=0.260) was the most frequent shrub species, followed by *Artemisia* sp. (RF=0.139). The most frequent herb species in the blue pine forest was *Poa* sp. (RF=0.284), followed by *P. indica* (RF=0.157).

In the Cool Broadleaved Forest type, *Symplocos* sp. (RF=0.389) was the most frequent tree species, followed by *Alnus nepalensis* (RF=0.176). *Cocculus* sp. (RF=0.148) was the most frequent shrub species, followed by *Strobilanthes* sp. (RF=0.071). *Pilea* sp. (RF=0.243) was the most frequent herb species, followed by *Poa* sp. (0.147).

In the Warm Broadleaved Forest type, *Duabanga grandiflora* (RF=0.1) and *A. nepalensis* (RF=0.1) were the most frequent tree species, followed by *M. denticulata* (RF=0.087). The *P. mullesua* (RF=0.135) was the most frequent shrub species, followed by *S. multidens* (RF=0.121). The most frequent herb species in the Warm Broadleaved Forest was *Digitaria cruciata* (RF=0.152), followed by *Bambusa* sp. (RF=0.134).

Discussion

Families with the most genera in Chamkhar River Basin were found to be from Asteraceae (18 genera), Poaceae (14 genera), and Fabaceae (10 genera). This result is similar with the studies by Leck and Leck (2005) in Delaware River of United States where the top two families having the most species were Asteraceae and Poaceae. Factors like seasonal flooding and anthropogenic activities lower species richness, whereas natural vegetation zones exhibited a higher species richness when left undisturbed (Jiang et al. 2005). The other finding states that the ungrazed meadow communities had comparatively lower species richness and diversity than their grazed counterparts (Green and Kauffman 1995). The entire stretch of Chamkhar River Basin is not dammed for hydroelectricity production, unlike other major rivers in Bhutan; therefore it is largely undisturbed by anthropogenic activities or major flooding as of now.

The study neither suggests increasing species richness with the decreasing altitude (Stevens 1992) nor increasing species richness with the increasing altitude (Dorji et al. 2014). On the forest type-wise, species richness along Chamkhar River Basin was higher in the broadleaved forest than conifer and blue pine forest. The reason is that the broadleaved forest, compared to the conifer and blue pine forest, occurs at a lower altitude where shrubs and herbs grow well (Xu et al. 2017) and is attributable to higher precipitation (Sekar et al. 2023). The other plausible reason is that the lower altitude is warmer than the higher altitude, where light availability and transmittance affect understory species richness (Dormann et al. 2020).

However, one study involving *K. pygmaea* revealed that moisture was the delimiting factor behind their dominance (Dorji et al. 2014). Therefore, we couldn't identify the definite and notable pattern of how the altitude or the environmental factors affected species abundance in our grids. The change in species diversity is due to changes in resource availability, like temperature and water, that change along the altitude (Shimono et al. 2010); geographic direction, humidity, and elevation influence vegetation distribution and diversity (Heydari and Mahdavi 2009). The 13th grid showed lower diversity than other grids from the broadleaved forests, as one of the plots was inaccessible and may have contributed to a lower diversity index.

In conclusion, the broad-leaved forest, found at a lower elevation, generally had comparatively better species richness than those found in the mixed conifer and blue pine forests at a slightly higher elevation. Species abundance showed no significant difference concerning the altitude or the forest type in our study area. Therefore, 10 out of the 13 grids along the Chamkhar River Basin fell under "medium diversity," Grid 1 and Grid 5 fell under "low diversity," and only Grid 11 fell under "high diversity". The general trend in the study was that the species diversity decreased with the increase in altitude. The study revealed that combined anthropogenic and ecological factors influence species richness, abundance, and diversity.

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Population structure and distribution of baobab (*Adansonia digitata*) in Malawi in an era of enhanced forest resource utilization

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Abstract. *Chirwa M, Mazibuko DM, Sagona WCJ. 2024. Population structure and distribution of baobab (*Adansonia digitata*) in Malawi in an era of enhanced forest resource utilization. Asian J For 8: 88-97.* Non-Timber Forest Products (NTFPs) contribute to people's livelihood security, especially those in rural areas. However, there is a growing concern that NTFP-providing trees are declining due to land-use change, use intensification, and over-harvesting, therefore an urgent need for sustainable use. This study was conducted in six districts in Malawi: Mangochi, Salima, Mwanza, Neno, Chikwawa, and Nsanje, to understand the population dynamics of *Adansonia digitata* L., which would inform sustainable management of the species. The study aimed to investigate the ecological conditions supporting *A. digitata* growth and assess human impacts on regeneration and seedling recruitment. The assessments were done on 1,223 trees in baobab clusters overlaid with systematic grids with a 500 m spacing interval between individual plots. The trees' diameter ranged between 230 and 305 cm, translating to yield estimates between 520 and 1,084 fruits per tree for the districts. The species was most prevalent in settlements and farmlands and least likely in grasslands. Population structures showed that the species is unstable in replenishment, with a limited number of saplings and juveniles in the sampled locations. Generally, the baobab population seemed less affected by diseases or pests, as no more than 3 % of the assessed population was infested. Deliberate efforts are required to promote raising baobab trees by nurturing the existing few seedlings and saplings or up-scaled integration of the resource on farmlands.

Keywords: Cluster, human activity, regeneration, stocking density, vegetation

INTRODUCTION

The African baobab (*Adansonia digitata* L.) is an iconic tree belonging to the Malvaceae subfamily Bombacoideae, widespread south of the Sahara, especially in savanna regions (Mpofu et al. 2012). Baobab has multiple uses, both for subsistence and as a source of income (Adesina and Zhu 2022). As an Indigenous Fruit Tree (IFT), it can improve nutrition, enhance food security, promote rural development, and facilitate sustainable landscape management (Pye-Smith 2010). IFTs provide crucial services to rural communities during famine and food scarcity by providing energy and nutrients, including vitamins, minerals, and proteins. Nearly every part of the baobab tree is used by humans (Sidibe and Williams 2002); for example, oil from seed is used in cooking, and leaves are an important vegetable in many parts of Africa, including Malawi (Darr et al. 2022). In West Africa (Buchmann et al. 2010), reports of more than 300 uses of *A. digitata* across ethnicities in 4 agroecological zones have been reported. The baobab fruit pulp is a highly sought-after product (Jäckering et al. 2019). Besides juice making, baobab fruit has huge potential for making jam, oil, and wine (Akinnifesi et al. 2008). Such products are very important for building local economies.

In Malawi, baobab is one of the important trees socially and economically. Traditionally, baobab has a variety of uses. The fruit pulp is widely eaten raw or mixed with porridge to add taste and flavor, fuelwood for smoking fish, baking soda from fruit shells, and the bark is used in making mats and other artworks (Sanchez 2011a). From around the year 2000, efforts to commercialize baobab took hold and changed the dynamics of its utilization (Welford et al. 2015). The fruit pulp is used in jam, juice, and ice-lollies production, and baobab seeds are used to make 'coffee' and cooking oil (Darr et al. 2020). From a socioeconomic perspective, baobab has gained enhanced importance; to some extent, its commercialization has played a role in its socioeconomic status in Malawi. Before the commercialization of baobab fruit, this species was casually used as a local snack by children, and most fruits were eaten by wild animals or left to rot (Welford et al. 2015). Baobab fruit commercialization from around the year 2000 led to high demand for fruits and thus removal of seed from its natural environment thereby affecting natural regeneration. Their study (Chirwa 2006) found low levels of regeneration of the species in the wild, a feature that could partly reflect the effects of commercialization.

In recent years, forests, including baobab populations, have been dwindling rapidly worldwide (Ziangba and Pouakouyou 2007), and in Malawi, forest cover loss has been estimated at 0.6% annually since 2021. This is largely due to biomass energy demand and increased land clearing for farming, a direct consequence of population increase (Oranu et al. 2022). The high demand for baobab products on one side and the undisputed increased negative human impact on the environment, particularly agriculture, which limits seedling recruitment (due to weeding), is noted as a threat to the existence of the *A. digitata* (Chitungo et al. 2022). This scenario has created the need to establish the extent of availability and productivity of baobab in Malawi so that its optimum off-take and silvicultural management options are understood for its improved management and sustainable utilization. Understanding the population structure is one way to inform sustainable management and species conservation options (Mohammed et al. 2021). The structure of the baobab population at a local level has been well documented in Malawi (Chirwa 2006). Models have also been used to simulate the habitat for baobabs in Malawi using secondary data sources (Sanchez 2010). However, its spatial distribution using empirical data at a large scale remained in Malawi.

This work sought to assess the population structure of *A. digitata* in six districts of Malawi. Specifically, we sought to investigate the ecological conditions that support *A. digitata* growth and assess human impacts on regeneration and seedling recruitment to inform baseline silvicultural recommendations for sustainable species management.

MATERIALS AND METHODS

Study sites

The study was conducted in Malawi's southern and central regions in districts with predominant baobab populations: Mangochi, Salima, Mwanza, Neno, Chikwawa, and Nsanje (Figure 1). According to Chirwa (2006), baobab occurs mostly in Malawi's Great Rift Valley area along the lake shore and Shire Valley area, predominantly highly active clay zones with vertisols, luvisols, and cambisols. These areas are generally dominated by undifferentiated woodland species *Vachellia* (previously *Acacia)* and *Combretum* (White et al. 2001). Forest cover loss in the study districts generally increases due to high human population densities (National Statistics Office 2019). The high population has resulted in over-exploiting forest resources to increase crop production through agricultural expansion (Kerr 2005; Malawi Gov 2010).

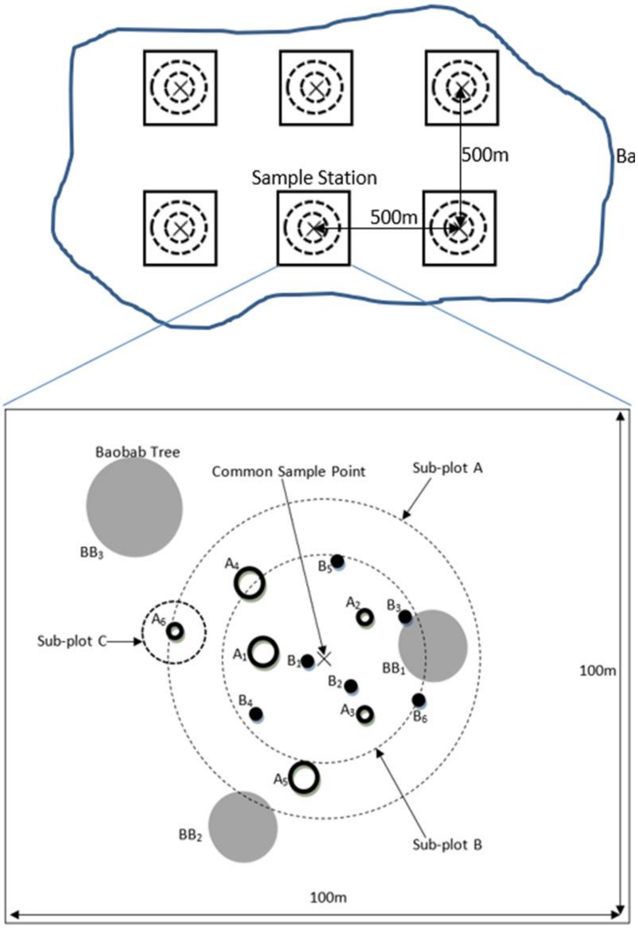

Figure 1. The sampling design used in this study

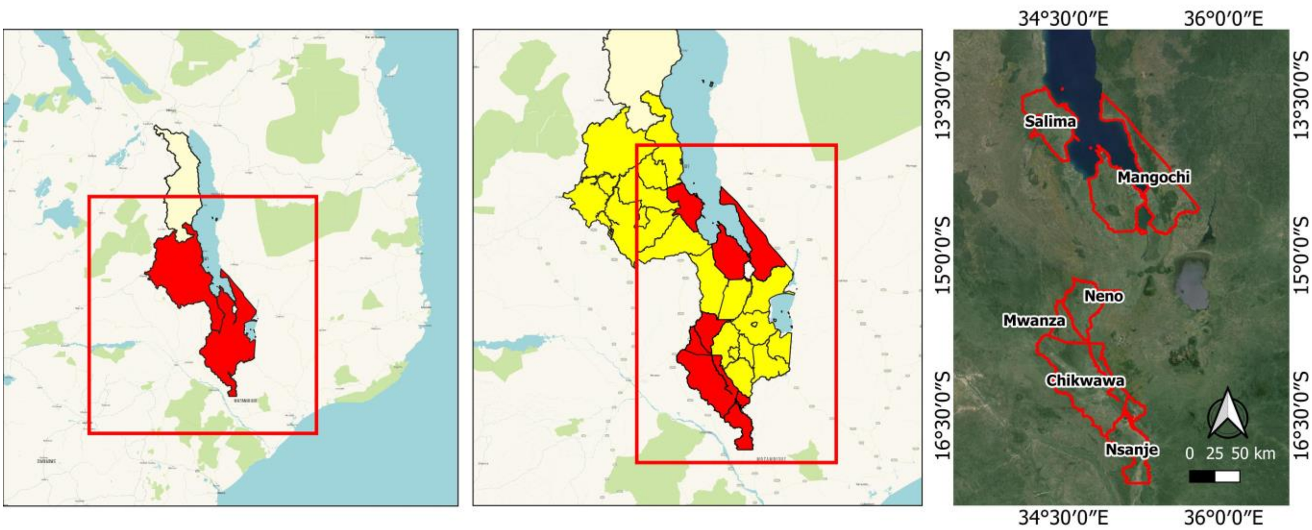

Figure 2. Map of Malawi showing areas where the study was conducted

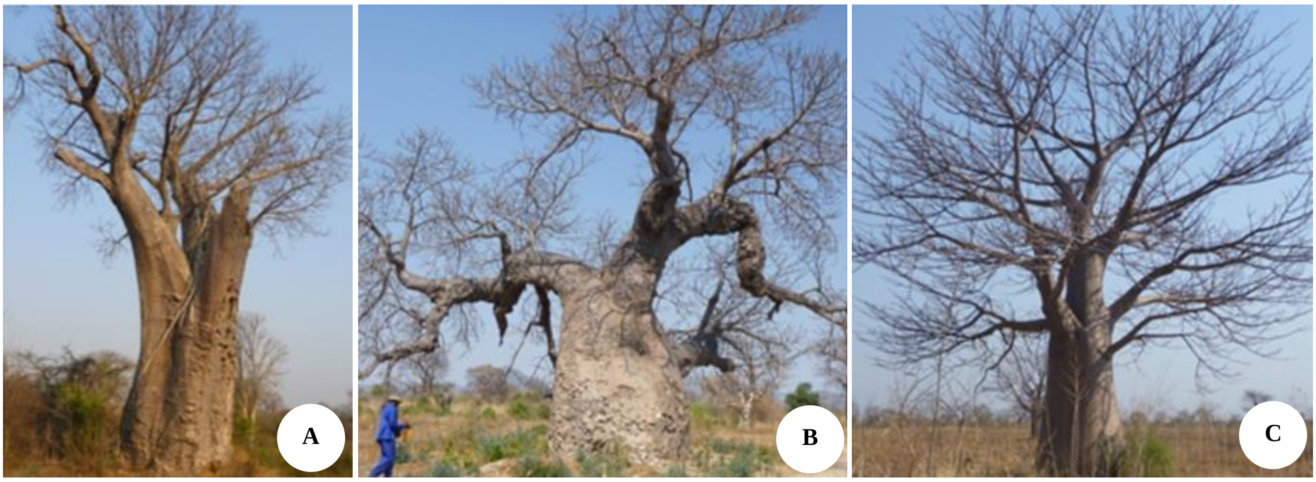

Figure 3. Pictorial view of some growth habits for *Adansonia digitata* from the study sites

Data collection

The survey employed a grid sampling system (Figure 2) within the baobab clusters. The start point was identified using randomly generated distance numbers while the grid was laid systematically over a baobab cluster using a pre-determined interval of 500 m between subsequent plots. GPS receivers were used to locate the subsequent plots with either an east-west or north-south directional orientation from the randomly selected start point. The sample point was also a common center for three k-tree sub-plots, according to Kleinn and Vilčko (2006), for assessing baobab regeneration and associated species.

In each of the three sub-plots, various assessments were made as follows: sub-plot A was for associated tree species >5 cm Diameter at Breast Height (DBH); Sub-plot B was for baobab regeneration and associated tree species <5 cm DBH, while sub-plot C was for associated shrubs and climbers. Sub-plot C was set around the farthest tree either in Sub-plot A or B. All other baobab assessments were assessed in the 1-hectare square plots engulfing the three sub-plots and the associated species.

Therefore, *K*-tree sampling where *k*=6 was employed to assess the associated trees and shrubs, whereby 6 trees or shrubs nearest to the plot center were assessed in each sub-plot. Species were recorded in all the plots while diameters were additionally assessed in sub-plot A (trees >5cm DBH) for determination of relative coverage of the species. Variables assessed for the baobab, irrespective of size, were Diameter at Breast Height (DBH), tree height, bole height, shape of trunk and fruit, and crown width. The choice of the variables was based on their influence on fruit productivity, harvesting techniques, and their relevance to the provision of multiple other products such as biomass, fiber, and fodder. Fruit shape was classified as either round, ovoid, or ovoid pointy. The trunk shapes were classified as pollarded, stunted, and upright (Figure 3.A-C, respectively).

Due to pollarding at some stage of their growth, the stunted trunks comprised trunks whose DBH was hugely disproportionate to growth in height. The crown width was defined as the average measurement of the tree's widest crown diameter and the measurement directly perpendicular to it (Kershaw Jr et al. 2016).

Data processing and analysis

Forest assessment: Statistical Package for Social Sciences (SPSS Version 27, 2019) and Minitab 16.1.1 (Minitab, 2010) were used to analyze the data. The diameter was grouped into the following classes: 1 = (<50 cm), 2 = (51-100 cm), 3 = (101-150 cm), 4 = (151-200cm), 5 = (201-250 cm), 6 = (251-300 cm), 7 = (301-350 cm) and 8 = (>351 cm). These classes were used to calculate stem frequencies in each diameter class per given district. Fruit yield per tree was estimated using a regression function developed by Muchiri and Chikamai (2003):

$$Y = 0.0004X^{2.5897}$$

Where:
Y : Total number of fruits per tree
X : Tree diameter (cm). Fruit yield was estimated to assess baobab productivity.

The data on associated species was analyzed separately to minimize the effect of site and social factors in determining species in a natural community and their abundance. Importance Values (IVs) of the species were determined from the sum of Relative Frequency (RF), Relative Density (RD) and Coverage (RC), which were obtained as follows: RF is frequency of species *i* / sum frequencies of all species multiplied by 100; RD is number of individuals of species *i* / total number of individuals multiplied 100 and RC is total basal area for species *i* / total basal area of all species multiplied 100 (Pereki et al. 2013). Due to time and financial limitations, relative frequency and density were used as an importance value of the shrubs (where shrubs included any trees and saplings less than 5 cm DBH) to a baobab environment, while the sum of relative frequency, density, and coverage was used as an importance value of the associated species greater than 5cm DBH as diameter was also assessed for these trees to represent the coverage. Relative density, frequency, or coverage may be interpreted as an "importance value" depending on which of the values the investigator considers most important for a species, group of species, or community (Brower et al. 1998).

RESULTS AND DISCUSSION

The ecology of *A. digitata* in Malawi

Baobab was found growing in diverse habitats in the study sites. As indicated in the GPS receiver, the altitudinal range of A. digitata in the study area is 73-842 meters above sea level (m asl.). This falls within the range (0-800 m asl.) reported earlier for African baobab (Sanchez 2011b); the Baobab tree is a characteristic species for drier areas. The species generally occurs from sea level to at least 1,500 m asl. and in areas receiving as little as 90 mm of rainfall to as much as 1,400 mm annually (Egbadzor et al. 2023). A common range for baobab sites in Malawi and the greater part of Africa is 0-800 m asl. with a mean maximum temperature from 25°C to 30°C (Sanchez 2011b). This explains the prevalence of baobab in the Great Rift Valley along Lake Malawi, Shire Valley, and Lisungwi Valley. Generally, the study locations were suitable for the African baobab, as documented by (Egbadzor et al. 2023).

An assessment of trees growing in association with *A. digitata* shows slight variation across forest layers. Within the Shrub/Herb layer, the ten most important species had importance values (IV) ranging between 4 and 13% (Table 1). Out of the ten species, *Capparis erythrocarpos* was the most important species recorded in this layer, while *Boscia corymbose* was the least important. The three least important species were *Barleria spinosa*, *Cissus integrifolia,* and *Phyllanthus ovalifolius.* Associated species break the monotony of a species by bringing some ecological balance through species diversity in the event of pests and disease outbreaks and provide shade that may facilitate the germination of *A. digitata* seed (Duvall 2007).

Within the regeneration layer, *Diospyros squarrosa* and *Albizia anthlemintica* were the two most important species in the regeneration layer (Table 1). *Albizia harveyi* (IV = 9%) was also among this layer's five most important species. *Azanza garckeana*, an indigenous fruit tree, was noted as another important species to a baobab habitat, albeit at 14^{th} with an IV of 6 % (data not shown). In that order, this layer's three least important species were *Monodora junodii, Tricalysia micrantha,* and *Combretum paniculatum.*

The tree layer was dominated by *Lannea stuhlmannii* and *Sterculia africana* as two of the most important species (Table 1). *Sclerocarya birrea*, a multipurpose indigenous fruit tree, and *Faidherbia albida*, an agroforestry species, were among this layer's ten most important species in a baobab habitat. Imoro and Barnes (2013) also recorded *F. albida* as a key species that grows associated with baobab. The three least important species recorded in this study for this layer were *Zanha africana, Grewia bicolor,* and *Deinbollia nyikensis*

Species that were present in at least two of the three layers were *Diospyros squarrosa*, *A. anthlemintica*, *L. stuhlmanii*, *A. harveyi*, *Lonchocarpus capassa*, *Combretum mossambicense, Vachellia tortilis,* and *Ehretia amoena*. Most of these species occur in low areas associated with alluvial soils. However, some species' association with baobab was more localized in some areas than others, such as *A. anthlemintica* in Neno. Site conditions could be the major factor attributed to most species' association with baobab. Table 2 shows some most encountered site conditions and the species associated with *A. digitata*.

However, the dominance of *L. capassa* amongst regeneration indicates that some areas are not affected by fire as this species is fire intolerant (Hoffmann et al. 2009). The presence of *Vachellia* species (e.g., *V. tortilis*) may also imply disturbance of some of the sites as *Vachellia* (*Acacia*) species can rapidly colonize disturbed sites, typical of encroaching species (Borah et al. 2021). This may positively and negatively affect baobab regeneration by shading tender baobab seedlings from scorching heat and suffocating regenerating baobab seedlings as they compete for soil nutrients and sunlight during growth. The *F. albida*, an agroforestry species, as noted by (Gning et al. 2023), is found in similar ecosystems to African baobab in Senegal.

Table 1. Top ten species associated with *Adansonia digitata* in different forest layers

Forest layer & top ten important species	IVI
Shrub layer	
Capparis erythrocarpos Isert	0.1265
Diospyros squarrosa Klotzsch	0.0765
Ehretia amoena Klotzsch	0.0668
Combretum mossambicense (Klotzsch) Engl.	0.0657
Boscia salicifolia Oliv.	0.0625
Dregea macrantha Klotzsch	0.0603
Cocculus hirsutus (L.) W.Theob.	0.0597
Dichrostachys cinerea (L.) Wight & Arn.	0.0551
Sesbania tetraptera Hochst. ex Baker	0.0481
Boscia corymbose Gilg	0.0443
Regeneration layer	
Diospyros squarrosa Klotzsch	0.1268
Albizia anthlemintica (A.Rich.) Brongn.	0.1204
Combretum mossambicense (Klotzsch) Engl.	0.0984
Albizia harveyi E.Fourn.	0.0946
Lannea stuhlmannii (Engl.) Engl.	0.0850
Ehretia amoena Klotzsch	0.0829
Lonchocarpus capassa Rolfe	0.0809
Acacia tortilis (Forssk.) Hayne	0.0741
Capparis erythrocarpos Isert	0.0668
Diospyros senensis Klotzsch	0.0655
Tree layer	
Lannea stuhlmannii (Engl.) Engl.	0.5867
Sterculia africana (Lour.) Fiori	0.3428
Lonchocarpus capassa Rolfe	0.2224
Acacia tortilis (Forssk.) Hayne	0.1438
Cordia africana Lam.	0.1417
Albizia anthelmantica (A.Rich.) Brongn.	0.1355
Sclerocarya birrea (A.Rich.) Hochst.	0.1188
Albizia harveyi E.Fourn.	0.0700
Faidherbia albida (Delile) A.Chev.	0.0698
Erythrina livingstoniana Baker	0.0661

Table 2. Species and site conditions associated with *Adansonia digitata* populations from some study areas

Species	Site conditions
L. capassa	Scattered in various woodlands at medium to low altitudes, frequently along rivers.
F. albida	A low veld tree occurs in woodland, wooded grassland, and riverine fringe forest.
V. tortilis	Widespread in low altitude, dry areas, in varied types of woodland.
Diospyros squarrosa	Deciduous woodland and thickets from sea level to around 1,200 m asl.. At higher elevations, the plant is only found on termite mounds
A. anthlemintica	Commonly occurs in deciduous or evergreen bushland and scrubland, especially along seasonal rivers at 80-1,520 m asl.
A. harveyi	*A. harveyi* is found in dry woodland up to 1,450 m asl.
C. mossambicense	This species is found in low-lying, hot, dry areas, on hills, and often near rivers
E. amoena	On sandy and alluvial soils in riverine thickets, open woodland, and along the margins of low-altitude forests, up to 1,150 m asl.
S. birrea	Occurs in medium to low altitudes, open woodland, and bush
A. garckeana	Occurs in almost all types of woodland from sea level to about 1,700 m asl., scattered and never dominant.

Table 3. Area assessed on stems per hectare and population of *Adansonia digitata* across all surveyed districts

District	Stems per hectar (SPH)	Area assessed (Ha)	Total tree count
Chikwawa	6.00	10.00	60.00
Mangochi	6.25	82.00	490.00
Mwanza	3.00	7.00	21.00
Neno	7.50	85.00	608.00
Nsanje	5.00	2.00	10.00
Salima	4.25	8.00	34.00
Total	32.0	194.00	1223.00
Average	5.33	32.33	203.83

The high diversity of associated species may benefit the regeneration of baobab and act as the natural habitat for animals that eat the baobab seed. This may assist in breaking seed dormancy of baobab seed after passing through the animals' digestive system, as observed by (Sidibe and Williams 2002). The shrub, regeneration, and tree layers have different important ecological roles related to baobab population structure. This study has discussed some roles, while others may require further ecological studies to understand their ecological roles and influence on the population structure.

Population structure

Sustainable silvicultural treatments and management require a clear understanding of several aspects of plant species in an ecosystem. These include understanding stand density, a measure that quantitatively expresses the number or count of trees on a unit of land (Sprintsin et al. 2009), used to predict plant growth, tree form, and assessment of forest integrity (Zeide 2005). Size class distributions in trees help in the prediction of future recruitment capacity. Naturally, a tree community comprises many small individuals, with progressively fewer older trees, creating the typical inverted J distribution (Shumi et al. 2019). Therefore, with its close relationship with a plant's photosynthetic capacity, crown diameter is pivotal in assessing stand growth and density (Hemery et al. 2005).

Stand density and stocking

Forty-one sites were assessed for the baobab distribution, representing a total area of 194 ha. A total of 1,223 trees were assessed in all sampled districts, representing an average of 204 baobab trees per district. Sites with high abundances were recorded in Mangochi and Neno (Table 3).

The stocking levels in the sampled districts can be considered scattered, with an overall average of 5.33 stems ha^{-1} and ranging from 3 to 7.5 stems ha^{-1} in different district sites. While Neno district had the highest mean stocking density (7.5 stems ha^{-1}) and Mwanza the least at 3 stems ha^{-1} (Table 3). No significant differences were detected in the stocking among all the six study districts ($F = 0.72$, $p < 0.614$). Elsewhere, (Sanchez 2011a) reported a stocking density of 2 stems ha^{-1} in northern Venda in South Africa, 0 to 2 stems ha^{-1} in agricultural fields in the Kibwesi district in Kenya, and as high and 10-12 stems ha^{-1} in some sites in Malawi; generally, the species stocking could be considered scattered. According to Duvall (2007), baobab habitat preferences correspond to patchiness in its stocking, and land use type impacts the population structure of baobabs.

Additionally, agricultural cropping has been reported to influence the number of surviving seedlings because baobab seedlings are normally removed when weeding crop fields to reduce competition (Lisao et al. 2018). Such observations have been reported in Malawi, Namibia, and South Africa (Chirwa 2006; Venter and Witkowski 2011; Lisao et al. 2018). However, the adult trees are normally retained, resulting in more adult trees in natural populations than those in the seedling stages. Ironically, most large trees, including baobab trees, are protected by cultural norms in African communities (Sidibe and Williams 2002); this may contribute to the high ratio of mature trees to juveniles.

Size Class Distribution (SCD)

Baobab diameter distribution in Malawi depicts a bell-shaped distribution pattern for Neno and Mangochi (Figure 4). There is no pattern for Nsannje and Mwanza distribution right-skewed distribution for Chikwawa and Salima. All studied sites lack smaller diameter classes with populations skewed towards baobab trees over 100 cm in diameter than below this threshold (Figure 5). The lack of seedlings among baobab populations has been noted across most African countries, attributed to herbivory, land clearing by farmers, and fires (Musyoki et al. 2022). The issue of fires can explain the observed low density in the fire-prone grassland of our study.

The negative exponential relationship of tree density to diameter has been observed and considered an indicator of equilibrium forest structure, especially at the stand level (Rubin et al. 2006). Despite Gebauer and Luedeling (2013) observing an inverse J-shaped curve indicating a viable regenerating population in Kordofan, Sudan, they further assert that low recruitment rates and bell-shaped or negatively skewed SCD patterns are typical of baobab populations across Africa. Venter and Witkowski (2011) further posited that such low recruitment patterns are characteristic of long-lived tree species as their recruitment is often episodic.

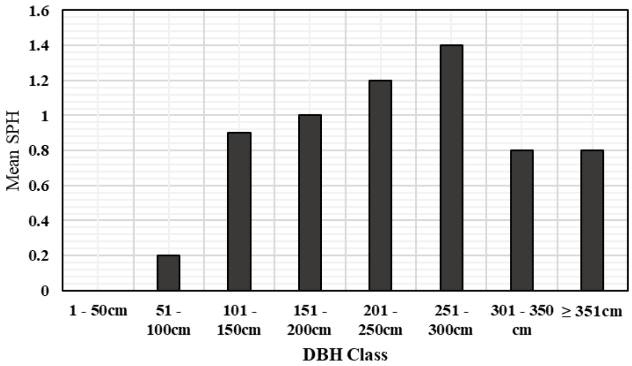

Figure 4. Plant density for diameter class for the whole study data

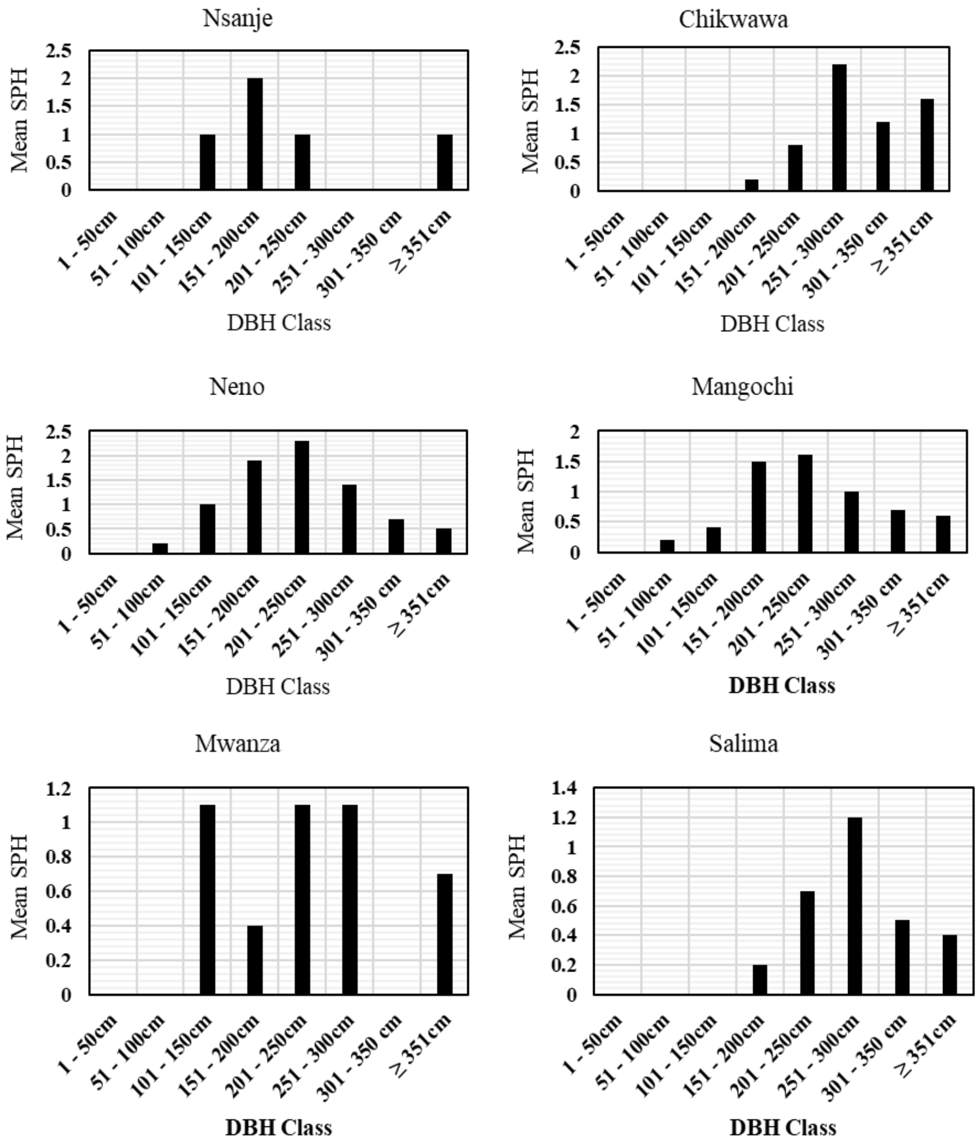

Figure 5. Size class distribution of *Adansonia digitata* from the six surveyed districts

Table 4. The five sampled districts ' total height, bole height, and crown diameter

District	N	Total height (m)	Bole height (m)	Crown diameter (m)
Mangochi	252	16.44	5.98	16.35
Neno	302	18.53	8.95	16.19
Mwanza	12	18.99	7.20	14.59
Nsanje	22	19.28	8.24	17.99
Chikwawa	30	20.02	8.98	17.29

The observed negatively skewed, bell-shaped baobab diameter distribution pattern in this study (Figure 6) could also be attributed to the species seed germination pattern. Studies on seed germination requirements have demonstrated that *A. digitata* seed possesses coat-imposed dormancy inhibiting water and gas uptake (Egbadzor 2020). Salami et al. (2021) observed that baobab seed sown without pre-treatment but only soaked in cold water overnight failed to germinate (0%) after 31 days. However, the seed was still viable (100%) when subjected to cutting tests. Optimum germination was only achieved when the seed was nicked or scarified with a rough surface. They concluded that under natural conditions, *A. digitata* seed takes longer to germinate, suggesting that the species presents a sporadic germination/regeneration pattern. Therefore, the observed diameter distribution pattern in the field confirms the baobab germination study conclusions; the disturbances trigger sporadic regeneration patterns. The lack of smaller diameter classes suggests that *A. digitata* also presents discontinuous recruitment, requiring the occurrence of triggers to seed germination. In this study, most baobab trees were encountered around settlements, followed by farmlands. Some human activities around homesteads and farms could trigger baobab seed germination, hence the high baobab tree densities recorded under these land-use categories. However, Venter and Witkowski (2011) observed that baobab is not seed-limited as it produces abundant viable seeds. Therefore, the microsite conditions such as infrequent rains and livestock browsing likely characterize these sites. Thus, beyond seed pre-sowing to break seed dormancy, there is a need to provide viable microsite management options to improve baobab recruitment. As observed by Venter and Witkowski (2011), these management pathways may include planting saplings as they register higher survival rates than seed and closing baobab regeneration sites to livestock browsing. The study found significant differences in mean diameter growth among study populations ($F = 6.092$, $p < 0.005$). Baobab trees in Chikwawa had the largest mean diameter (305 cm) and were significantly different from those in Mangochi (242 cm) and Neno (230 cm). Gebauer and Luedeling (2013) reported baobab stem diameters ranging between 6 and 477 cm, with most individuals assessed exhibiting diameters greater than 1 m. The authors further indicated that such diameters are in the range observed in Western and Southern Africa (Assogbadjo et al. 2011; Duvall 2007).

Tree heights and crown diameter

Total tree and bole heights can both influence harvesting techniques in baobab (Fischer et al. 2020) which can resultantly impact the health of trees. As such, differences in tree height may be useful in developing future domestication programs. For this study, Table 3 shows total tree height distributions by districts, and the height varied significantly. Mangochi was recorded as the most inferior (16.44 m) ($F = 15.989$, $p < 0.005$), while Mwanza, Nsanje, and Chikwawa as the most superior at 18.99, 19.28, and 20.02 m, respectively. Neno was in between the two subsets at 18.5 m. The morphology of the trunk for the study districts was hugely dominated by the uprights (92 %) followed by the pollarded ones (5%), with the stunted ones (3%) being the least. The pollarded were almost non-existent in Chikwawa, Mwanza, Nsanje, and Salima but were available in Mangochi and Neno at 9 and 3%, signifying the need for management interventions in the latter two. Imoro and Barnes (2013) report that baobabs can attain heights of 18-25 m at maturity. No significant differences were detected between bole heights and crown diameter in the respective study districts (Table 4).

The bole heights ranged between 6 and 9 m. Similarly, no significant differences were detected in crown attainment for the baobabs despite the crowns ranging between 14.6 and 18 m for Mwanza and Nsanje, respectively (Table 4). An increase in the crown diameter of baobab trees represents a potential for the tree to produce more fruits. This equally means all the sites have the same potential to produce fruits, signifying variability in diameter grown as a better predictive variable for fruit production, as reported by Muchiri and Chikamai (2003). Species morphological and phenological characterization of baobab needs to be further studied to understand the influence of variation in tree growth habit and size on fruit production; those studies are important to present empirical evidence of how much of this variation is influenced by the environment.

Productivity and health in Malawi (fruit production)

Baobab is a multipurpose species. However, upon maturity, the most common product from this species is the fruits. In this work, we utilize baobab fruits to assess population productivity. Therefore, using a regression function developed by Muchiri and Chikamai (2003) to estimate fruit production per tree in the study area, it was observed that Chikwawa district had the highest potential of producing more fruits per tree (1,084 fruits per tree) while Neno had the least (520 fruits per tree), Table 5.

Regarding plant health, there was no apparent disease or pest infestation, except for 1% (estimated during survey) of the trees infested by sooty baobab disease. The districts with the high prevalence of baobab, Mangochi, and Neno had their degree of infestation estimated at 3 and 1%, respectively. However, this has been reported as purely a secondary manifestation of a physiological disorder with certain trees afflicted earlier this century having since recovered (Sanchez 2011a). Bark harvesting in baobab enhances vulnerability to bark-targeting fungi, which cause sooty baobab disease (Mugangavari et al. 2021). Tree damage has been reported on baobab trees due to harvesting practices that may not be sustainable in the long term (Rhodes and Setshogo 2012).

Human recruitment impacts on *A. digitata*

The impact of humans on the recruitment of baobab partly emanates from the increasing human population, leading to intensifying land use (Chitungo et al. 2022). An assessment of plant density in different land use types can thus enable one to glean the potential impact of humans on this species. Baobab populations are very variable in different land use types. This could be due to factors like soil requirements, competition for water, disturbances of regeneration by browsing animals, pest attacks, and agriculture (Sanchez 2010). This study revealed more trees per hectare on farmlands and settlement areas in Chikwawa, Mangochi, Nsanje, and Salima (even though not significant, $P \geq 0.05$ Figure 6). This agrees with what (Assogba et al. 2020) found in a study where farmland showed more density than the national park and the buffer zone.

In Neno and Mwanza Districts, more baobab distribution was observed in forest land than in any other land use type, possibly because of immense undergrowth in the forests, making it difficult for animal grazing and browsing. Generally, baobab density may be higher in farmlands as farmers selectively choose to maintain useful trees in their farmlands and clear those that are not very important. Moreover Gebauer and Luedeling (2013) hypothesized that the high baobab abundance in many settlement sites in Africa suggests a strong relationship between trees and people, for example, in Sudan and Kenya, where baobab trees appear to be rarely planted but are commonly protected by households. The relatively low density in forest land could be attributed to competition with other species (Razafimahefa et al. 2022) for growth-supporting nutrients.

The future of baobab in Malawi

The future of baobab population in Malawi is uncertain at best. Challenges to sustainability of baobab populations include climate change effects and land use changes that come with population growth. Climate change, especially increasing temperatures are predicted to lead to contraction of suitable habitats for baobab (Birhane et al. 2020). For southern Malawi, modelling data indicate that suitable habitats for cultivation exist (Sanchez 2011a,b). The current challenge to baobab population in Malawi include reduced recruitment as a byproduct of agriculture, and deforestation. With the predicted population growth for Malawi, pressure for agricultural land is likely to increase, further impacting on baobab recruitment and distribution. Considering these existing challenges, in situ conservation alone is inadequate. Ex situ conservation efforts need to be promoted. Domestication efforts A. digitata led by SADC-ICRAF Agroforestry Regional Programme, date back to the early 2000s (Akinnifesi et al. 2002) but wider adoption has been slow. Currently domestication efforts could benefit from the lucrative participation of baobab products on the Malawian retail market (Meinhold and Darr 2022). Involvement of all players (in conservation efforts) in the baobab value is urgently needed to ensure a sustained future for *A. digitata* in Malawi.

In conclusion, baobab in Malawi is limited to a few areas (Neno and Mangochi Districts) where commercial ventures and improved sustainable management must be focused. The diameter distribution for the resource in Malawi is bell-shaped but more skewed towards adult trees. The lack of saplings and regeneration failure may be attributed to fires, browsing, farming, or the lack of catalytic events that could trigger regeneration. Deliberate efforts should, therefore, be made to promote raising baobab trees either through nurturing existing seedlings and saplings or up-scaled integration of the resource on farmlands. Additionally, factors that can potentially improve the baobab fruit tree should further be explored, including fruit productivity and preferred provenances and/or cultivars, to ensure long-term benefits from the various market opportunities the species offers. Our method can not fully account for existing baobab diversity in the country A nationwise survey of the species in thus recommended.

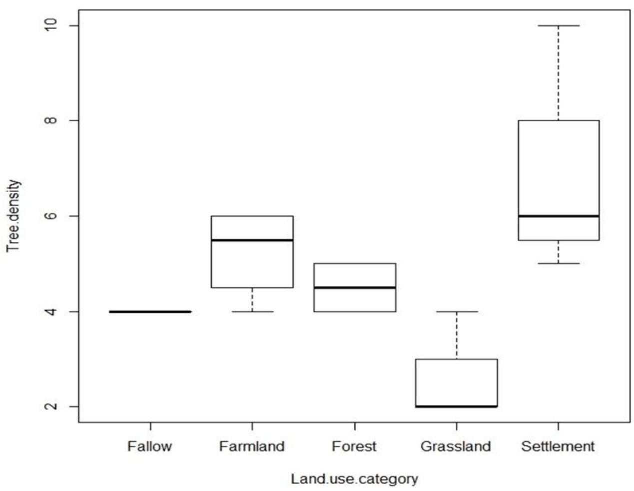

Figure 6. Density of *Adansonia digitata* as observed from different land uses

Table 5. The estimated productivity of *Adansonia digitata* stands from all studied sites

District	Diameter (cm)	Estimated total number of fruits per tree	Tree density (SPH)	Expected number of fruits per hectare
Neno	229.60	520.00	7.50	3902.39
Mangochi	241.53	593.00	6.25	3707.83
Mwanza	253.25	671.00	3.00	2012.12
Nsanje	271.48	803.00	5.00	4014.96
Chikwawa	304.82	1084.00	6.00	6503.37

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Knowledge and perception of wild animal diversity by the local community in Mount Merbabu, Central Java, Indonesia

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Abstract. *Khawarizmi IA, Sari IP, Riswari IA, Sani MF, Izdihar RS, Indrawan M, Setyawan AD. 2024. Knowledge and perception of wild animal diversity by the local community in Mount Merbabu, Central Java, Indonesia. Asian J For 8: 98-105.* Local people view wild animals based on their ecological, social, and economic advantages or disadvantages. The interactions and conflicts between humans and wildlife can be identified from the knowledge and perception of wildlife by the local community, which can be used to inform conservation strategies. Biodiversity on Mount Merbabu, Central Java Province, Indonesia, plays an important role in maintaining ecosystem balance, but people still have little understanding of wildlife. This study aims to document the knowledge and perception of wild animal diversity by the local community living on the eastern slopes of Mount Merbabu to increase community awareness and conservation potential. The research was conducted in three villages on the slopes, administratively located in Ampel Sub-district, Boyolali District, Central Java Province, Indonesia, i.e., Ngagrong, Candisari, and Ngargoloka, using a combination of interviews, observation and questionnaire techniques. The results show that the demographic characteristics of the respondents mostly have a limited level of education, where 60% of respondents are elementary school graduates, with the most occupation being farmers (80%). The respondents mentioned 42 species of wild mammals (14 sp.), aves (24 sp.) and herpetofauna (4 sp.). The respondents perceive wild animals based on ecological, social, and economic aspects. Some species are perceived to have positive impacts (benefits), while others are perceived negatively (disadvantages), resulting in conflicts between humans and wild animals. Ecologically, some species are useful for pest control and seed dispersal. Some species play a social role as signs of the season and traditional beliefs. Economically, some species are commercial goods and traditional medicine. There is conflict between the respondents and monkeys (Javan fuscous langur (*Presbytis comata* subsp. *fredericae*) and Long-tailed macaque (*Macaca fascicularis*), which often invades agricultural land in the dry season. Meanwhile, attempts to catch wild animals were prevented by National Park officers, causing disappointment among some respondents. People knowledge about the ecological, social and economic role of wildlife needs to be increased. Collaboration between the government, educational institutions, and conservation organizations is needed to increase public understanding of wildlife diversity and encourage active participation in nature conservation endeavors.

Keywords: Animal, community knowledge, conservation, eastern slope of Mount Merbabu, wildlife

INTRODUCTION

Indonesia is known for its rich biological diversity, both for flora and fauna. The high biodiversity in Indonesia is related to variations in geography and climate (Fikriyanti et al. 2018), as well as various types and large extent of tropical forests. These forests are important repositories of biological diversity because they contain more than 25,000 species of flowering plants and 400,000 terrestrial animals (Nugroho 2017). According to Arini et al. (2018), the rich diversity of flora and fauna in Indonesia is a potential capital for national development. Therefore, it is important to be documented and studied. This potential might also be useful for future generations. Protecting and preserving biodiversity is one of the most important steps to be taken to mitigate the environmental impacts that might lead to biodiversity decline and extinction (Zamzami et al. 2020).

Wild animals are fauna that still have wild characteristics and live freely in nature. Wildlife is an irreplaceable part of the earth's natural system that must be protected for present and future generations (Rajagukguk 2014). In the context of the utilization of wild animals, there is a need to balance between their existing population and exploitation in the natural habitat (Hanim et al. 2020). In Indonesia, the utilization of wild animals is regulated through Government Regulation Number 8 of 1999 concerning the Use of Wild Plant and Animal Species. This law regulates the procedures for utilizing protected species for certain activities with conditions and requirements permitted by the Ministry of Environment and Forestry.

The unavoidable interactions between humans and wildlife can lead to human-wildlife conflict with negative consequences for both parties (Sugianto et al. 2023). This happens because many humans lack knowledge and awareness about wildlife and its role in maintaining the balance and sustainability of the ecosystem (Handziko et al. 2021). Conservation ignorance can lead to wildlife extinction (Selni et al. 2021). Therefore, the perception and attitude of a local community toward wildlife are important for conservation, especially in the context of protected area management (Rumimpunu 2020). This situation is well-presented on the eastern slope of Mount Merbabu National Park.

Mount Merbabu National Park (MMbNP) is a national park located in Central Java Province, Indonesia. This park was established on May 6, 2014, through the Decree of the Minister of Forestry Number SK.3623/Menhut-VII/KUH/2014. The park has an extent of 5.820,49 hectares with altitudes ranging from ± 600 to 3.142 m above sea level. The national park has various fauna species including Javan fuscous langur (*Presbytis comata* subsp. *fredericae* (Sody, 1930), Javan lutung (*Trachypithecus auratus* (É.Geoffroy Saint-Hilaire, 1812), Long-tailed macaque (*Macaca fascicularis* (Raffles, 1821), and other wild animals (Gunawati 2017). Mount Merbabu, where MMbNP is situated, is threatened by several factors, but fires are the most imminent threat due to the drought, which also impacted the surrounding community and wildlife (Putranto et al. 2020). For example, a forest fire occurred in Mount Merbabu in 2023, burning more than 400 hectares of land. This disaster can directly impact wildlife, including the death of several animals, and also indirect impacts, including the destruction of wildlife habitat and decreased food availability (Hidayat et al. 2016).

The community living around a conservation area might serve as the buffer and protector of biological natural resources (Rusiani 2018). However, many people still do not care about wildlife and ecosystem conservation due to a lack of understanding and knowledge (Sabrina et al. 2023). Therefore, this research was performed to document local people's knowledge of wild animals in the eastern slope area of Mount Merbabu National Park. The data resulting from this study might contribute to enriching the information on wildlife species, including habitat conditions, population levels, and distribution in the MMbNP area. This study might help the management of MMbNP since they are constrained by the limited quality and quantity of human resources managing Mount Merbabu National Park.

MATERIALS AND METHODS

Study area and period

Administratively, MMbNP encompasses three districts in Central Java Province, Indonesia, namely Boyolali, Magelang and Semarang. Geographically, Mount Merbabu National Park is located between 110º26'22" E and 7º27'13" S. This research was conducted on the eastern slope of Mount Merbabu at the border area of the Mount Merbabu National Park from October to November 2023. Data collection was performed in 3 villages in Ampel Sub-district, Boyolali District, namely Ngagrong (7°27'28.5"S, 110°29'42.0"E), Candisari (7°27'26.6"S, 110°29'47.1"E), and Ngargoloka (7°26'39.3"S, 110°29'38.8"E) (Figure 1). The study sites are all located around 1,000 masl altitude with a temperature of 24-30°C. Most of the people in the studied area work in farming and animal husbandry and use the land resources for their daily needs. Therefore, they are very concerned about the sustainability of the natural environment.

Data collection

This research used a combination of qualitative and quantitative methods. The qualitative method was performed through interviews and observations. Interviews were conducted with people living in the study location. The respondents were determined by snowball sampling to identify key figures until the data was balanced or saturated (Putri et al. 2017). The snowball method was used in this research with the rationale that informants are known and can provide information according to research needs. Thus, if the information on research needs has been obtained, the information collection is complete (Damaywanti 2013).

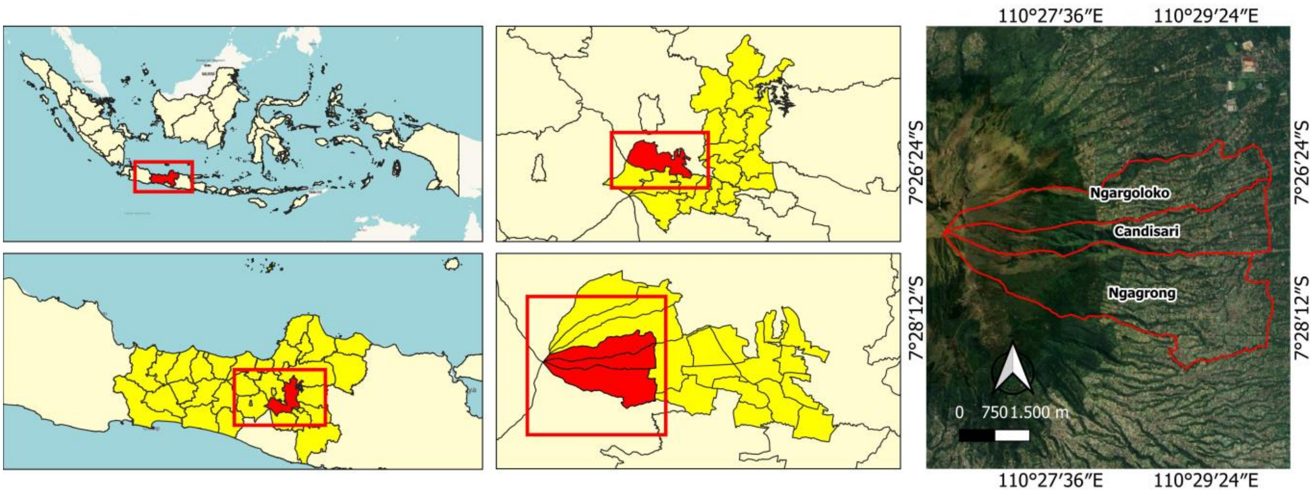

Figure 1. Map of the study area in Ngagrong, Candisari and Ngargoloka Villages, Ampel Sub-district, Boyolali District, Central Java Province, Indonesia

The interviews were done with 65 informants consisting of 30 male and 35 female. The informants included the village head, village officials, farmers, breeders, traders, and factory workers. While conducting interviews, observations were also carried out by directly observing the diversity of wildlife in each village. The quantitative method was conducted by administering questionnaires to 65 respondents. The respondents were selected using a simple random regardless of their strata in society. In this technique, every member of the population has the same opportunity to be selected as a study subject (Firmansyah and Dede 2022).

Data analysis

The data collected was then analyzed and validated using existing literature. Animals were identified by matching their vernacular name with common names. After that, the scientific name was added by matching their name and morphology based on reliable references, such as iNaturalist (https://www.inaturalist.org) and GBIF (https://www.gbif.org). The ecological, social, and economic functions were described based on knowledge and perspective from the local community. Meanwhile, the collected quantitative data is analyzed by calculating the percentage to explain the data descriptively (Newing et al. 2010).

RESULTS AND DISCUSSION

Biodiversity on the eastern slope of Mount Merbabu plays an important role in maintaining the balance of the ecosystem. However, there are significant challenges related to community knowledge of wildlife diversity. Therefore, the community knowledge on wildlife diversity was collected from 65 respondents in Nganggrong, Candisari and Ngaragoka Villages, with demographic data presented in Table 1.

There were 30 male and 35 female informants, most of whom were aged 26-35 years old (24.6%). Respondents had various occupations, but most of them were farmers (80%), 13.8% laborers, 4.6% merchants, and 1.5% civil servants. According to Makabori and Tapi (2019), occupation shows a strong connection with the agricultural sector in each village. The lower percentage of non-farming professions, such as traders, entrepreneurs, teachers, or civil servants, shows economic activities that focus more on the agricultural sector. The result of this study indicates that most people in these villages are strongly linked to agriculture, which may not always have an adequate understanding of wildlife diversity.

Sixty percent of the respondents had an elementary school education, 9.2% had a high school education, 27.7% had a senior high school education, and 3.1% had a university education. This diversity shows the complexity of the community's understanding of environmental issues. Therefore, there is a need for extension and education strategies tailored to the demographic characteristics of each village, emphasizing the participation of underrepresented groups and lower levels of education (Managanta et al. 2018). Secondary and higher education levels were only represented by a few respondents, creating an imbalance in the distribution of potential knowledge on wildlife diversity in the community (Garekae et al. 2017).

Geographical factors, lack of education, and limited access to information may be the main causes of this lack of awareness of the importance of maintaining biodiversity (Abdullah et al. 2022). Improving the local community's understanding of wildlife can increase appreciation of the natural environment and encourage more effective preservation and conservation efforts in the Merbabu area (Muchrodji et al. 2017). Collaboration between the government, educational institutions, and conservation organizations is needed to provide educational and information programs to increase public awareness of wildlife diversity and encourage active participation in nature conservation efforts (Afriza et al. 2018).

Wildlife diversity of fauna

Table 2 provides a comprehensive overview of the wildlife diversity of fauna in Ngagrong, Candisari and Ngargoloka Villages, highlighting the wide variety of species inhabiting this region. There were 42 fauna species documented across different categories, including mammals, birds, and herpetofauna. There were 14 species of wild mammals from 10 families, namely Cercopithecidae, Cervidae, Felidae, Hystricidae, Manidae, Muridae, Sciuridae, Tupaiidae, Vespertilionidae, and Viverridae. The family with the most species was the Cercopithecidae which consisted of monkeys such as Long-tailed macaque (*M. fascicularis*), Javan surili (*P. c.* ssp. *comata*), Javan fuscous langur (*P. c.* ssp. *fredericae*), and Javan Lutung (*Trachypithecus auratus* (É.Geoffroy Saint-Hilaire, 1812). Among the notable mammalian species, Small-toothed palm civet (*Arctogalidia trivirgata* (Gray, 1832) and Asian leopard cat (*Prionailurus bengalensis* (Kerr, 1792) are recognized for their ecological function as pest control. The presence of Sunda pangolin (*Manis javanica* Desmarest, 1822) and Sunda porcupine (*Hystrix javanica* (F.Cuvier, 1823), locally known as *Landak Jawa*, suggests the significance of these species in traditional medicine and trading practices. *Musang Luwak* (*Paradoxurus musangus* (Raffles, 1821) ssp. *javanicus*) plays a crucial role in seed dispersal through its feeding habits.

Table 1. Socio-demographic of the respondents in Nganggrong, Candisari and Ngaragoka Villages, Ampel Sub-district, Boyolali District, Central Java Province, Indonesia

Category	Description	Total (n)	Percentage (%)
Gender	Male	30	46.2
	Female	35	53.8
Age (years)	16-25	4	6.2
	26-35	16	24.6
	36-45	10	15.4
	46-55	13	20.0
	56-65	13	20.0
	> 66	9	13.8
Occupation	Farmer	52	80.0
	Merchant	3	4.6
	Laborer	9	13.8
	Civil servant	1	1.5
Education	Elementary School	39	60.0
	Junior High School	6	9.2
	Senior High School	18	27.7
	College	2	3.1

Table 2. Wildlife diversity of fauna in Ngagrong, Candisari and Ngargoloka Villages, Ampel Sub-district, Boyolali District, Central Java Province, Indonesia

				Role-based on respondent's knowledge		
Scientific name	**Local name**	**Common name**	**Family**	**Ecological function**	**Social function**	**Economic function**
Mammals						
Arctogalidia trivirgata	*Musang*	Small-toothed palm civet	Viverridae	-	-	-
Bandicota bengalensis	*Tikus wirok*	Lesser bandicoot-rat	Muridae	-	-	-
Callosciurus notatus	*Bajing*	Plantain squirrel	Sciuridae	-	-	-
Hystrix javanica	*Landak jawa*	Sunda porcupine	Hystricidae	-	Traditional beliefs	Commercial, traditional medicine
Macaca fascicularis	*Monyet ekor panjang*	Long-tailed macaque	Cercopithecidae	-	Sign of the season	-
Manis javanica	*Trenggiling*	Sunda pangolin	Manidae	-	-	-
Muntiacus muntjak	*Kijang*	Southern red muntjac	Cervidae	-	-	-
Paradoxurus musangus ssp. *javanicus*	*Musang luwak*	Javan palm civet	Viverridae	Seed dispersal	-	-
Pipistrellus javanicus	*Kelelawar*	Javan pipistrelle	Vespertilionidae	-	-	-
Presbytis comata ssp. *comata*	*Surili*	Javan surili	Cercopithecidae	-	-	-
Presbytis comata ssp. *fredericae*	*Rekrekan*	Javan fuscous langur	Cercopithecidae	-	-	-
Prionailurus bengalensis	*Blacan*	Asian leopard cat	Felidae	-	-	-
Trachypithecus auratus	*Lutung budeng*	Javan lutung	Cercopithecidae	-	-	-
Tupaia javanica	*Tupai*	Horsfield's treeshrew	Tupaiidae	-	-	-
Aves						
Acridotheres javanicus	*Jalak kerbau*	Javan myna	Sturnidae	Seed dispersal	Traditional beliefs	Commercial
Copsychus saularis	*Kacer*	Oriental magpie-robin	Muscicapidae	-	-	Commercial
Corvus enca	*Gagak hutan*	Slender-billed crow	Corvidae	-	Traditional beliefs	-
Cyornis banyumas	*Sulingan*	Javan blue-flycatcher	Muscicapidae	-	-	Commercial
Dicrurus macrocercus	*Srigunting*	Black drongo	Dicruridae	Pest control	-	-
Eumyias indigo	*Sikatan ninon*	Indigo flycatcher	Muscicapidae	-	-	Commercial
Falco peregrinus	*Alap-alap kawah*	Peregrine falcon	Falconidae	Seed dispersal	-	-
Geopelia striata	*Perkutut jawa*	Zebra dove	Columbidae	Pest control	Traditional beliefs	Commercial
Ictinaetus malayensis	*Elang hitam*	Black eagle	Accipitridae	Pest control	-	-
Lanius schach	*Pentet*	Long-tailed shrike	Laniidae	Pest control	Traditional beliefs	-
Lonchura punctulata	*Bondol peking*	Scaly-breasted munia	Estrildidae	Seed dispersal	-	-
Macropygia unchall	*Uncal loreng*	Barred cuckoo-dove	Columbidae		-	-
Nisaetus bartelsi	*Elang jawa*	Javan hawk-eagle	Accipitridae	Pest control	-	-
Otus angelinae	*Celepuk jawa*	Javan scops-owl	Strigidae	Seed dispersal	-	-
Pernis ptilorhynchus	*Sikep-madu asia*	Crested honey buzzard	Accipitridae	Seed dispersal	-	-
Prinia familiaris	*Perenjak jawa*	Bar-winged prinia	Cisticolidae	Pest control	Traditional beliefs	Commercial
Psittacula alexandri	*Betet*	Red-breasted parakeet	Psittaculidae	-	-	Commercial, traditional medicine
Pycnonotus aurigaster	*Kutilang*	Sooty-headed bulbul	Pycnonotidae	Pest control	Traditional beliefs	Commercial
Rhipidura phoenicura	*Kipasan ekor merah*	Rufous-tailed fantail	Rhipiduridae	Seed dispersal	-	-
Serinus canaria	*Kenari*	Canary	Fringillidae	Pest control	-	Commercial
Spilornis cheela	*Elang ular bido*	Crested Serpent Eagle	Accipitridae	Pest control	-	-
Sturnus contra	*Jalak suren*	Asian Pied Starling	Sturnidae	-	-	Commercial
Tyto alba	*Burung hantu*	Barn owl	Tytonidae	Pest control	-	-
Zosterops flavus	*Pleci*	Oriental White-Eye	Zosteropidae	Seed dispersal	-	Commercial

Herpetofauna						
Chalcorana chalconota	*Kongkang kolam*	Javan white-lipped frog	Ranidae	Pest control	-	-
Gekko gecko	*Tokek*	Tokay gecko	Gekkonidae	-	-	Traditional medicine
Naja sputatrix	*Ular kobra jawa*	Javan spitting cobra	Elapidae	Pest control	-	-
Polypedates leucomystax	*Katak pohon bergaris*	Striped Tree Frog	Rhacophoridae	Pest control	-	-

There were 24 species of Aves belonging to 17 families dominated by the Accipitridae family. *Elang Hitam* (*ctinaetus malayensis* (Temminck, 1822) and *Alap-Alap Kawah* (*Falco peregrinus* Tunstall, 1771) are the species that contribute to seed dispersal. The avian diversity also included species like the Oriental white-eye, known as *Pleci* (*Zosterops flavus* (Horsfield, 1821) and Rufous-tailed fantail (*Rhipidura phoenicura* S.Muller, 1843), known for their seed dispersal function.

In the herpetofauna category, there were 4 species from 4 families, namely Ranidae, Gekkonidae, Elapidae, and Rhacophoridae. Ranidae and Rhacophoridae are family of frogs such as Javan white-lipped frog (*Chalcorana chalconota* (Schlegel, 1837) and Striped tree frog (*Polypedates leucomystax* (Gravenhorst, 1829), while the species found from Gekkonidae family was Tokay gecko (*Gekko gecko* (Linnaeus, 1758) and species from Elapidae family was Javan spitting cobra (*Naja sputatrix* Boie, 1827). Javan spitting cobra, locally known as *Ular Kobra Jawa*, stands out for its pest control role. Our results underscore the importance of preserving the diverse wildlife in villages for ecological balance and potential economic benefits.

Research on wildlife diversity in Ngagrong, Candisari and Ngargoloka Villages, as revealed in Table 2, is strengthened by similar findings from previous studies in other areas. For example, research by Gunawan et al. (2022) in Ciherang Kehati Park, Bogor, West Java, highlights the importance of understanding the diversity of wildlife in Indonesia. Their findings, which recorded 137 animal species, including 61 bird species, 30 mammal species, and 46 amphibian and reptile species, provide a perspective that aligns with the research results expressed in Table 2. This similarity confirms that Indonesia has geographical conditions as an archipelagic country; diverse, it is indeed home to an extraordinary diversity of wildlife. The importance of wildlife diversity in maintaining ecosystem balance and providing economic and social benefits to society has been confirmed by various studies. Therefore, conservation efforts are a must. Public education, regular patrols to prevent poaching, and the creation of protected areas are concrete actions to protect biodiversity, which is a valuable asset for Indonesia.

Local community knowledge of wildlife animals based on ecological function

The main occupations of the people in the eastern slopes of Merbabu National Park, Ampel sub-district, Boyolali District are farming and livestock raising, so agriculture is the primary livelihood for the community. According to the local community perception, animal wildlife has several functions that can be grouped into ecological, socio-cultural, and economic. Wildlife animals have three ecological functions: pest control and seed dispersal. Disturbances to wildlife in Mount Merbabu National Park, which act as pest control, might result in reduced yields and even crop failure in the surrounding agricultural land. On the other hand, some wild animal species might encroach on cultivated crops when food supplies in the national park are reduced due to disturbances in their habitat. Monkeys are the natural enemies of plantations (forest gardens) from nursery to harvest, so people must spend extra energy and time protecting the farm (Tamia and Zafia 2022).

Respondents were generally unfamiliar with the monkey types, and they often identified them based on their fur color. Therefore, based on their characteristics, two monkey types can be identified, namely Javan fuscous langur (*P. c.* subsp. *fredericae*) and Long-tailed macaque (*M. fascicularis*) that often damage people's farms. These monkeys come in groups of up to hundreds and often encroach the farmland when food supplies are insufficient during the dry season or when disasters such as fires occur in their habitat. The monkeys usually ate and damaged fruit and vegetable crops such as bananas and corn. Until now, there has been no effective way to solve the problem. When the monkeys come down and damage the farm, the community just leaves them because they fear being attacked by the monkeys. However, some communities have also tried to prevent monkey attacks from their farm with dogs. Besides monkeys, several mammals, such as Horsfield's treeshrew (*Tupaia javanica* (Horsfield, 1822) and Lesser bandicoot-rat (*Bandicota indica* (Bechstein, 1800), are also considered as farm pests. These animals often eat seeds, fruits, vegetables, and plant roots. It can also damage plants by tearing and digging them up.

Various species of Aves or birds, such as Javan hawk-eagle (*Nisaetus bartelsi* (Stresemann, 1924), Black drongo (*Dicrurus macrocercus* Vieillot, 1817), Sooty-headed bulbul (*Pycnonotus aurigaster* (Vieillot, 1818), Long-tailed shrike (*Lanius schach* Linnaeus, 1758), Turtle dove (*Geopelia striata* (Linnaeus, 1766), Black eagle (*Ictinaetus malayensis* (Temminck, 1822), and Canary (*Serinus canaria* (Linnaeus, 1758), are considered as pest control by eating insects in the farm (Schupp et al. 2019). Canaries are native to Madeira, the Canary Islands and surrounding areas, but have been found wild in Java. This species is known in Europe as an invasive bird (GBIF Secretariat 2023). The birds prey on various insect pests, damaging crops, such as caterpillars, aphids, and grasshoppers. Not only Aves, herpetofauna such as Javan white-lipped frog (*C. chalconota),* Striped tree frog (*P. leucomystax*), and Javan spitting cobra (*N. sputatrix),* also known for its benefits as pest control by the local community. Not only as pest control, frogs are also herpetofauna, which consume many insects known to be important vectors of zoonotic diseases (Khatiwada et al. 2016). Therefore, frogs are one of the important biological pest controllers. Javan spitting cobra is a snake that has a predatory role in the ecosystem. Snakes are the animals that control the rat or mouse, which are considered as pests (Kholis et al. 2021). Although snakes can be dangerous, these animals also positively impact farmers because they help reduce farm rat pests.

According to the respondents, wildlife animals that are useful in ecology because it's ability to maintain the sustainability of ecosystems and the preservation of species are Javan palm civet (*P. musangus* ssp. *javanicus*), Javan myna (*Acridotheres javanicus* Cabanis, 1851), Peregrine falcon (*F. peregrinus),* Scaly-breasted munia *(Lonchura punctulata* (Linnaeus, 1758), Javan scops-owl (*Otus angelinae* (Finsch, 1912), Crested honey buzzard *(Pernis ptilorhynchus* (Temminck, 1821), Rufous-tailed fantail *(R. phoenicura),* and Oriental white-eye (*Z. flavus*). These animals can disperse seeds after eating them through their feces (García-Rodríguez et al. 2021).

The community still recognizes quite a lot of wildlife. Still, they do not understand their function in ecology, such as the Asian leopard cat (*P. bengalensis*), Sunda porcupine (*H. javanica*), Sunda pangolin (*M. javanica*), and others. Several herpetofauna species from reptiles and amphibians are not widely known and recognized by the community. Only a small number of respondents knew the existence and ecological function of the herpetofauna, such as Striped tree frog (*P. leucomystax*), Tokay gecko (*G. gecko*), and Javan spitting cobra (*N. sputatrix*). Imron et al. (2021) state that herpetofauna are important animals in the food chain to maintain the ecosystem balance, and they have responded well to environmental changes.

Local community knowledge of wildlife animals based on social function

People living on the eastern slopes of Mount Merbabu encounter a lot of wildlife animals daily. However, people's knowledge of wildlife can certainly be observed from its social function, such as signs of seasonal changes, traditional beliefs, or even rituals. Long-tailed macaques (*M. fascicularis*) that creep into residential areas and invade people's plantations (forest gardens) occur during the dry season. Long-tailed macaques will enter residential areas because the food in the forest has become scarce, so they will go into human areas to search for food (Widiyanti 2001). Therefore, almost every day during the dry season, many Long-tailed macaques come to residential areas to find food in people's plantations. However, if the monkeys are chased away or caught by residents, usually the next day, the monkeys will come back in greater numbers for revenge. Therefore, residents think that it is better to let the Long-tailed macaques take a little of the plantation products and not forcefully expel them to avoid greater damage and losses. Sharing kindness and not hurting animals are believed to be good deeds, and those attitudes benefit humans (Maharani et al. 2023).

The presence of some animals is believed to be a sign of seasonal changes, which is associated with local myths and traditional beliefs, such as the crows. In Indonesia, Slender-billed Crow (*Corvus enca* (Horsfield, 1822) are often associated with mystical stories and bad luck because they are a symbol of the arrival of heavenly creatures and a messenger or death signal. Many people believe that the myth of the death-messenger crow is true, although scientifically, it does not make sense (Dwi et al. 2022). If the crows caw continuously around them, people believe that it is a sign that someone will die in the village. However, if the crow lands on a house, it is a sign that the house is being sent by witchcraft or occult, and someone in the house might die. The myth about crows not only occurs in Ngagrong, Candisari, and Ngargoloka Villages but also other areas; many still believe in this myth. In Java, crows flying around a house are always associated with someone dying soon (Suprayitno 2022). Perhaps, this belief is rooted in the Koran (Al-Maidah 5: 31), where the crow provides an example of the first burial of a corpse on earth.

Local community knowledge of wildlife animals based on economic function

Local communities living around forest areas have various interactions with wild animals, both directly and indirectly (Asri and Yanuwiadi 2017). These interactions can include utilization, management, protection, and conflict. Based on the interviews with the respondents in the eastern slopes of Mount Merbabu, Ampel sub-district, Boyolaly District, they have positive and negative perceptions of wildlife animals in terms of economic aspects. Positive perception arises because wildlife provides economic benefits to local communities for commercial and traditional medicine purposes. Local communities derive many commercial benefits from wildlife, such as a source of protein and income through agriculture, trade, and tourism. Wild animals such as monkeys, birds, butterflies, and insects can attract visitors who want to see biodiversity in the Mount Merbabu National Park area. Local communities said these animals also help pollinate wild and cultivated plants, increasing agricultural productivity.

Not only for commercial purposes, the local community on the eastern slopes of Mount Merbabu also uses wild animals as traditional medicine. According to Lusma (2015), 27 species of animals are used as traditional medicine by the Lom, Bugis, Tionghoa, and Malay tribes. Communities around the eastern slopes of Mount Merbabu use Sunda porcupine (*H. javanica*), Red-breasted parakeet (*Psittacula alexandri* (Linnaeus, 1758), and gecko (*G. gecko*) for medical purposes. According to Farida (2012), porcupine liver contains amino acids, such as aspartic acid, glutamic acid, histidine, leucine, and phenylalanine, higher than beef, duck, tuna, and chicken liver. With its high amino acid content, porcupine liver can speed up the healing process of disease. In Senggul Village, Silat Hilir Sub-district, Kapuas Hulu District, local people use porcupine thorns and *Geliga* to treat jaundice, liver, and back pain by drinking dried and brewed *Geliga* and applying the burnt tips of the thorns as an external medicine (Krisyanto et al. 2019). *Geliga* is a collection of undigested organic and inorganic materials from porcupine food mixed with other substances in the digestive tract or blood that clump together and form spheres like stones (Syahputri 2020). The *P. alexandri* gall has benefits for treating food poisoning when ingested immediately following the onset of the acute symptoms (Dimaer 1986). Geckos can be a traditional medicine for asthma (Liu et al. 2008) and can also be used to treat stomach ulcers where the part used is the liver (Pakaenoni et al. 2023).

The community living on the eastern slope of Mount Merbabu also has a negative perception of wild animals due to economic losses caused by such animals, such as destroying crops, disturbing livestock, disease vectors, and causing conflict. On the eastern slopes of Mount Merbabu, monkeys often encroach and destroy residents' farms, and Long-tailed macaques are the type most likely to do that (Maula et al. 2017). Wild animals can also be a source of conflict between the community and conservation area managers, especially if there is illegal hunting or land encroachment.

Local community knowledge of wildlife based on economic function is heterogeneous and complex. This knowledge is influenced by the perceived benefits and disadvantages, as well as other factors related to culture and environment. Therefore, the function of wild animals in the economic sector in the studied area must be managed well so that they can provide maximum benefits and reduce negative impacts. This management involves collaboration between the community, government and conservation area managers so that common goals can be achieved and on target (Abdullah et al. 2022). Some efforts that can be made are providing education and outreach about the importance of wild animal conservation, developing the potential for wild animal-based tourism, providing incentives and assistance to farmers who are experiencing losses due to wild animal pests, implementing health and safety protocols for visitors and the public, and enforcing laws against perpetrators of illegal poaching or land encroachment.

In conclusion, local people living on the eastern slopes of Mount Merbabu still maintain knowledge of wildlife diversity and conservation with diverse perceptions of ecological, social, and economic aspects. However, there is a lack of understanding about wildlife in the community, especially regarding environmental issues and human-wildlife conflict. Therefore, socialization and education strategies tailored to the demographic characteristics of each village are needed, as well as cooperation between the government, educational institutions, and conservation organizations to improve community understanding of wildlife diversity and encourage active participation in natural conservation. In addition, it is also necessary to increase the awareness and participation of local communities in wildlife conservation and reduce human-wildlife conflict in a mutually beneficial approach.

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