Optimum Forest Management through Investigating Land-cover Changes, Deforestation Drivers, Forest Structure and Local Livelihoods in Banmauk Township, Myanmar

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Table of Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

AAC	Annual Allowable Cut
AUC	Area Under the Curve
BSS	Burma Selection System
BUCF	Banmauk Unclassified Forest
CF	Community Forest
CFI	Community Forestry Instructions
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
DFID	Department for International Development
EAO	Ethnic Armed Organization
EIA	Environmental Impact Assessment
FAO	Food and Agriculture Organization
FD	Forest Department
FDI	Foreign Direct Investment
FGD	Focus Group Discussion
FRA	Forest Resource Assessment
GDP	Gross Domestic Income
GIS	Geographic Information System
IUCN	International Union for Conservation of Nature
IVI	Importance Value Index
MCRB	Myanmar Centre for Responsible Business
MONREC	Ministry of Natural Resources and Environmental Conservation
MSS	Myanmar Selection System
MTE	Myanmar Timber Enterprise
NMDS	Non-metric Multidimensional Scaling
NTFP	Non-timber Forest Product
OLS	Ordinary Least Square Regression
PA	Protected Area
PFE	Permanent Forest Estate
PPF	Protected Public Forest
RF	Reserved Forest
ROC	Receiver Operating Characteristic
SFM	Sustainable Forest Management
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VIF	Variance Inflation Factor
WGS	World Geodetic System
WHO	World Health Organization
ZNP	Zalon Taung National Park

Abstract

Despite having a long history of forest management and preserving substantial forest cover on Southeast Asia's mainland, Myanmar has been ranked as the seventh most deforested nation and is a worldwide hotspot for deforestation. For three decades, specifically, from 1990 to 2020, Myanmar's forest cover significantly decreased from 39.7 million hectares (57.97%) to 28.5 million hectares (42.19%), with an annual forest loss rate of 1.17% in 1990-2000, 1.03% in 2000-2010, and 0.96% in 2010-2020. The drivers of deforestation and forest degradation in Myanmar are primarily human activities, including agriculture expansion, mining, infrastructure development, over-exploitation of forest resources, illegal logging, use and demand for fuelwood, and shifting cultivation. Land-cover changes and deforestation threaten the country's natural and socio-economic environment and hinder its target to reach a low-carbon, climate-resilient, and sustainable development pathway. Under the current pressure of deforestation and livelihood systems in Myanmar, this study aims to investigate human impacts on: (1) forest cover, (2) forest structure and diversity, and (3) local community forest dependency to optimize forest management and people's well-being. Banmauk Township, Sagaing Region in northwest Myanmar, was selected as a study area due to its immense natural forest cover with recent land-cover changes and deforestation concerning gold mining and agriculture expansion, which threaten its ecological integrity.

Chapter 1 describes the research background and issues, the history of forest management in Myanmar, and the general descriptions of the research site. To fulfill the main objective, firstly, Chapter 2 investigated land-cover changes and probable factors driving deforestation in the forest landscape of north of Banmauk Township, which confronts challenges with the spread of gold mining. Landsat 7 ETM+ and Landsat 8 OLI satellite imagery were used to identify seven land-cover classes via supervised random tree classification. A stratified random sampling method assessed the classified maps' accuracy and estimated the areas. Binary logistic regression analysis predicted the probable biophysical and locational factors to affect deforestation. The results of Chapter 2 revealed that dense forest coverage decreased from 45.65% in 2000 to 29.01% in 2021, while open forest areas increased from 49.33% to 54.51%. Mining areas increased considerably from 0.37% to 5.35%, while settlement and barren/scrub land areas increased from 0.16% to 0.51% and 1.71% to 7.70%, respectively. Agricultural areas slightly increased from 2.11% to 2.33%, while water areas remained almost the same at around 0.60%. Post-classification change detection analysis showed that deforestation occurred mainly through converting forest land to mining and barren/scrubland. The results of binary logistic regression indicated that lower altitudes and road accessibility are significantly associated with the potential for deforestation.

The Zalon Taung National Park (ZNP) in Banmauk Township was established as a protected area (PA) in 2022 to protect the area's cultural value, ecosystems, native flora, and

wildlife. Before its declaration as a PA, ZNP was gazetted as Nantkaunghu reserved forest, a part of the timber production working circle, from which teak and other hardwoods were selectively logged to get the nation's revenue. Chapter 3 examined how human activities impact the forest structure, tree species diversity, and composition inside ZNP and outside (the Banmauk Unclassified Forest-BUCF). The vegetation survey was conducted in April and May of 2022 by setting up 34 sample plots (40 × 40 meters) using a random sampling approach. The tree density, basal area, Shannon-Wiener diversity index, Simpson index, Pielou evenness, fisher's α diversity, and Importance Value Index (IVI) were used to determine forest structure and tree species diversity. A total of 116 tree species (≥10 cm dbh), representing 87 genera and 48 families, were identified. The ZNP sample plots had a slightly higher stand density (322 individuals ha^{-1}) and a basal area (20.6 m^2 ha^{-1}) than BUCF (stand density: 306 individuals ha^{-1} and basal area: 15.0 m^2 ha^{-1}), which is accessible to collect firewood and timber extraction by residents. The reverse J-shaped pattern of population structure indicated that the stands' populations were progressive and healthy. BUCF featured the most Verbenaceae (12.9%) and ZNP the most Euphorbiaceae (7.2%) families. *Protium serratum* had the highest IVI in BUCF (26.91%) and *Dipterocarpus alatus* (18.39%) in ZNP. The dominance of *Dipterocarpus alatus* and *Dalbergia oliveri* (IUCN Red List-endangered species) in BUCF require special attention in conservation planning. In ZNP, previous logging activity dramatically reduced the relative density and IVI values of commercially important species such as *Tectona grandis*, *Dalbergia oliveri*, and *Protium serratum*. Numerous species of medicinal plants, such as *Lannea coromandelica*, *Cinnamomum obtusifolia*, *Millettia cinerea*, *Garcinia paniculata*, and *Millingtonia hortensis*, are found in ZNP. These medicinal plants exhibit high conservation values and should be protected for biodiversity and human safety. Despite the human impact on the forests, the high tree density and basal area of economically valuable timber species suggest that these forests remain essential for human well-being. According to the NMDS ordination, differences in tree species compositions were significantly linked with elevation, the intensity of logging, and distance to the village and road. The decision to designate ZNP as a PA is a worthy measure. However, it is imperative to ensure the preservation of the adjacent BUCF to protect the biodiversity of ZNP effectively.

According to Chapters 2 and 3, the results revealed that human activities, including gold mining, logging, and local people's reliance on forest resources, all led to changes in forest cover, structure, and composition. Chapter 4 assessed the determinants of rural households' dependency on forest resources for livelihoods and income in three villages near ZNP and BUCF. Information was gathered from 90 randomly selected households from three villages using a semi-structured questionnaire. All respondents were asked to recall how much they had obtained, sold or consumed from farms and forests over the previous 12 months. The econometric analyses use descriptive statistics, Kruskal Wallis tests, binary logistic regression, and ordinary least squares (OLS) regression models. Gini coefficients and Lorenz curves were also calculated to assess the income disparity among rural households. The findings revealed that family income from the forest accounted for 14–16% of the total income, farm income comprised 37–44%, off-farm income comprised 3-29%, and income from wage labor in the gold mining accounted for 20–38%. Among all forest products, timber contributed more to forest income with a share of 43-60%, followed by firewood (18-24%), medicinal plants (8-26%) and bamboo (4-15%), respectively. The binary logistic regression analysis results show that family size and distance to the forest significantly affect the dependency of households on forest resources, while other variables seem to be insignificant. The OLS regression model revealed that agriculture income, wage employment income, salaried job income and distance to the forest were significantly related with the household's income from forest. The overall computed Gini coefficient of total income with forest revenue was 0.19. However, it increased to 0.23 without forest income, indicating that the exploitation of forest resources may help to lessen economic inequalities among rural households.

The general discussions were offered in Chapter 5 to improve forest management and local livelihoods in Banmauk Township based on the critical findings of Chapters 2, 3, and 4. The study suggested that additional efforts are needed to enforce laws and regulations regarding mining operations to ensure following sustainable mining practices and systematic post-mining land reclamation and plantation establishment once gold mining is complete. The Forest Department and relevant institutions must continuously monitor, manage, and execute laws and regulations on unlawful mining on the forest land to lessen damage to the forest ecosystem services and biodiversity. In the degraded and jungle forest areas of the BUCF, community forestry development might encourage local participation in forest management, therefore decreasing poverty and reliance on ZNP. Since unclassified forests are more vulnerable to species compositional fluctuation and extinctions owing to their easy access, forest managers must prevent illegal logging and the local use of certain tree species for fuel in BUCF. The study suggested that if the remaining natural habitats in BUCF, where the villagers collect forest resources, are effectively managed to encourage native species to persist, it will gain enormous biodiversity both inside and outside ZNP. The forest management should take into consideration the beneficiaries of forest resources to households' socio-economic context in order to apply appropriate measures to balance conservation and livelihoods. Alternative energy sources, support for the agricultural sector, access to higher education, and public awareness about biodiversity conservation are essential for balancing forest dependency and biodiversity conservation in the area.

Chapter 1. Introduction

1.1 Research Background and Issues

Myanmar has a variety of habitats and ecosystems, as well as forests and biological resources, due to its location at the intersection of three ecoregions: the Sino-Himalayan, Indochinese, and Malayan Peninsular. The forests of Myanmar are a crucial component of the country's forest management plan since they provide a significant source of revenue for the nation and enhance the socio-economic and well-being of local populace. Although the country has a long history of forest management and is still holding the second-largest extent of forest cover in mainland Southeast Asia, Myanmar has been ranked as the seventh most deforested nation and identified as a deforestation hotspot in the world [1]. The extent of forest cover in Myanmar declined from 57.97% of the country area in 1990 to 46.96% in 2010, and 42.19% in 2020 with an annual forest loss rate of 1.17% in 1990-2000, 1.03% in 2000-2010, and 0.96% in 2010-2020 [2]. In Myanmar, 24.8% of the population lives in poverty, and the proportion of poor individuals in rural regions is 6.7 times greater than in urban areas [3]. Land use conflicts and rural poverty related to deforestation and biodiversity loss are rising in rural areas, where 63% of the land is forested or wooded, and most rural households depend on forest resources for food, shelter, fodder, and fuel [4]. Unsustainable resource utilization frequently results in decreased tree diversity, loss of forest cover, habitat fragmentation, and disruption of ecological processes. Consequently, loss of forest resources would hamper the nation's aspirations to transition to a low-carbon, climate-resilient, and sustainable development pathway [5].

In global debates, specific actions have been proposed to prevent or mitigate any potential environmental and socio-economic consequences caused by the loss of forest resources. As an immediate response to the issues of forest cover loss and to encourage biodiversity conservation, the government of Myanmar has increased the amount of land under the permanent forest estates (PFE) and protected area system (PAS) [6] which cover 25.84% and 6.44% of the nation's area, respectively [7]. However, just 41% (11.8 million hectares) of the nation's forests are under the status of PFE, with the majority of the remaining forests located in the Sagaing, Kachin, Shan, and Tanintharyi regions [8]. Interventions that effectively combat deforestation and forest degradation need comprehensive data and analysis of forest cover changes and the factors that cause these changes [9, 10]. Meanwhile, changes in forest cover are happening at the local level, so the reasons that directly drive these changes and the underlying social, economic, and political forces behind these changes are recognized to some extent locally [10]. This information on local land use activity is critical for place-specific evaluation and optimizing forest management plan to address and monitor the changes in forest cover. Studies on deforestation assessments often use remote sensing data, records, and scientific literature at the global, regional, or national level [11-13]. Remote sensing has been used in location-specific investigations to track changes in forest cover on a smaller scale [14, 15]. However, remote sensing data are constrained since image interpretations rely on the technical abilities and experience of individuals studying the maps and other technical issues, including continuous cloud cover [16]. Most critically, some indicated drivers are not entirely captured by the remote sensing data, especially selective logging related to forest degradation [17, 18]. Field observations will better understand the many factors and explain the dynamic processes resulting in forest cover changes [10, 19]. Analysing forest cover, forest structure and tree species composition affected by human activities and socio-economic reliance of local community is necessary to establish policy interventions, conservation initiatives, and community engagement approaches that promote effective forest management.

Analysis of human interactions with the forests has proven essential for promoting forest management under the growing pressure of deforestation and livelihood systems in biodiversity-rich areas like Myanmar [20-22]. This study's targeted area, Banmauk Township, possesses a significant and continuous natural forest with the vigorous growth of commercially valuable tree species like teak (*Tectona grandis*), kanyin (*Dipterocarpus alatus*), tamalan (*Dalbergia oliveri*), ingyin (*Shorea siamensis*), and sagat (*Quercus glauca*). These forests are a crucial component of the forest management plan because they provide a significant source of income for the nation and enhance the well-being of the local population. On the other hand, the literature and remote sensing data highlighted the serious issues with converting forest land to other land uses due to the growth of agricultural land and the explosive growth of mining in Banmauk Township [2, 23]. Although mining, logging, and agricultural expansions result in land cover and forest stock change, studies on these land use activities' impacts on forest cover and structure still need to be conducted in Banmauk Township. Likewise, local communities' reliance on forests, their livelihoods and traditional farming practices are little understood. Understanding the interactions between local communities' socio-economic conditions and the forest stock conditions that emerge through the development of various land uses, such as gold mining, logging, and agriculture expansion can be used to give some basic information for future landscape management which combines economic development and biodiversity conservation. This study aims to evaluate the following three components of human-forest interactions to investigate the underlying causes of forest loss and improve forest management based on the actual causes and rationales -

Component 1 - Forest cover changes at the local scale to identify the causes and driving factors of these changes,

Component 2 - Vegetation structure and diversity driven by human activities on forest, and

Component 3 - Forest income contribution of rural households and determinants of their dependency on forests.

Some studies conducted in Myanmar examined the issues of changing forest cover and its driving factors [14, 24], the importance of forests in sustaining local livelihoods [25, 26], and the effects of human reliance on forest diversity and composition [27]. These studies aim to foster biodiversity conservation and enhance local livelihoods, primarily at the local, regional, and national levels. The current research intends to optimize forest management while acknowledging the connections among forest cover, forest structure and local livelihoods throughout the components of the landscape. It is essential to consider all connected aspects when forest biodiversity and other land use activities compete and offer competing interests [28]. Due to the increasing demands for land and forests, sustainable forest management will be necessary to ensure that the forests are maintained successfully to balance different objectives involving timber production, social outcomes, and environmental concerns. Governments must consider the local needs, encourage public engagement, and develop locally appropriate policies and governance structures to promote sustainable forest management [29]. The study’s findings will be crucial in guiding forest managers and policy planners in implementing holistic approaches for promoting forest management, local livelihoods and biodiversity conservation.

1.2 Literature Review of Forest Management in Myanmar

1.2.1 Forest resource base and forest management

Myanmar is a tropical nation in continental South East Asia with a total area of 676,577 km^2. It has borders with China, India, Laos, Thailand, and Bangladesh. Due to the diverse range of topography and meteorological conditions, Myanmar's forests are diverse in composition and structure and form a valuable ecosystem. There are six major forest types in Myanmar. They are (1) tropical evergreen forest, (2) mixed deciduous forest, (3) dry forest, (4) deciduous Dipterocarp Forest, (5) hill and temperate evergreen forest, (6) tidal, beach and dune, and swamp forest [6]. Among them, the most common forest type is mixed deciduous forest, representing about 38.2% of the total forest area [30]. Teak trees found in the mixed deciduous forest are of better quality; for example, the best teak trees grow in moist, mixed deciduous forests [31]. According to data from 2003, Myanmar was home to 16.5 million hectares (86.7%) of the world's natural teak forests [31].

The state owns all forests of Myanmar but grants certain management rights to communities or private companies. The Forest Department (FD) is responsible for managing forest resources, and the forest areas under the management of FD are reserved forest (RF), protected public forest (PPF), and protected area system (PAS), all gazetted through a legal process. RF and PPF collectively constitute the Permanent Forest Estate (PFE). RF is the area of the forest landscape with higher value timber stands at that time that the government declared for state timber production under a forest management plan, with no public harvesting rights. PPF is the area of forest landscape with lower commercial value timber stands. PPF is declared for the people's welfare to meet their requirements for forest products under legal rights and to discourage people's encroachment into RF. In contrast, PAS is decided to protect the diverse

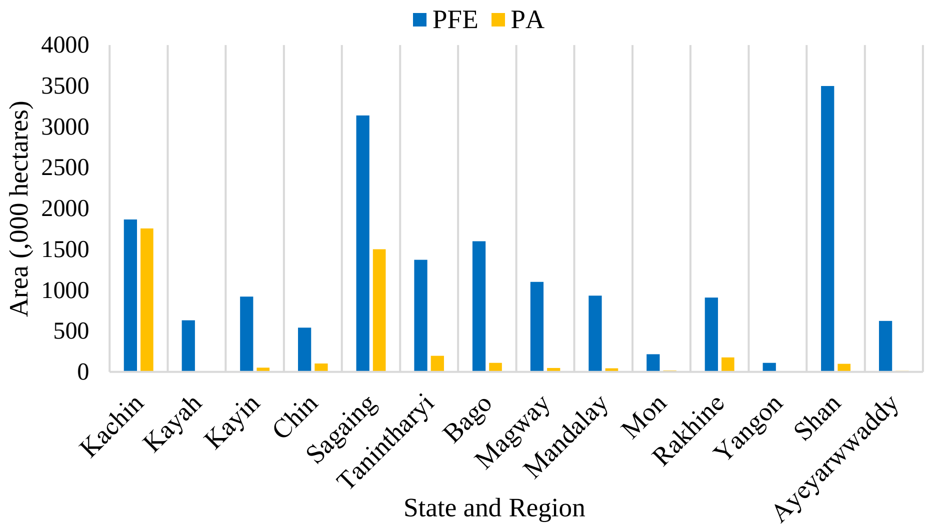


Figure 1.1: PFE and PA coverage

ecosystems, flora, and fauna of Myanmar in long-term. Unclassified forests are forested areas not under the PFEs or PAs but under the land at the disposal of the government. Presently, PFEs and PAs cover 25.61% and 6.43% of the nation, respectively, and the Forest Department aims to expand them up to 30% and 10% by 2030 [6]. According to the national statistics for 2021, Shan State and Sagaing Region have the most significant coverage of PFE with 3.5 million hectares and 3.1 million hectares, respectively, while Kachin State has the most PAs of 1.7 million hectares [32] (Figure 1.1).

According to the definition of FAO, forest management is the purposeful formulation and implementation of plans for the intelligent and sustainable use of forests and other wooded areas for achieving the environmental, economic, social, and cultural targets [33]. The ultimate goal of forest management is sustainable forest management (SFM), and many strategies and approaches have been used to reach the goal. Myanmar has practiced systematic and scientific forest management for sustainability in the forestry sector since 1856 [6]. A German Botanist, Dr. Dietrich Brandis, developed the Exploitation-Cum-Cultural System in 1856 to ensure the long-term viability of natural teak-bearing forests. This system was referred to as the Brandis Selection System. Although Brandis considered the traditions and culture of Myanmar people and the governing principles of Myanmar monarchs, the policy and rules for the development of the forest sector and the management of forest resources were based on Indian policy and law [34, 35]. The Burma Selection System (BSS) and, eventually, the Myanmar Selection System (MSS) were later modifications of the Brandis Selection System.

The main objectives of the MSS are to harvest annual yield on a sustainable basis and to work out estimated future yield. MSS involves forming felling series, each divided into 30 annual coupes based on equal productivity and more or less the same size and worked over a 30-year felling cycle. The features of MSS include determining the Annual Allowable Cut

(AAC) for teak and hardwood, doing pre- and post-harvest inventories, and performing silvicultural treatments such as improvement felling, enrichment planting, climber cutting, and so on. Forest management strategies alter with the changes in socio-economic factors, technological advances, traditional values, and other considerations. SFM in Myanmar has several obstacles and fails due to overexploitation, disorganized shifting cultivation, illegal logging, the conflict between forest sustainability and forest income, and policy inconsistency between the forest sector and other economic sectors like agriculture and mining.

1.2.2 Deforestation and forest degradation drivers

Deforestation and forest degradation are severe issues in most developing countries like Myanmar. In past decades, Myanmar has seen alarming rates of deforestation and forest degradation; the net annual loss of forest area was 1.17% in the years 1990–2000, 1.03% in the years 2000–2010, and 0.96% in the years 2010–2020 [2]. The mountainous and hilly regions of the Kachin, Sagaing, Tanintharyi, Shan, and Chin States are where most of Myanmar's intact forests reside [36]. On the other hand, Shan and Sagaing Region lost the most intact forests, presumably due to being severely fragmented and surrounded by mining and agricultural development [36]. Unfortunately, most forest loss and degradation have occurred in RF. In 2014, RF comprised 27% of intact forest, 55.2% of degraded forest, 14.9% of non-forest, and 2.1% of plantations [36]. Between 1990 and 2000, the growing stock of Myanmar's most economically important tree species dropped from 1.34 billion to 560 million cubic meters [37]. In addition to its rapidly expanding domestic needs, an insatiable demand for raw materials from the neighbouring countries are forcing significant changes in forest resources [36].

The primary drivers of deforestation and forest degradation within the forestry sector are over-exploitation of timber (both legal and illegal), over-extraction of fuelwood and charcoal, unstable shifting cultivation, forest fires, over-grazing, pests and diseases, storms, and landslides [21]. Beyond the forestry industry, the expansion of agriculture (for both subsistence and commercial purposes), mining, infrastructure development, hydropower development, urbanization, resettlement, and aquaculture development are primarily responsible for deforestation and forest degradation [21]. Figure 1.2 shows the changes in forest cover from 1990 to 2020 according to the data of forest resources assessment by FAO.

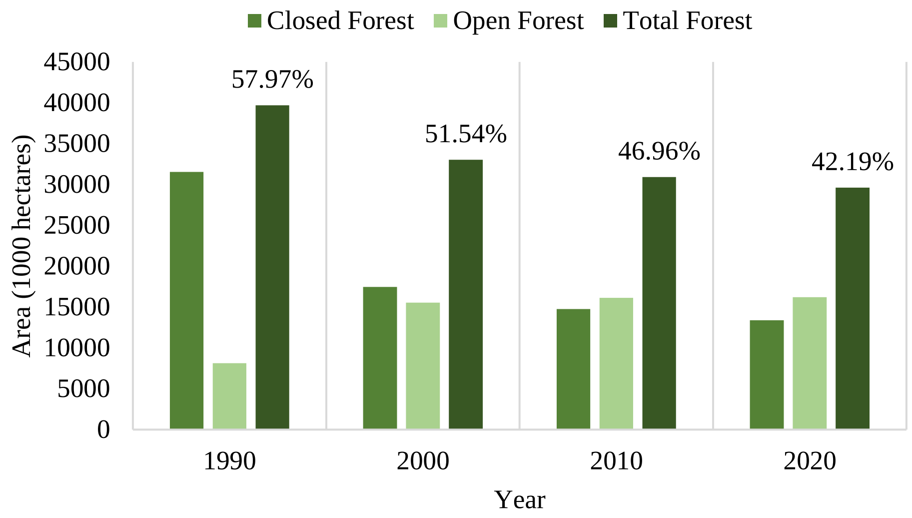


Figure 1.2: Forest cover changes from 1990 to 2020

Illegal logging is exploiting timber and fuelwood without authorization or contravening the law. Exploiting the forest trees above the AAC, overlooking MSS, and getting permission to take down young trees are all harmful practices similar to illegal logging. Like other countries, Myanmar must work to meet its goals for economic development, but these goals often disagree with sustainability. In order to boost both the regional and national GDP, the forestry sector in Myanmar has established an annual income target. Attempts to meet this income target often encourage the overuse of forest resources above AAC. Although reliable data are difficult to find, the EITI report for 2015-2016 showed that 29 million hectares of forest in Myanmar contributed USD 254 million to the national economy in 2011, equivalent to around 1% of the country's GDP [38]. Timber exports comprised 12% of all exports in 2013, with wood and wood products being the third-largest export earner [4]. To seize foreign exchange earnings, MSS for forest management and AAC had gone unnoticed in the past years. In addition, household fuelwood usage is high and rising. Biomass from natural forests supplies around 75% of the country's energy requirements [39]. Fuelwood provides 69.2% of cooking energy, and 4 out of 5 homes utilize it [40]. According to 2015 forest resource assessment data, 90% of all wood extracted from the forest is for fuelwood [41]. Unsustainable fuelwood collection is an issue, leading to deforestation and forest degradation.

While acknowledging past failures in sustainable forest management and addressing the alarming rate of deforestation and forest degradation, Myanmar is taking steps to reform the institutional arrangements in the forestry sector, restructure Myanmar Timber Enterprise (MTE), impose a time-limited logging ban on timber production, revise AAC for the relevant timber species, and extract timber below AAC [19]. However, a comprehensive plan for the improvement of forest management that links to other sectors and the chance to better serve communities still needs to be developed [19].

Rapid agricultural expansion with public favour is often the principal driver of deforestation nationwide. Agriculture normally contributes nearly one-third of the country's GDP, accounts for 20 to 30% of total export earnings, and employs more than 70% of the workforce [42]. However, efficient land-use plans are needed to safeguard the forested landscapes and forest resources from the expansion of shifting cultivation. Shifting cultivation is frequently said to lead to deforestation since slash-and-burn methods eliminate forest cover. Leimgruber et al. (2005) demonstrated significant forest cover loss in Chin State and the Naga self-administration zone of the northern Sagaing Region due to extensive shifting cultivation [43]. Shifting cultivation in southern Chin State is causing an environmental disaster owing to decreased cycle durations, vacant land farming, and forested area encroachment [44]. Shifting cultivation at the mountainous Shan State has evolved into a more permanent form of agriculture or monoculture plantation due to rising political, social, and demographic pressures, posing an increasing danger to the forest ecosystem services [45]. However, the survival of natural forests and ecosystems is supported by shifting cultivation if practiced with a sufficient rotational period. In the traditional shifting cultivation system in Bago Mountains, shifting cultivation plots were abandoned as fallow land for over 15 years, which local people said to recover the forest vegetation again [46]. Shifting cultivators were the first step in developing the Taungya method, which was the precursor of agroforestry and community forestry [47].

Mining operations which have rapidly expanded since 2011, have been regarded as a significant deforestation driver in recent years, causing long-term damage to the forests. Mining is the third largest recipient of FDI, earning approximately USD 1.5 million in 2013-14 financial year [48]. Myanmar has historically mined precious metals and other minerals. There are two primary gold resources in Myanmar based on geology: (1) placer and (2) hard rock ore [49]. In placer deposits, mineral concentrates in the loosely packed sedimentary material. Hard rock deposits are composed of quartz veins found within rock masses [49]. The Mining Law and rules provide licenses for large-scale, medium-scale, small-scale, and subsistence mining. Despite the legislative framework, forest and water resources as well as local communities need environmental and social protection in mining operations [50, 51]. Mining operations in Myanmar can be seen as (1) formal and (2) informal mining. Formal mines are permitted or licensed by the Union Government or its representatives. Informal mines include Ethnic Armed Organizations (EAO)-permitted or company-leased mines without a government-issued mineral production permit. More than 46,000 hectares of mining areas are likely to exist in Myanmar, with 88% concentrated in the Kachin, Sagaing, and Mandalay Regions [52]. Gold mining is expanding along the major rivers and their tributaries in Sagaing Region and grew by 743.6% between 2002 and 2014 [52]. According to the Mining Law (2015), large-scale mining operations must engage in land rehabilitation through plantation establishment [53]. Due to weak law enforcement, the mandate for forest restoration does not influence small-scale operations or subsistence mining that have trespassed upon the permanent forest estates (PFEs)

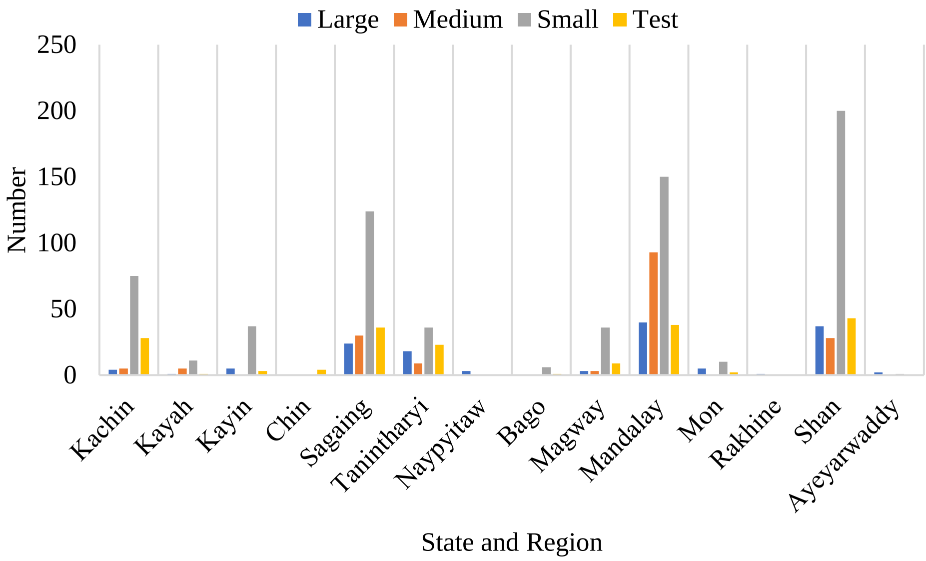


Figure 1.3: Formal mining permits in 14 States and Regions of Myanmar

Note: "Test" refers to the prospecting and exploration stage of the mining process, which is the initial step in finding a deposit with considerable profit potential.

and pose a severe threat to the forests [49]. Figure 1.3 shows the formal mining operations in the fourteen States and Regions of Myanmar.

1.2.3 Policies, laws and action plans

Myanmar lacked a comprehensive national forest policy prior to 1994. The development of the forest sector was addressed by the India Forest Policy of 1894 and occasionally through ad hoc measures until the enactment of the Burma Forest Act in 1902 [54]. A team of specialists including the local experts, foreign experts, and the officials from the Ministry of Forestry established Myanmar Forest Policy in 1995 with the support of FAO [54]. The Forest Policy (1995) was developed with proper respect for forestry principles, the larger context of sustainable development, and environmental issues. The 1902 Burma Forest Act was the foundation for the 1992 Forest Law. The Forest Law, revised in 2018 based on the former Forest Law of 1992, is the primary legal framework to effectively implement the government's forest and environmental conservation policies. The Forest Law (2018) describes the principles of sustainable forest management while aiming to encourage people to participate in the forest management and simultaneously supporting their fundamental necessities [55].

The Conservation of Biodiversity and Protected Areas Law (2018) promotes co-management, supports safeguarding community-protected areas, and acknowledges local communities' rights and potential responsibilities in protected area management [56]. According to the Community Forestry Instructions (CFI-2019), community forest (CF) is allowed to establish in the protected area's buffer zone and produced not only for local consumption needs but also for small- to large-scale CF-based enterprise development [57].

Table 1.1: Policies, Laws and action plans for the management of forests

No.	Year	Policies/Laws/Action Plans
1.	1995	Myanmar Forest Policy
2.	2012	Environmental Conservation Law
3.	2014	Environmental Conservation Rules
4.	2016	National Land Use Policy
5.	2018	Forest Law (Revision of 1992 Forest Law)
6.	2018	Conservation of Biodiversity and Protected Areas Law (Revision of 1994 Protection of Wildlife and Protected Areas Law)
7.	2018	Conservation of Biodiversity and Protected Areas Rules (2002 Protection of Wildlife and Protected Areas Rules)
8.	2019	National Environment Policy
9.	2019	Myanmar Climate Change Policy
10.	2019	Community Forestry Instructions (Revision of 1995 and 2016 Community Forestry Instructions)
11.	2019	Forest Rules (Adds to revises 1995 Forest Rules)
12.	2001-02 to 2030-31	The National Forestry Master Plan
13.	2009	National Sustainable Development Strategy for Myanmar
14.	2017-18 to 2026-27	Myanmar Reforestation and Rehabilitation Programme
15.		National REDD+ Strategy

Land tenure rights for producing timber and forest resources in CF are granted to local communities for 30 years, which is extendable [57]. Despite encountering various obstacles, CF has the potential to influence the forestry sector positively and significantly. Table 1.1 shows policies, laws and strategic action plans in Myanmar to preserve forest resources, conserve natural biodiversity, and mitigate and adapt to climate change.

1.3 Research Objectives

The main objective of this study is to investigate forest cover, forest structure, and tree species diversity impacted by human activities and socio-economic reliance of local communities in Banmauk Township, Sagaing Region in Myanmar, to provide evidence-based guidance for forest managers and decision-makers to optimize forest management and people well-being.

The specific objectives are-

1. To explore the extent of forest cover changes and deforestation drivers in the forested landscape affected by various human activities,
2. To analyze the vegetation structure, diversity, and composition of the forests impacted by human activities and socio-economic reliance of local communities,
3. To examine the reliance of the nearby communities on forests and the extent to which forest-based income contributes to their livelihood, as well as to evaluate the underlying socio-economic factors that motivate these trends, and

4. To offer thorough recommendations that can effectively mitigate the current disturbances in the area and safeguard the remaining forests, thereby promoting sustainable forest resource management and local livelihoods in the long-term.

1.4 Research Site

1.4.1 Location and forest resource base

All research was conducted in Banmauk Township, Katha District, Sagaing Region, in Northwestern Myanmar (Figure 1.4). Banmauk Township shares borders with Homalin Township and Mohnyin Township of Kachin State to the north, Indaw Township to the east, Wuntho Township to the south, and Paungbyin Township to the west. At the border of Kachin State and Banmauk Township, there are three-mountain ranges with a height of over 1,700 meter, and the ridges descend to Banmauk and Indaw Township [58]. The prominent rivers in the township are the Mu River and Meza River. The rivers and several big and small streams are essential water sources for agriculture and domestic use. The Banmauk Township is accessible by road, and the primary mode of transportation is by car and motorcycle. The township covers an area of approximately 3,418.25 km^2, with about half of the total area covered by forests. The remaining portion of the township is characterized by agriculture fields and mining sites, with gold and copper being the primary minerals extracted.

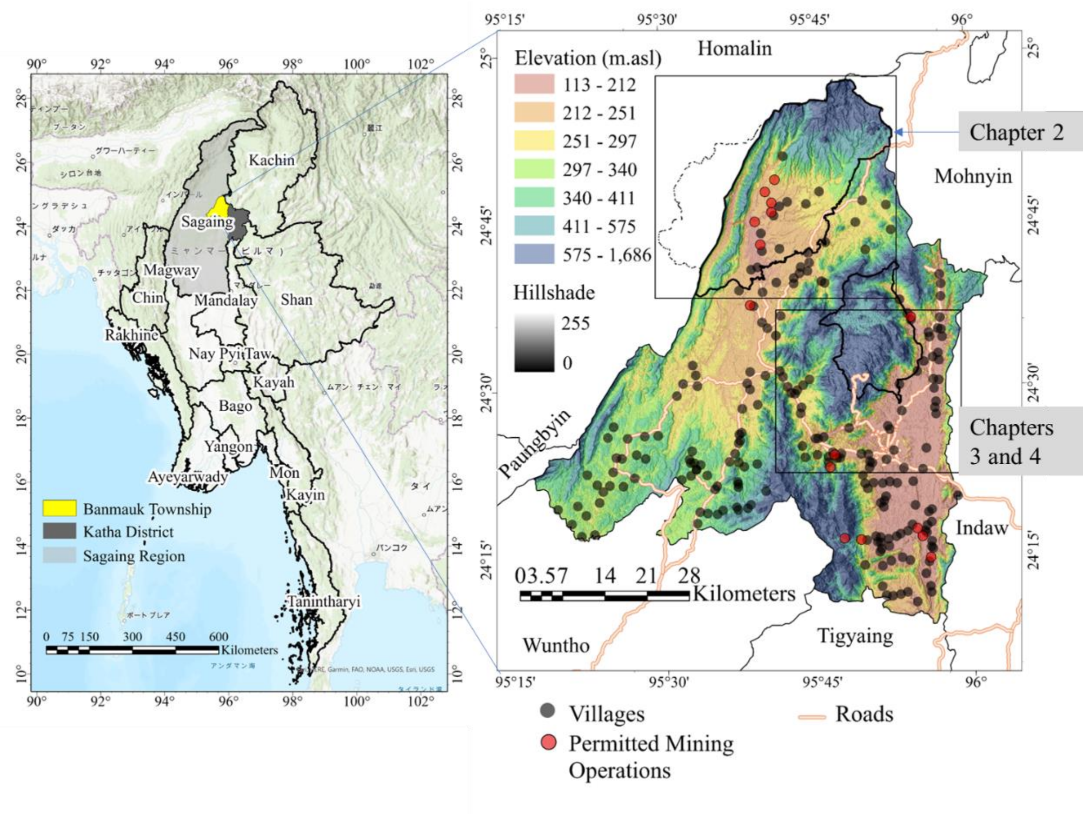


Figure 1.4: Location of Banmauk Township

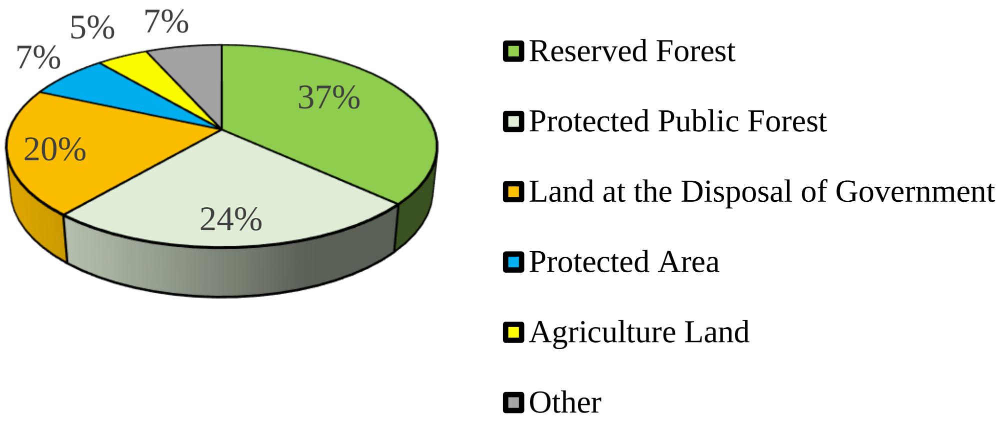


Figure 1.5: Land use of Banmauk Township

Under the management of the Forest Department, there are 28 RFs and PPFs, totalling 209,528 hectares (61%), and a PA (Zalon Taung National Park) covering 244 hectares (7%) of the township area (Figure 1.5). All RFs and PPFs are part of the production working circle for timber production using MSS [58]. The remaining 20% of the township comprises unclassified forests, which are not included in the forest land category but fall within the land at the government's disposal [58]. Agricultural land makes up around 15,461 hectares (5%) of the total area of the township [58]. Banmauk forests are mixed with teak and Dipterocarps, so it has been managed and extracted for teak and other hardwoods using MSS. The current logging system in the township is managed by Myanma Timber Enterprise (MTE), which uses animals like elephants and buffalos to carry the harvested logs, so there is a minimum chance of damage to the natural forest. However, teak has been primarily used for extraction for a long time. Less extraction has been done on other hardwood species, which may impact long-term forest management.

1.4.2 Population, livelihoods and land-cover changes

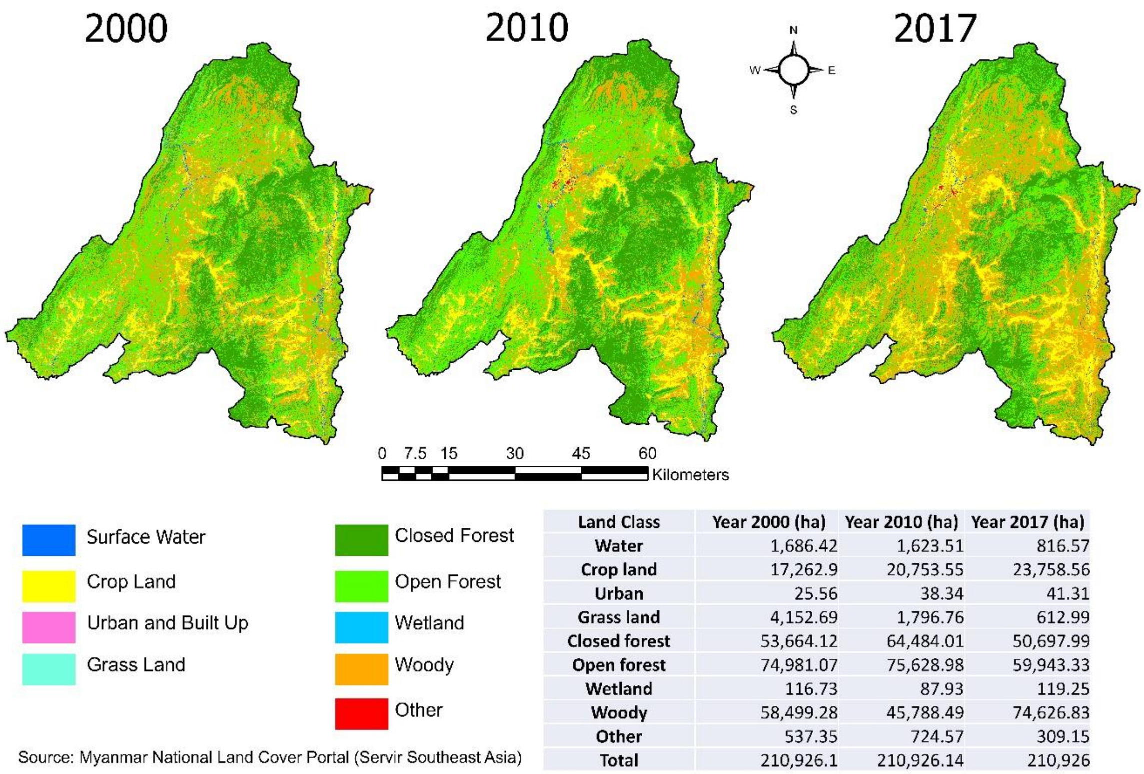
Banmauk Township is primarily a rural area with a total population of 112,668 and a population density of 33 people/km^2 [59]. According to 2014 national census, there are 18,868 total households, of which 1,212 are in Banmauk town area and 17,656 are in villages [59]. Banmauk town comprises three wards; the remaining are rural areas, including 47 village tracts. 70.4% of households live in wooden houses and 22.9% live in bamboo houses. Only 5.5% of the population lives in urban areas, and the rest live in rural areas. The average family size is 5.4, and the population growth rate is 0.89. The literacy rate is 88.8%; however, school attendance drops after age 11. 94.9% of families utilize firewood as their major source of energy for cooking, indicating that forests are essential to meeting household demands [59].

Table 1.2: Permitted mining companies in Banmauk Township

No.	Issue No.	Company	Area (Acre)	Place	Year	From	To	Type
1	0101/2020	Aye Nyein Dana	20	Man Kat	11	4.8.2020	3.8.2031	gold
2	0102/2020	Aye Nyein Dana	20	Man Kat	11	4.8.2020	3.8.2031	gold
3	0105/2020	Aga Yadanar	20	Lae Nat Gyi	11	27.8.2020	26.8.2031	gold
4	0126/2013	727	49.32	Man Laung Pay Pin	-	12.7.2018	31.5.2019	copper
5	0244/2014	Hein Thein Than	20	Man Min Inn Kone	1	17.9.2017	16.9.2018	gold
6	0264/2014	727	20	Khonan	-	15.10.2018	31.5.2019	gold
7	0268/2014	Shwe Win Aung Aung	20	Narnant Twun	1	15.10.2015	14.10.2016	gold
8	0281/2014	Aga Yadanar	20	Lae Nat Gyi	-	26.11.2018	31.5.2019	gold
9	0299/2014	Shwe Oh Si	20	Nantmah	-	24.12.2018	31.5.2019	gold
10	0291/2014	Shwe Lat Wae Thone Dara	18.6	Nantmah	1	17.12.2018	16.12.2019	gold
11	0292/2014	Shwe Lat Wae Thone Dara	18.6	Nantmah	1	17.12.2018	31.5.2019	gold
12	0011/2015	Tan Chu Shin	20	Nar Nant Twun	1	7.1.2019	31.5.2019	gold
13	0170/2015	Tin Myint Aung	20	Nar Nant Twun	1	12.8.2015	11.8.2016	gold
14	0244/2015	Zalat Pwint Phu	13.58	Nar Nant Twun	1	23.12.2018	31.5.2019	gold
15	0054/2018	Aye Aye Khaing	20	Sone Taw	-	18.7.2018	31.5.2019	gold
16	0055/2018	Aye Aye Khaing	20	Sone Taw	-	18.7.2018	31.5.2019	gold
17	0027/2019	Than Htaik Shwe Sin	20	Nar Nant Twun	-	22.1.2019	31.5.2019	gold
18	0001/2016	Wuntho Resort	5,275,099	Haechain, Pinhinkha, Nant Aww	4	19.1.2018	18.1.2022	copper
19	0006/2016	Su Htoo Pan	220	Sone Taw	3	5.2.2016	4.2.2019	gold
20	0001/2018	Wuntho Resort	40,031	Naw Nga Pat	5	5.7.2018	4.7.2023	gold, copper
21	0002/2018	Wuntho Resort	49,420	Taung Kone	5	5.7.2018	4.7.2023	copper
22	0003/2018	Wuntho Resort	49,420	Tone Kyaung	5	5.7.2019	4.7.2024	copper

The proportion of the productive working population between 15 to 64 years of age is 62.5%, with an employment rate of 98.5%, which is relatively high compared to other regions of Myanmar [59]. The proportion of employed persons working in the “Agriculture, forestry and fishing” industry is the highest, with 64.1%. The most common crops grown in the area are rice, groundnut, and sunflower. The second highest industry is “Mining and quarrying,” in which 14.4% of employed people are involved [59].

Banmauk Township, which has both primary and placer gold resources, is one of the most productive gold mining regions in Myanmar's Sagaing Region [60]. Local populations participate in mining operations by providing labour at the gold mining sites operated by the mining companies. Gold and copper are the main minerals harvested in the township, and the many placer gold mining sites are a vital source of revenue for the nearby people [61]. With the people’s increasing interest in mining, the mineral exploration licenses are also permitted in RFs and PPFs due to the increasing price of gold and market demand. According to the Katha District forest management plan, 190 hectares of forest land have been allocated for mining between 2020 and 2025 [58]. Table 1.2 displays the list of mining companies by 2020 with government permissions to undertake mining activities in the township [61]. The location of authorized mining sites is shown in Figure 1.4.



Land Class	Year 2000 (ha)	Year 2010 (ha)	Year 2017 (ha)
Water	1,686.42	1,623.51	816.57
Crop land	17,262.9	20,753.55	23,758.56
Urban	25.56	38.34	41.31
Grass land	4,152.69	1,796.76	612.99
Closed forest	53,664.12	64,484.01	50,697.99
Open forest	74,981.07	75,628.98	59,943.33
Wetland	116.73	87.93	119.25
Woody	58,499.28	45,788.49	74,626.83
Other	537.35	724.57	309.15
Total	210,926.1	210,926.14	210,926

Figure 1.6: Land-cover maps of Banmauk Township in 2000, 2010 and 2017

Numerous human activities, such as gold and copper mining expansion, shifting cultivation, illegal logging, and overexploitation of forest resources, have led to changes in land use and land-cover in Banmauk Township. The entire forest area decreased from 128,645 hectares (60.99%) to 110,641 hectares (52.45%) between 2000 and 2017, with an annual deforestation rate of 1.22% [23] (Figure 1.6). The issue of humans encroaching on forest areas for farming, residential usage, and other purposes is another issue for land use change. Between 2013 and 2015, with the government's release policy on the settlements with 50 or more households residing in the forest land, 114 hectares of RFs and 1,368 hectares of PPFs were transferred into the category of village land [58].

1.5 Thesis Structure

The thesis includes five chapters (Figure 1.7). Chapter 1 provides research background and issues, literature review, research objectives, and thesis structure. Following this, Chapter 1 also presents background information on the study site, including its historical land use/land-cover changes in two decades, forest resource base and management, population density, livelihood activities, and the community's reliance on forests.

Chapter 2 presents a detailed analysis of land-cover changes and the possible factors affecting deforestation on the forest landscape of Banmauk Township between 2000 and 2021 using remote sensing and GIS technology. The study site for Chapter 2 is the Moede, Nant Kyin, Payintaung, Nant Si, Nankut, Hwelit RFs, and Hwelit PPF in the northern part of Banmauk Township because they have concerns about gold mining and agriculture expansion, which harm the area's forest resources [62] (Figure 1.4).

Chapter 3 assesses how human activities, such as agricultural encroachment, logging, and local people's exploitation of forest resources, have altered the forest's structure, diversity, and composition. This research could not evaluate the vegetation structure in the heavily mined places because of the ongoing conflict between the national military and the local armed groups since 2021. Thus, within and outside of the recently-established Zalon Taung National Park (ZNP) in the middle part of Banmauk Township serve as the study sites for Chapter 3. The vegetation data were collected through a random sampling method in April and May 2022 (Figure 1.4). The ZNP was formerly categorized as a RF and subject to selective logging by the Forest Department for teak and other hardwood species. The analytical results will help forest managers create effective land use plans that balance resource usage and biodiversity conservation for sustainability of protected area management [63].

Chapter 4 investigates the livelihood activities of rural families and how they rely on forests by analyzing forest income using the information obtained from the household questionnaire survey carried out in three villages close to the forests (Figure 1.4). This chapter examines the socio-economic determinants of households' participation in forest product collection and assesses the distributional effect of forest income on narrowing income inequalities among rural households. Understanding the linkages between forest dependence and local livelihoods may help to encourage forest management in a way that balances biodiversity conservation and socio-economic benefit.

As the last chapter of the thesis, Chapter 5 wraps up by thoroughly discussing the previous chapters' critical findings and answering the research objectives mentioned in 1.3. This chapter presents recommendations for optimizing forest management while recognizing the ecological and socio-economic conditions of the study site. The thesis structure is shown in Figure 1.7.

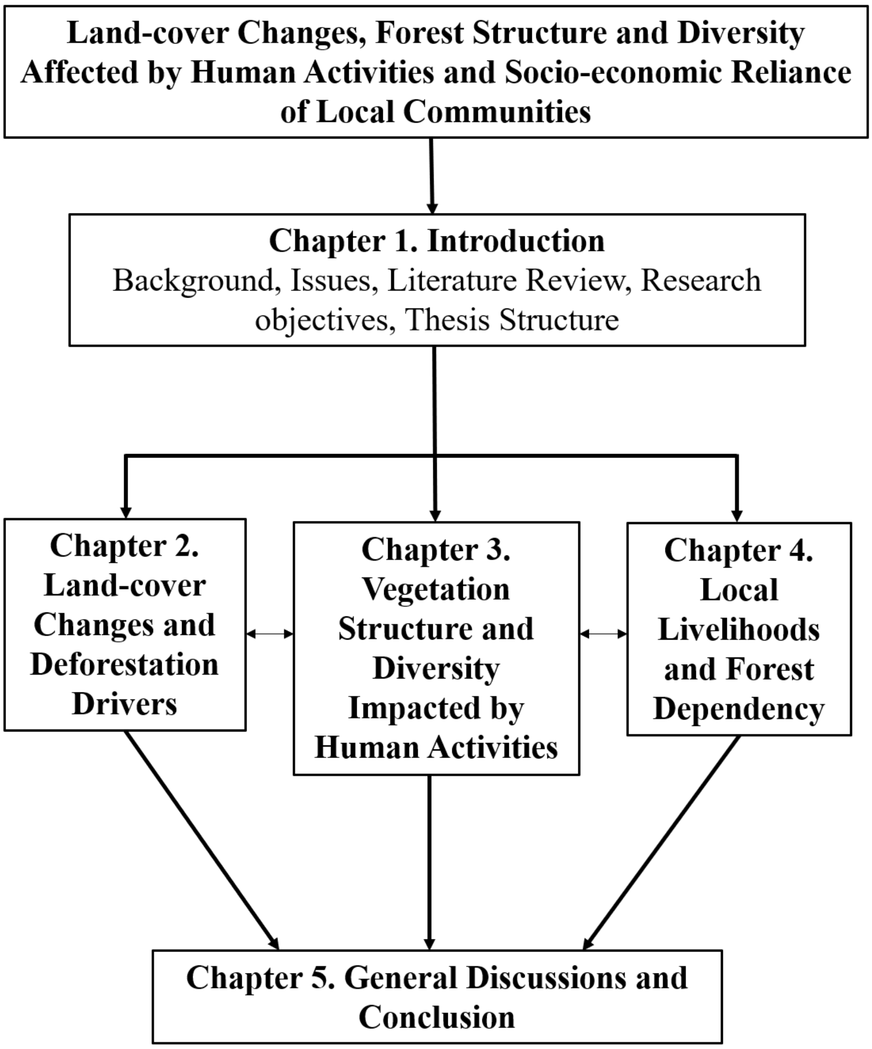


Figure 1.7: Thesis structure

Chapter 2. Land-cover Changes and Deforestation Drivers in the Forest Landscape of Banmauk Township

2.1 Introduction

Forests regulate ecosystems, protect biodiversity, contribute significantly to the carbon cycle, and provide goods and services that promote sustainable growth [64]. In particular, tropical forests have some of the highest species diversity [65] and operate as globally essential carbon sinks which reduce greenhouse gas emissions and moderate climate change [66]. Loss and degradation of tropical forests cause a massive carbon flow in the atmosphere and affect the global carbon cycle and regional climate variations [66]. Global forest areas reduced from 7.8 million hectares (ha) annually in the 1990s to 4.7 million between 2010 and 2020, with 420 million ha converted to other land uses since 1990 [67]. Southeast Asian Forests have shrunk even faster, with 37.6 million ha lost between 1990 and 2020 [68]. Tropical forests in Southeast Asia are conservation priorities due to their great species diversity and threatened habitats [69]. Myanmar has the second-largest extent of forest coverage in Southeast Asia, with the forest area decreasing from 57.9% in 1990 to 46.96% in 2010 and 42.19% in 2020 [2]. The patterns of deforestation in Myanmar vary by region [43], but are mostly linked to agriculture expansion, mining, urbanization, aquaculture, hydropower, and infrastructural development [5].

Tropical deforestation has historically been related to expanding large-scale agricultural plantations, clear-cutting, selective logging, and shifting cultivation [70-72]. In recent years, gold mining-driven deforestation has begun to manifest in some tropical regions [73, 74] due to people's growing interest in it with the rising price [75]. The mining and energy industries account for most of Myanmar's GDP [76], and gold mining in the Sagaing Region is an important source of revenue for both the government and residents [21, 74]. Between 2002 and 2015, Sagaing Region hosted 30.6% of all new mining sites in Myanmar [52]. These mining land use patterns often result in substantial land degradation, along with an increase in roads and settlement [43], loss of forest cover [74, 77] and farmland [77] and impact on forest biodiversity [78]. A recent study in Nant Kyin reserved forest (RF) in Banmauk Township showed high concentrations of heavy metals in the soil of several mining sites, which can cause adverse health effects to the mining community [79]. Gold mining influences the tropical forest ecosystem; however, it is generally neglected in deforestation analyses as it usually occupies a small amount of land [73].

Remote sensing and GIS technology using satellite imagery to help interpret and clarify historical disturbances to forest ecosystems has been widely used for long-term assessment of forest cover changes [80-82]. Remote sensing also provides a cost-effective option for assessing land-cover changes due to mining activities in remote areas or areas of armed conflicts [52, 83]. Studies in Myanmar have applied remote sensing technology using satellite imagery to analyse forest cover change and deforestation [12, 43, 84, 85]. Nevertheless, factors affecting deforestation and land-cover changes relate to various site-specific factors [86]. Some studies in Asia and Myanmar have developed spatial modelling of forest cover changes based on logistic regression algorithms and predicted the factors affecting deforestation [87-90]. Various spatial variables such as soil type, slope, elevation, accessibility, and population density are regularly included to explain the deforestation process; however, non-spatial variables such as socio-cultural and political factors are not included within the scope of the models [91, 92].

Banmauk's forests are an essential part of Myanmar's forest management plan as they offer a substantial and continuous natural forest cover, which is a significant source of income for the nation and improves the well-being of the local population [58]. This study's target area includes the Moede, Nant Kyin, Hwelit, Payintaung, Nant Si, Nankut RFs and Hwelit PPF, all established between 1899 and 2017 as part of PFE to conserve biodiversity and encourage sustainable forest management [55]. These forests are of utmost importance to preserve since they include the remaining fauna and flora of the vulnerable Irrawaddy moist deciduous forest ecoregion [93]. However, despite being legally preserved, the area faces the problems of agricultural expansion, illegal logging, shifting cultivation, and gold mining [58]. The Ministry of Natural Resources and Environmental Conservation (MONREC) Myanmar reported the increasing threat of open-pit and illicit mining in the Moede, Payintaung, and Hwelit RFs [94]. Gold mining expansion was anticipated to cause environmental degradation and forest loss. However, the extent and causes of deforestation and the consequences of gold mining in this area have received little attention.

Studies of forest cover dynamics, especially those in tropical forests, have primarily focused on how changes in land use have affected forest cover at the regional and national levels [24, 95, 96]. In particular, in forest reserves where mining is a significant land use activity, few studies have downscaled to the local level and simulated the link between land-cover changes and its driving variables. In this context, a comprehensive local assessment is needed in the tropical forest environment to investigate the relationship between the extent of land-cover changes by gold mining and the variables affecting them. This knowledge will enable effective forest management in Banmauk’s RFs, which have been vulnerable to open-pit gold mining and other environmental stresses. In this study, supervised classification was applied to identify land-cover changes using Landsat satellite imagery between 2000 and 2021. The main objectives were (1) to assess land-cover changes in the Moede, Nant Kyin, Hwelit, Payintaung, Nant Si, Nankut RFs, and Hwelit PPF between 2000 and 2021 and (2) to develop a binary logistic regression model to predict the possibility that certain factors may contribute to local deforestation, especially by gold mining.

2.2 Materials and Methods

2.2.1 Study area

The study sites were the Moede, Nant Kyin, Hwelit, Payintaung, Nant Si, and Nankut RFs, and Hwelit PPF in Banmauk Township, Sagaing Region, at latitude between 24°37' and 24°60' N and longitude between 95°30' and 95°55' E (Figure 2.1). The study sites cover 71,699 ha at an altitude of 163-1,696 meters above sea level. Local temperatures range from 6.7 to 41.9°C, with an average of 24.7°C and 1,337 mm of annual rainfall. Continuous natural forest with the vigorous growth of teak (*Tectona grandis*), kanyin (*Dipterocarpus alatus*), tamalan (*Dalbergia oliveri*), ingyin (*Shorea siamensis*), and sagat (*Quercus glauca*), cover a large part of the reserved forests [58]. In literature and satellite images, several activities related to gold mining, agricultural growth, shifting cultivation, exploitation of forest products, and other industries brought about by the presence of mines are emphasized [79, 94, 97]. Due to the research site's closeness to Kachin State, ongoing armed conflicts between ethnic armed groups and the national military may damage the forest.

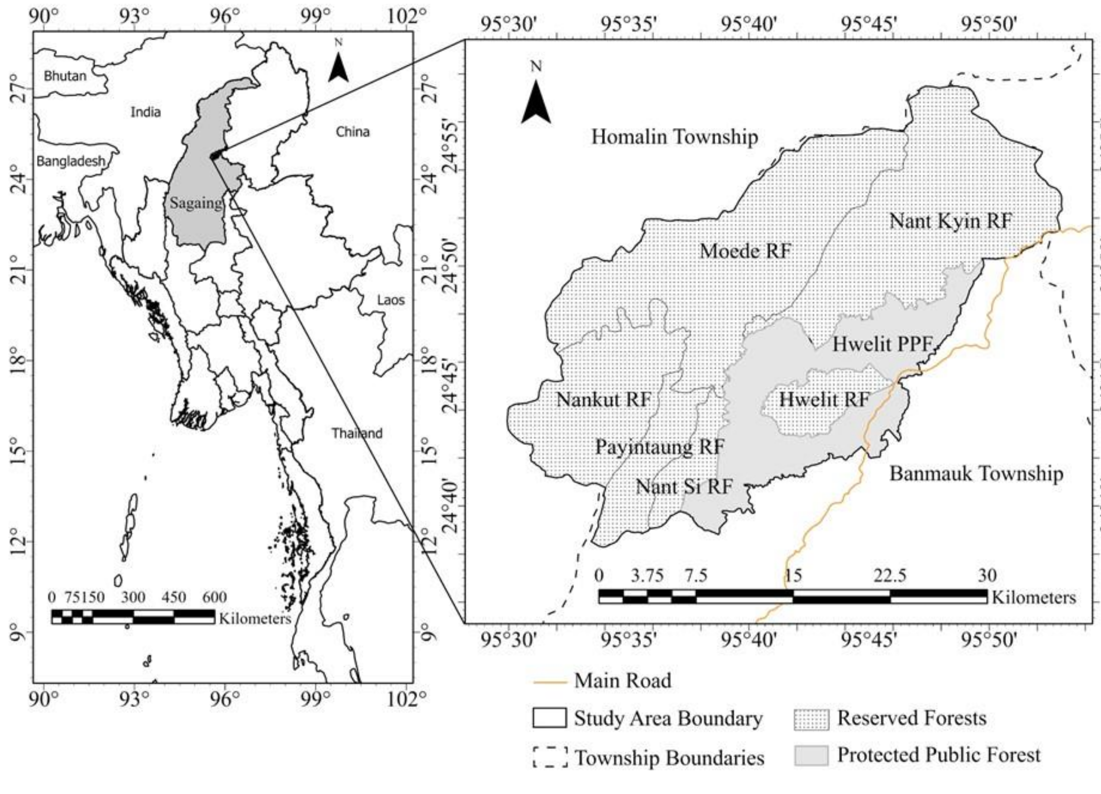


Figure 2.1: Location map of study site

2.2.2 Image classification accuracy assessment and area estimation

Two Landsat satellite images were downloaded from the United States Geological Survey (USGS) website (http://earthexplorer.usgs.gov/) (Table 2.1), and radiometric/atmospheric correction was implemented in pre-processing. The 2000 and 2021 imagery were already georeferenced to the coordinate system of WGS 1984, UTM Zone 46 N. Bands 1-5 and 7 of Landsat 7 imagery taken in 2000 and bands 1-7 of Landsat 8 imagery taken in 2021 were extracted, combined, and clipped to the study area. The training polygons were selected separately for each Landsat imagery based on the visual interpretation of the Landsat imagery with the help of high-resolution Google Earth images and the ground truth points observed in 2020. Seven land-cover classes were classified using supervised random-tree classification algorithm [98] in Arc GIS Pro version 2.7 (Tables 2.2 and 2.3). The performance of the random-tree classification algorithm is easier to use, more forgiving to overfitting and outliers, and it is suitable for remotely sensed data classification and land use/land cover change mapping [99].

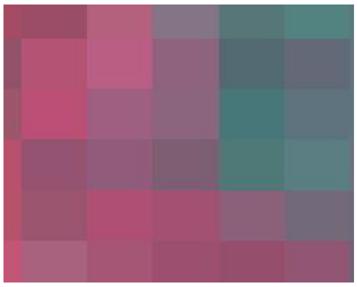
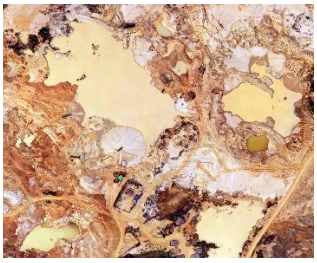
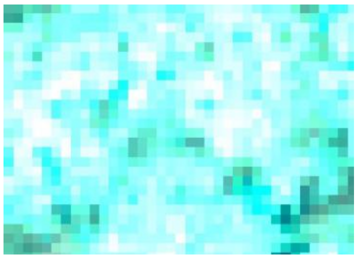
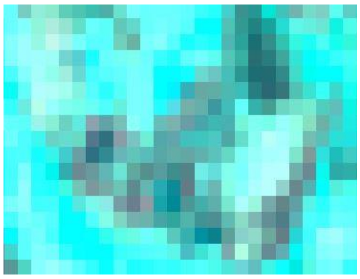
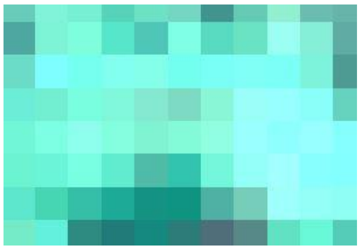
Table 2.1: Satellite imagery used for classification

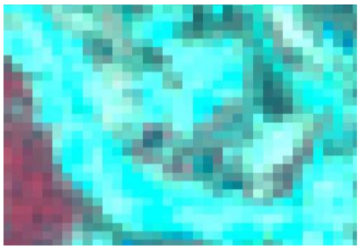
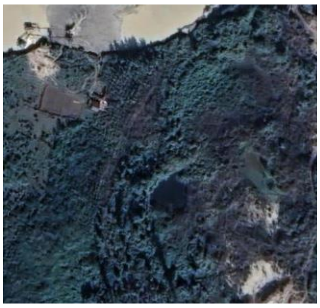
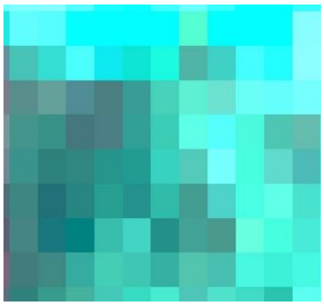
No.	Year	Imagery	Path & row	Spatial resolution	Date of acquisition
1.	2000	Landsat 7 ETM+	134/43	30 m	February 23, 2000
2.	2021	Landsat 8 OLI	134/43	30 m	March 12, 2021

Table 2.2: Land-cover classes

No.	Class	Definition
1	Dense forest	Dense canopy cover with tree domination
2	Open forest	Thinner canopy forest predominantly composed of bamboos and shrubs with many small trees and some large trees
3	Mining	Areas characterized by mining operation coverage
4	Settlement	Villages and dispersed settlements associated with mining sites
5	Agriculture	Coverage with paddy fields, cropland and upland cultivation
6	Water	Streams and other bodies of water
7	Barren/scrub land	Bare soil, bush or shrub land, and roads

Table 2.3: Description of seven land-cover classes with field photos, google earth and satellite image

Class Name	Field Photo	Google Earth Image	False-Color Satellite image
Dense forest			
Open forest			
Mining			
Settlement			
Agriculture			

Water			
Barren/Scrub land			

Note: Dark red in the false-color image denotes dense forest cover; blue indicates water flow and water bodies (often in mining land); green means fast growing plant-covered land.

Sampling points were created using Arc GIS Pro's Create accuracy assessment points tool via stratified random sampling method. Ground truth data points obtained from observation performed in 2020 and high-resolution imagery (CNES/Airbus) from Google Earth Pro were also combined with Landsat imagery to assess the accuracy of classified imagery. Confusion/error matrix analysis [100] was carried out to evaluate the accuracy assessment of the 2000 and 2021 land-cover classification maps and land-cover change map. A change matrix was formulated via cross-tabulation analysis [95] generated via an intersection of the 2000 and 2021 land-cover classification maps.

The pixel counting approach for calculating land-cover area does not guarantee the actual proportion of area or the unbiased area estimates [101-103]. Therefore, a sample-based approach was used as an independent method to estimate the areas of land-cover changes between 2000 and 2021. The accuracy assessment error matrix provides sample data that can be used to avoid the measurement bias of pixel counting and to decrease the estimated area's standard error [103]. Using the estimating area and assessing accuracy formulas provided [104], the bias-corrected area estimates and accuracy of the land-cover classes between 2000 and 2021 were calculated.

2.2.3 Logistic regression model: Generation of dependent and independent variables

Remote sensing technology was combined with spatial statistical modeling to assess the probable factors affecting deforestation [87, 90, 105, 106], and logistic regression analysis was used to identify significant factors affecting the probability of local deforestation. An ultimate digital map of deforestation representing the forest to forest (no deforestation) and forest to non-forest (deforestation) classes was produced with the pixel size of 30 m × 30 m and subjected to binary coding (1 for deforestation and 0 for no deforestation) for dependent-variable usage.

The explanatory variables may differ from one region to another but similar factors such as proximity to roads, water, settlements, slope, elevation, soil types, and population density were examined in the deforestation studies in Myanmar [14, 87]. In this study, (1) distance to roads, (2) distance to streams, (3) distance to villages, (4) soil types, (5) altitude, and (6) slopes were considered as independent variables in logistic regression modeling. Roads and streams were manually digitized from topographic mapping compiled from 1:50,000 aerial photographs taken between December 2003 and March 2004 by Myanmar's Survey Department. GIS layers of roads and streams were based on Euclidean distance analysis using digitized data. As road/stream accessibility in the study area can be significant in determining land rents in mining, the focus was placed on these factors owing to a higher potential for deforestation. Data on village points were downloaded from the Myanmar Information Management Unit (MIMU; http://www.themimu.info), and distances to village points were based on Euclidean distance. As local residents tend to do shifting cultivation in uplands and rice cultivation in lowlands near village areas, it was hypothesized that such areas might be affected by deforestation.

A soil map of the study area was extracted from mapping analysis conducted by Myanmar's Agriculture Department in accordance with the FAO soil classification system. The study area largely contained (1) yellow-brown forest soil (Xanthic Ferralsol), generally found in deciduous forests on gentle slopes in low hills, and (2) red-brown forest soil (Rhodic Ferralsol) generally found on mountainous terrain in the study area. As yellow-brown forest soil is regarded as favorable garden land [107], such areas were associated with a higher probability of agriculture-related deforestation. Altitude and slope information was derived from a digital elevation model (DEM) obtained from the USGS website (https://earthexplorer.usgs.gov). I hypothesized that deforestation occurs at lower altitudes and slopes where conditions are better for growing crops, causing agricultural encroachment into the forest. All variables were used as raster datasets with a pixel size of 30 x 30 m, and 1,500 random points were created with Arc GIS Pro's Create random points tool throughout the study area. The attribute values of dependent and independent variables were then extracted using Arc GIS Pro's Extract values to points tool.

As multicollinearity among independent variables can cause unstable estimation and inaccurate variances in logistic regression modeling [108], multicollinearity testing was conducted via linear regression prior to logistic regression analysis to check the variance inflation factors (VIFs) and tolerances of each independent variable. The receiver operating characteristics (ROC) curve and the value of the area under the curve (AUC) were also developed for model validation. The logistic regression model and all other forms of analysis were implemented using Microsoft Office Excel and R statistical program (version 4.1.0).

2.3 Results

2.3.1 Map accuracy assessment

The classification maps of the study area for 2000 and 2021 are shown in Figure 2.2. The land-cover change map between 2000 and 2021 is shown in Figure 2.3. The accuracies of two classified maps and the change map from 2000 to 2021 were expressed as producer's and user's accuracies (Tables 2.4 and 2.5). The overall accuracies for the 2000 and 2021 classified maps and the change map were 89.08%, 91.00%, and 85.93% respectively.

2.3.2 Land-cover changes between 2000 and 2021

The reference sample data of the error matrix of 2000 and 2021 classified maps and the change map provided sample-based area estimates and associated confidence intervals for area estimates (Tables 2.4 and 2.5). There was a considerable decrease in amounts of dense forest, with other classes (open forest, mining, settlement, agriculture, and barren/scrub) showing an increase (Table 2.4).

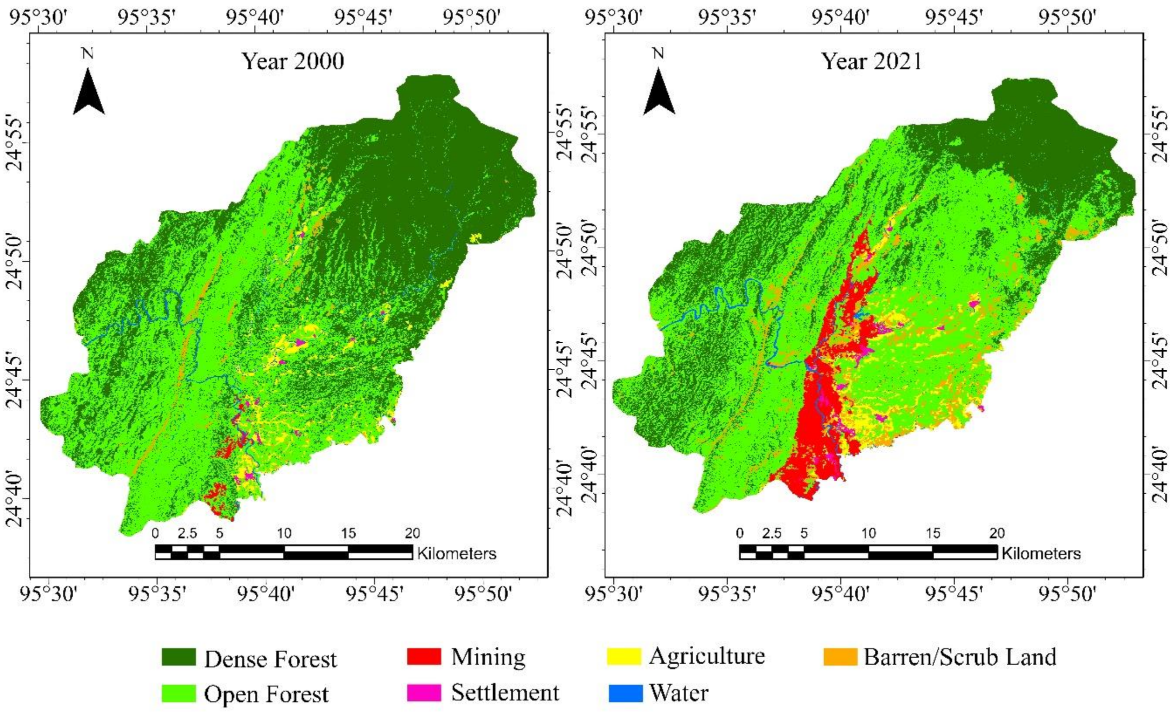


Figure 2.2: Land-cover classification maps

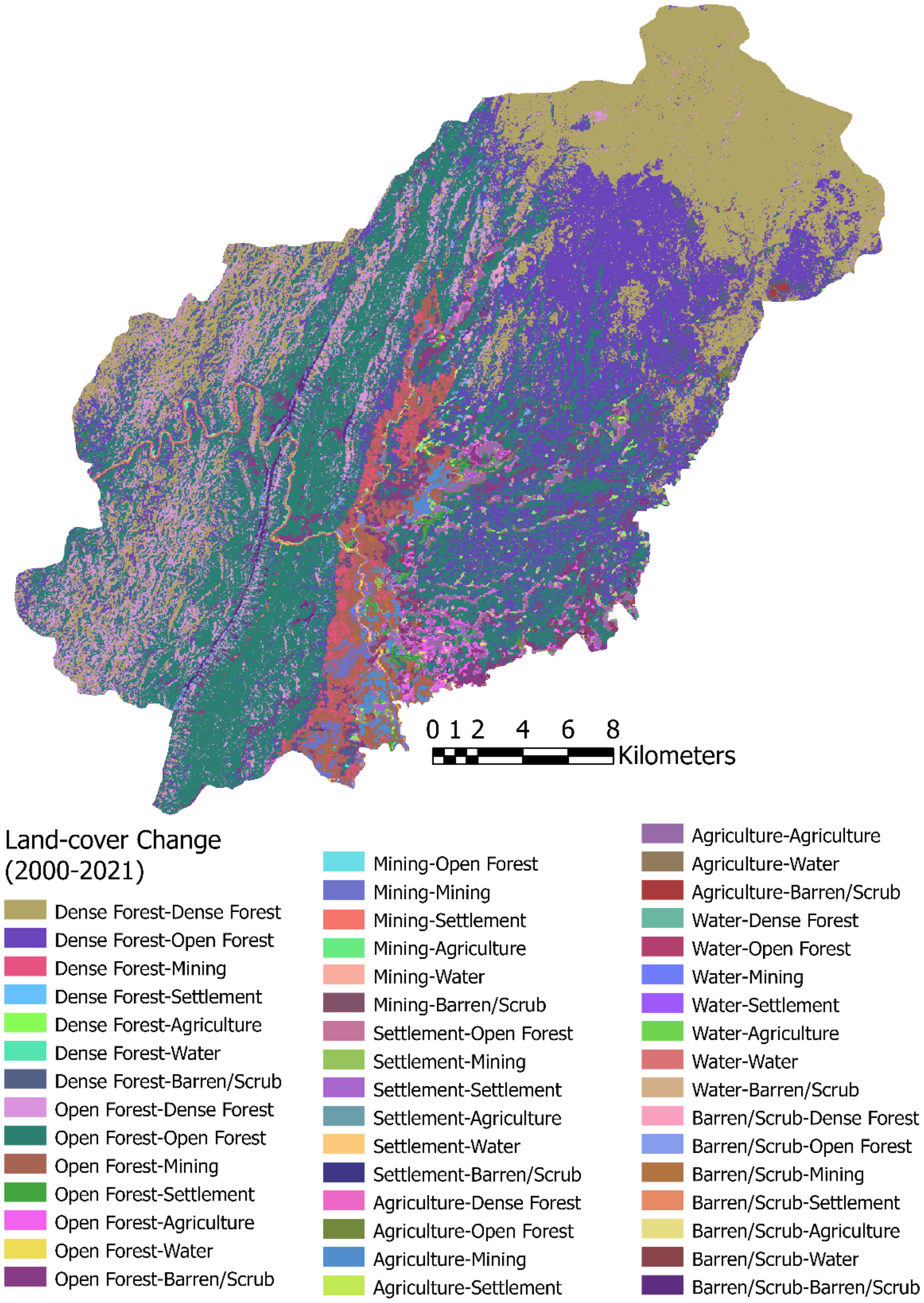


Figure 2.3: Land-cover change map

Analysis for the period between 2000 and 2021 showed that dense forest experienced significant decrease, with an estimated 32,727.88 ha of the total area being converted mainly to open forest (15,460.44 ha), followed by barren/scrub land (917.86 ha), mining sites (902.09 ha), water (325.13 ha), agriculture (220.94 ha) and settlements (149.92 ha) (Tables 2.4 and 2.5). The open forest increased from an estimated 35,366.28 ha in 2000 to 39,083.25 ha in 2021, with the conversion mainly from the dense forest (Tables 2.4 and 2.5). During 21 years, mining and barren/scrub land increased from 264.87 ha to 3,843.59 ha and 1,225.10 ha to 5,521.08 ha, respectively, with the conversions mainly from the open forest (Tables 2.4 and 2.5).

Table 2.4: Bias-corrected area estimates in hectare (ha) with 95% confidence intervals (CI), producer's and user's accuracy under land-cover classes for the years 2000 and 2021

Class	Accuracy		Map Area (ha)	Sample-based Area Estimates			
	Producer's	User's		Area (ha)	Area (%)	SE (ha)	CI (ha)
Year 2000							
Dense forest	0.92	0.88	33,936.96	32,727.88	45.65	596.51	1,169.16
Open forest	0.87	0.92	33,563.35	35,366.28	49.33	626.42	1,227.78
Mining	1.00	0.70	378.39	264.87	0.37	57.80	113.28
Settlement	1.00	0.60	194.70	116.82	0.16	31.79	62.31
Agriculture	0.95	0.73	1,972.99	1,514.87	2.11	167.83	328.94
Water	0.88	0.64	665.44	483.61	0.67	117.74	230.78
Barren/scrub land	0.67	0.82	987.60	1,225.10	1.71	163.69	320.85
		Total	71,699.43	71,699.43	100		
Year 2021							
Dense forest	0.94	0.91	21,546.50	20,795.62	29.01	419.01	821.26
Open forest	0.92	0.95	38,179.82	39,083.25	54.51	523.38	1,025.84
Mining	0.97	0.85	4,383.73	3,843.59	5.35	201.70	395.33
Settlement	1.00	0.70	517.63	362.34	0.51	79.06	154.97
Agriculture	0.93	0.68	2,268.03	1,672.07	2.33	193.05	378.38
Water	1.00	0.60	662.32	421.48	0.59	100.75	197.47
Barren/scrub land	0.63	0.84	4,141.40	5,521.08	7.70	373.91	732.87
		Total	71,699.43	71,699.43	100		

Note: SE = standard error

Table 2.5: Bias-corrected area estimates in hectare (ha) with 95% confidence intervals (CI), producer's and user's accuracy under changes of land-cover classes from 2000 to 2021

Class Changes (From 2000 to 2021)	Accuracy		Map Area (ha)	Sample-based area estimates		
	Producer’s	User’s		Area (ha)	SE (ha)	CI (ha)
Dense forest-Dense forest	0.88	0.86	16,241.10	15,959.12	360.87	707.31
Dense forest-Open forest	0.87	0.87	15,534.00	15,460.44	345.62	677.42
Dense forest-Mining	0.81	0.95	790.57	902.09	79.20	155.23
Dense forest-Settlement	0.69	0.90	30.70	149.92	50.02	98.04
Dense forest-Agriculture	0.60	0.60	305.74	220.94	52.22	102.35
Dense forest-Water	0.42	0.60	93.73	325.13	83.24	163.15
Dense forest-Barren/scrub land	0.74	0.71	941.12	917.86	122.74	240.59
Open forest-Dense forest	0.76	0.81	5,162.62	5,600.24	272.67	534.43
Open forest-Open forest	0.94	0.92	21,910.00	21,481.41	306.91	601.53
Open forest-Mining	0.87	0.80	2,450.51	2,248.86	153.20	300.27
Open forest-Settlement	0.46	0.60	279.48	423.82	98.83	193.71
Open forest-Agriculture	0.82	0.76	918.48	789.43	91.43	179.20
Open forest-Water	0.41	0.70	177.42	484.32	110.02	215.64
Open forest-Barren/scrub land	0.96	0.86	2,664.94	2,358.25	113.83	223.12
Mining-Open forest	0.80	0.40	3.46	73.83	49.59	97.19
Mining-Mining	1.00	0.90	337.46	303.71	33.74	66.14
Mining-Settlement	0.81	0.90	6.15	41.49	35.70	69.97
Mining-Agriculture	0.60	0.90	2.64	42.91	35.75	70.08
Mining-Water	0.75	0.60	12.94	45.03	35.79	70.15
Mining-Barren/scrub land	0.81	0.90	15.74	51.16	35.75	70.07
Settlement-Open forest	1.00	0.80	6.39	5.11	0.85	1.66
Settlement-Mining	0.83	1.00	40.96	66.36	16.93	33.19
Settlement-Settlement	0.66	0.80	127.02	106.52	17.05	33.42
Settlement-Agriculture	0.85	0.60	12.27	7.71	2.03	3.98
Settlement-Water	0.81	0.90	3.46	4.03	0.70	1.38
Settlement-Barren/scrub land	0.80	0.80	4.6	4.19	0.70	1.37
Agriculture-Dense forest	0.77	0.70	2.58	40.60	25.86	50.70
Agriculture-Open forest	0.77	0.70	193.99	172.01	46.59	91.33
Agriculture-Mining	0.82	0.93	539.43	533.98	41.52	81.39
Agriculture-Settlement	0.62	0.80	55.57	225.37	74.52	146.05
Agriculture-Agriculture	1.00	0.81	940.73	759.82	74.15	145.33
Agriculture-Water	0.69	0.90	56.56	124.56	30.59	59.96
Agriculture-Barren/scrub land	0.60	0.60	184.13	117.80	30.60	59.99
Water-Dense forest	0.87	0.70	5.54	18.62	14.76	28.93
Water-Open forest	0.88	0.80	147.37	130.11	23.13	45.34
Water-Mining	0.75	0.90	122.09	127.20	19.21	37.65
Water-Settlement	0.80	0.80	12.85	18.06	5.46	10.70
Water-Agriculture	0.88	0.80	38.90	62.22	31.53	61.80
Water-Water	0.88	0.80	311.04	251.59	41.56	81.46
Water-Barren/scrub land	1.00	0.90	27.65	24.89	2.76	5.41
Barren/scrub land-Dense forest	0.54	0.60	134.37	255.57	64.45	126.32
Barren/scrub land-Open forest	0.50	0.45	384.87	259.79	71.56	140.26
Barren/scrub land-Mining	0.83	1.00	102.81	138.40	34.99	68.58
Barren/scrub land-Settlement	0.75	0.90	5.89	20.08	7.54	14.79
Barren/scrub land-Agriculture	0.87	0.70	49.27	35.21	7.56	14.81
Barren/scrub land-Water	0.87	0.70	7.17	35.34	30.34	59.46
Barren/scrub land-Barren/scrub land	0.81	0.90	303.22	274.33	30.33	59.46
Total			71,699.43	71,699.43		

Note: SE = standard error

2.3.3 Factors affecting deforestation

The assumption of no multicollinearity was made for tolerance > 0.20 or VIF < 4 [109]. Testing showed no collinearity among the six independent variables with tolerances ranging from 0.28 to 0.78, and all VIF values were less than 4 (Table 2.6). Binary logistic regression analysis was conducted with the attributes of 1,343 randomly allocated points (184 in deforestation areas and 1,159 in no-deforestation areas). Among the six independent variables, distance to roads and altitude negatively and significantly correlated with the potential for deforestation at a significant level of 0.000 (Table 2.7). Areas near roads exhibited a higher potential for deforestation, while high altitude areas decreased the probability of deforestation. At the same time, other independent variables (soil type, distance to streams, and slopes) were negatively correlated with the probability of deforestation, and distance to villages was positively correlated. Among local soil types (yellow-brown forest soil (Xanthic Ferralsol), coded as ‘1’, and red-brown forest soil (Rhodic Ferralsol), coded as ‘2’), deforestation was prominent in the yellow-brown type which was preferred by local farmers for crop cultivation [107]. The area under the ROC curve value was 0.8913, indicating 89% model accuracy (Figure 2.4) and a significant role of all independent variables in forest conversion.

Table 2.6: Multicollinearity testing for independent variables

Variable	Unstandardized coefficient		Standardized coefficient	t	Significance	Collinearity statistics	
	Beta	Standard error	Beta			Tolerance	VIF
(Intercept)	0.367	0.023		16.296	0.000		
Soil	0.055	0.021	0.077	2.641	0.008	0.717	1.394
Distance to villages	-0.011	0.004	-0.136	-2.904	0.004	0.280	3.571
Distance to roads	-0.027	0.005	-0.277	-5.944	0.000	0.283	3.533
Distance to streams	0.004	0.008	0.018	0.511	0.609	0.499	2.004
Altitude	0.001	0.000	0.009	0.250	0.802	0.518	1.931
Slope	-0.005	0.001	-0.118	-4.207	0.000	0.784	1.276

Table 2.7: Binary logistic regression for deforestation prediction

Independent variable	B	Standard error	Z value	Pr (>|z|)	Exp (B)	95% C.I. for Exp (B)	
						Lower	Upper
Intercept	1.922	0.430	4.469	0.000	6.835	1.079	2.765
Soil	-0.028	0.201	-0.141	0.888	0.971	-0.424	0.367
Distance to villages	0.056	0.053	1.044	0.297	1.057	-0.049	0.161
Distance to roads	-0.552	0.076	-7.243	**0.000**	0.575	-0.701	-0.402
Distance to streams	-0.003	0.177	-0.022	0.983	0.996	-0.351	0.343
Altitude	-0.007	0.001	-4.005	**0.000**	0.992	-0.010	-0.003
Slope	-0.030	0.018	-1.600	0.110	0.970	-0.067	0.006

Note: AIC: 739.86; number of Fisher scoring iterations: 7; Chi-squared test: X^2 = 263.50; df = 7; P (> X^2) = 0.000; -2 log likelihood = 362.93; efficiency of fitted model=0.90; AUC=0.89

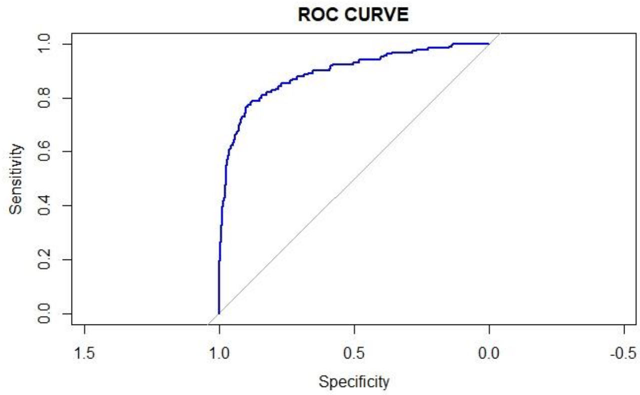


Figure 2.4: ROC curve (Area under the curve: 0.89)

2.4 Discussion

In the study area, the landscape experienced a considerable decrease of 16.64% (45.65 - 29.01%) in dense forest cover, while open forest, mining, settlement, agriculture, and barren/scrub land increased over the study period. Such changes are consistent with other studies conducted in Myanmar [15, 87, 110], which reported that dense forest cover decreases at the expense of other land use. Even though the land use activity resulted in a loss of dense forest cover, some dense forest area was added or recovered due to the conversion, mostly from open forest, reflecting the forests' healthy natural regeneration status. On the other hand, open forests increased from 49.33% in 2000 to 54.51% in 2021, with the conversion mainly from dense forests. The conversion of dense forest to open forest may have been affected by the over-harvesting of precious timber tree species beyond the annual allowable limit and widespread illegal logging before the 2014 national logging ban [111]. Furthermore, when mining-related immigrants and local populations increase, the need for firewood, meat, and construction materials may rise along with it, causing the forest to degrade. Assisted natural regeneration and enrichment planting might be preferable forest management operations to improve open forest regeneration and quality.

Mining increased significantly from an estimated 264.87 ha in 2000 to 3,843.59 ha in 2021 (14.5 times, 170.42 ha/year), primarily due to conversion mainly from open forest, dense forest, and agriculture, however, transitions from mining to other land-cover classes were noticeably less significant. This is similar to other research findings indicating that mining areas increased substantially in past years, while a slight transition to other land use types was observed in India [112] and Ghana [78]. However, the slightly changed transition from mining to open forest may have been affected by the natural regeneration and the mining companies' post-mining land reclamation and restoration activities during the 21-year study period. Mining permits in Myanmar are granted to companies by the Mining Enterprise under the Ministry of Natural Resources and Environmental Conservation for various fixed periods, with the smallest land area applicable for gold mining being 20 acres (approximately 8 ha) [49]. After the gold mining ceased, systematic land reclamation and replanting with native tree species could assist in the area's recovery.

The slight increase of 0.22% of agricultural land in 2021 was mainly from open and dense forest in 2000. Interestingly, larger areas of open and dense forest with an estimated amount of 3,276 ha were transformed into barren/scrub land during 2000-2021. In the study area, mining displaced agricultural land in low-elevation areas, resulting in the expansion of cultivation into forests. However, due to remoteness and legal factors, some cultivated areas within forests were transformed into bare or fallow land as part of the shifting cultivation cycle rather than permanent agricultural areas. The noticeable and widespread expansion of barren/scrub land in 2021, which was mainly converted from the open forest in 2000, confirmed that a portion of the open forest changed into fallow land due to the shifting cultivation in which land was left fallow for years. Mon et al. (2009) reported that forests were fragmented due to shifting cultivation and became open/bare land, as seen in the Paunglaung watershed area between 1989 and 2000 [87]. Other studies claimed that the expansion of shifting cultivation in the dense and degraded forest patches converted into shrub/fallow land [113], leading to land degradation and forest cover loss due to the reduced fallow period [114, 115] in Africa. To address the expansion of shifting cultivation in the reserved forests, establishing community forests in degraded land may have been a practical forest management approach for maintaining residual forest resources and supporting local livelihoods [57].

Meanwhile, the transformation of forests to non-forest areas in the study area is attributed to mining development (Figure 2.5), and other disturbances brought about by mining-related effects, as also reported by other studies conducted in South America, Africa and Asia [16, 73, 77, 83, 116]. Myanmar research indicated that gold mining has been a significant driver of deforestation and is likely to remain so [24, 52, 117], especially in upper Myanmar [74]. While mining development brings local economic benefits [118, 119], associated increases in illegal logging, mining activity and expansion of barren/scrub land might impair ecosystem services, inhibit biodiversity conservation, and negatively impact the quality of life in the area. The study suggested that effective regulation and law enforcement on the current mining activities are necessary to minimize environmental impact, balance mining and local livelihoods, and move away from unsustainable resource use. Schueler et al. (2011) also reported in their study in Western Ghana that more efforts are needed to enforce legislation for restoring ecosystem services and biodiversity once gold mining is complete [77].

Figure 2.5: Gold mining in Banmauk Township (Source: Planning and Statistics Division of Forest Department Myanmar, 2020)

The spatial logistic regression showed that deforestation increased with reduced distance between forests and roads. This may be due to increased logging, the exploitation of forest products, and forest encroachment due to the easy road access to the forest. This confirms previous results that forests close to roads were significant predictors of the probability of deforestation [89, 106, 120]. The logistic analysis also indicated a greater chance of deforestation in low-elevation forests. This may be due to the expansion of agriculture, notably rice cultivation, and a considerable increase in gold mining in lowland forests. As hypothesized, deforestation is strongly driven by biophysical factors, and that lower elevation is more likely to cause deforestation [87, 90, 106]. Data on the distance to streams showed a negative association with deforestation, suggesting that forests near streams may be related to deforestation due to extensive gold mining activities in streamlet areas. As socio-economic and demographic aspects are associated with deforestation, future research should consider additional variables such as the level of education, income and the demographic data of migrants and residents to enhance the current spatial logistic model.

2.5 Conclusion

This chapter, employing remote sensing and GIS technology using Landsat imagery, showed a considerable loss in dense forest areas with increased open forest, mining, barren/scrub land and settlement from 2000 to 2021. Mining and agricultural land use have resulted in the loss of forest resources, which might damage biodiversity. The current logistic regression analysis effectively modelled all six explanatory variables and helped determine their relative importance in deforestation. Road accessibility and lower altitudes were strong determinants of the local deforestation process. Additionally, more investigation is required to determine the relationship between mining and local livelihoods and the status of biodiversity due to gold mining activities. The government should invest in the region’s education, healthcare, and agriculture to provide a route toward sustainable development and to provide people with opportunities for jobs and income without harming the environment. The remote sensing and GIS approach in this study is expected to be helpful in forest monitoring and rehabilitation toward the region's societal, ecological, and economic benefits. The research findings could help policy planners develop appropriate policies and management interventions for mining industries with significant land use impacts on biodiversity.

Chapter 3. Vegetation Structure and Tree Species Diversity Inside and Outside the Zalon Taung National Park in Banmauk Township

3.1 Introduction

Numerous studies focus on tropical forests since they include some of the most diverse vegetation [121], conserve carbon stocks and timber [122], and provide food, feed, shelter, energy, medicine, and revenue for human progress [67]. Globally, the highest percentage of forests (45%) is in tropical regions [123]. Tropical forests are biodiversity hotspots of conservation priority [65], as people in poor tropical nations rely on forest resources for daily needs, compared to biodiversity conservation activities [124]. Such disparities are particularly concerning in Myanmar, a part of the Indo-Burma and Himalaya hotspots [125], with 70% of its 51.48 million people living in rural areas and dependent on forest resources [40]. Myanmar's three basic types of forests are tropical, subtropical, and temperate, all determined by climate and geography [126, 127]. Hardwoods comprise the majority of these forests [126]. National parks, marine national parks, wildlife sanctuaries, and other nature reserves are designated as protected areas in Myanmar to protect biodiversity, ecosystem services, and forests' spiritual and cultural significance [128]. According to the forest resource assessment by FAO in 2020, the forests cover in Myanmar is 42.19% of the entire country [2]. Currently, 6.43% of Myanmar's total area has been established as protected areas, although the nation has targeted to increase that to 10% by the 2015 Paris Climate Change Conference [6].

Tropical forests are being increasingly affected by population explosion, agriculture expansion, mining, logging, and road building [129]. Although illegal logging activities target the most valuable timber species with promising revenues, logging intensities have been exceptionally high in Southeast Asia, leading to loss and damage to species and ecosystems [130]. Furthermore, collecting firewood from local communities is another distinct driver of the degradation of tropical forests in Southeast Asia [131]. While emphasizing the sustainability, habitat protection, and ecosystem preservation of tropical forests, a comprehensive understanding of the diversity and composition of tree species in these forests is required [132, 133]. Understanding tropical forests' diversity and ecological features is vital to sustaining their functions in regulating species diversity, food webs, water and air filtration, microclimate, and soil fertility [134, 135]. Considerable research on tropical vegetation focuses primarily on how variations in topography, edaphic conditions, human activities, management types, and land use/land cover impact the diversity, composition, and structure of tree species in the forest reserves [136-139].

Tropical forests in Myanmar have been studied for their management status and plant community compositions [27, 140], soil and environmental characteristics [141, 142], tree species diversity distribution along a precipitation gradient [143], and topographic and edaphic variations [144]. These studies provided details on Myanmar's tropical forest structure and floristic richness. Most of these studies were conducted in well-maintained protected areas and reserved forests, ideal for conserving biodiversity. However, the unprotected forests of Myanmar have yet to be studied. A substantial portion of the biodiversity in Myanmar and the tropics remains outside of protected areas [145, 146]. Recent years have seen an increase in the importance of biodiversity conservation outside protected areas in the global conservation debate [147, 148]. Most environmentalists focus on effective land use planning to protect the biodiversity of protected areas outside to achieve conservation goals and livelihood security [149]. A specific study claimed that while certain species were more prevalent outside the protected area than inside, conservation efforts inside protected areas alone were inadequate to guarantee the long-term survival of endangered species [150]. Conservation of Southeast Asian biodiversity is geared toward protected areas [151]; therefore, recording forest tree species outside protected areas is rare. Supporting the maintenance of unprotected tropical forests near protected areas might result in a situation where biodiversity conservation is achieved while also boosting the local economy [146]. To combine biodiversity conservation with local livelihood security, it is critical to understand human dependence on forest resources and its effects on forest structure and diversity. Disturbances by humans have decreased species diversity and structural characteristics such as stand density, diameter class distributions, and basal area of tropical forests [152, 153].

This study was conducted inside and outside Zalon Taung National Park (ZNP) in Banmauk Township, Northwest Myanmar. According to the FAO 2020 forest resource assessment, 42.54% of Banmauk Township is forested [2]. However, as the population rise and human activities such as illicit logging, gold mining, fuel wood collection, shifting cultivation, and plantation establishment endanger forest resources [97], the extent of forest cover in the Banmauk Township is declining at a rate of 0.6% per year between 2010 and 2017 [23]. The Ministry of Natural Resources and Environmental Conservation (MONREC) of Myanmar issued ZNP as a PA in 2022 [154]. However, with the expansion of human populations, their settlements and farmlands contributed to the destruction of natural forests, particularly in the periphery of ZNP [155]. The inhabitants use forest resources to generate income, especially to collect wood, medicinal plants, and firewood [97]. Additionally, ZNP has a history of selective logging, in which the government extracted teak and other economically significant hardwood species for foreign revenue [58]. To implement effective conservation measures under the ZNP designation as a PA, a quantitative investigation of the floristic composition, richness, and stand structure along this human-dependent natural forest is urgently required.

This study aimed to assess tree species diversity, composition, and stand structure inside and outside a newly established ZNP in Myanmar. The specific objectives are to (1) identify the tree species diversity and stand structural features; (2) assess the stand density, abundance, and dominance of total tree species and economically important tree species; and (3) evaluate the changes in tree species composition, diversity, evenness, and stand structure in response to environmental variables. The results will help to evaluate the vegetation structure, diversity, and composition in and out of ZNP for long-term conservation planning to balance biodiversity protection and resource use.

3.2 Materials and Methods

3.2.1 Study area

The vegetation survey was conducted during April and May 2022 in ZNP and its adjacent unclassified forest (BUCF), located between 95°44′E and 95°56′E longitude and 24°28′N and 24°42′N latitude in Northwest Myanmar (Figure 3.1). As a limitation of this study, I cannot assess the vegetation in the upper part of ZNP because of ongoing armed conflicts between the national military and local armed groups that have rendered it insecure or inaccessible. ZNP was designated as a PA in January 2022 to preserve the cultural value of Zalon Taung Pagoda, the native flora, wildlife, and water resources after it was gazetted in 1994 Nantkaunghu reserved forest, covering 21,616 ha [154]. ZNP is a significant protected habitat for Hoolock gibbons, pangolins, Dhole dogs, Asiatic black bears, and clouded leopards [155]. National parks are included in the category of Protected Area System, in which the forest law strictly prohibits harvesting forest resources [55]. Unclassified forests are included in the category of vacant land or land at the government's disposal [156]. Unless the forest law expressly forbids a particular behaviour, such as cutting "reserved tree species" (e.g., teak), villagers can harvest wood and non-timber forest products for subsistence in the unclassified forest [55]. After Myanmar Timber Enterprise deliberately felled 2,439.54 tons of teak (*Tectona grandis*) and 5,207.852 tons of kanyin trees (*Dipterocarpus alatus*) between 2005 and 2010, the government stopped timber exploitation in ZNP [154]. In BUCF, selective logging of teak and other hardwood trees has continued. The extraction of non-timber forest products, especially medicinal plants, is noticeable in ZNP.

Natural vegetation is a diverse range of tropical moist upper mixed deciduous forests, with most species defining the deciduous forest type. Physiographic conditions include steep hills, valleys, flat plains, and flat-topped ridges, with an elevation range of 100 to 1,600 meters above sea level. The typical soil types are Rhodic Ferrasols (red-brown forest soil) and Lithosols (primitive crushed stone). The region has a tropical monsoon climate with an average of 1,337 mm annual rainfall, with the most rainfall between June and September [48]. The mean monthly temperature ranges from 6.7°C to 41.9°C; the hottest month is April, and the coldest month is January. The relative humidity is high throughout the year, averaging 86% [157].

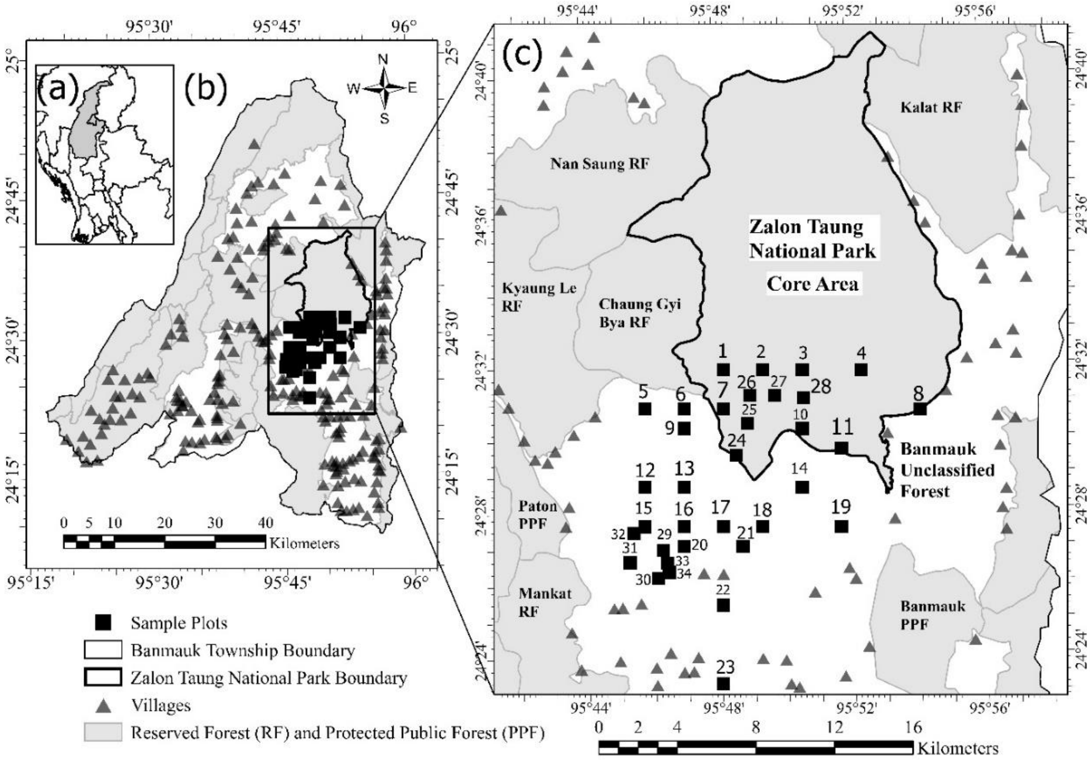


Figure 3.1: Location map of (a) Sagaing Region, (b) Banmauk Township and (c) Sampling plots with numbers

There are around 40 villages on the plains surrounding BUCF and ZNP. Most people who live near and within the territory of BUCF and ZNP are farmers. Data from the 2014 national census showed that the population density in Banmauk Township was 33 persons/km^2, with 83% of total population living in villages [59]. The majority of local villagers cultivate rice and groundnut, collect firewood, timber and non-timber forest products, especially medicinal plants, from the forest, and work as gold mining labours [59]. Residents rely on forests for extraction and timber harvesting even though the forests are under the management of the Forest Department of Myanmar.

3.2.2 Sampling design and environmental parameters

34 sampling plots (40 × 40 m) were randomly selected, while 21 plots were located in BUCF and 13 plots in ZNP at least 500 m apart (Figure 3.1 (c)). The sample locations had various human disturbances, including legal and illicit tree cutting and residents harvesting firewood and medicinal plants. Every tree ≥10 cm diameter at breast height (dbh) was identified, numbered, and measured for height and diameter using a clinometer and diameter tapes. The survey team, including local Forest Department staff, local guides, and the botanists of the local nongovernmental organization, assisted in identifying tree species. The local names of the species were converted into scientific names following Kress et al. (2003) [158].

Figure 3.2: Signs of logging

(a) Old-growth

(b) Selectively logged secondary forest

(c) Jungle forest

Figure 3.3: Land classes (a) old-growth, (b) secondary forest and (c) jungle forest

Seven environmental parameters were determined for each plot, including elevation, slope, aspect, land class, logging level, and distance to the nearest village and road. A GPS (*Garmin 62s*) was used to determine each plot's latitude, longitude, and altitude. The slope and aspect were derived from the 30 m resolution digital elevation model (DEM) using the coordinates of the sample plots. In each sampling plot, the number of cutting and stumps were recorded as indicators of logging activities (Figure 3.2). Then, the land class of each sampling plot, such as old-growth forest land (i.e., minimally disturbed land), secondary forest land (i.e., the land disturbed by selective logging and harvesting of forest products), and jungle forest land (i.e., the land heavily disturbed by road and farmland encroachment) were recorded (Figure 3.3). Additionally, understory vegetation, including bamboo, shrubs, and herbs, was recorded in general, although it was not considered in the woody vegetation analyses.

3.2.3 Data analysis

To determine the stand structural characteristics, the mean DBH (cm), the maximum tree height (m), the total basal area (m^2), and tree density were calculated for each plot. The Shannon Wiener's index [159], Simpson's index [160], and Pielou's evenness [161] were used to calculate the woody species diversity in each sample plot.

Shannon index H' = $-\sum_{i=1}^{s} p_i \ln(p_i)$ ……………………………………………………….(1)

Where s is the number of species in the community and is the percentage of individuals found in the ith species, the Shannon index may range from 1.5 to 3.5, seldom going over 4.5, where high levels suggest a large diversity.

Species dominance Simpson index D=1-(Σn(n-1)/N(N-1)) ……………………………….(2)

Where n is the number of individuals of a single species, and N is the number of individuals in the total population. The Simpson index has a potential range of 0 to 1, with high values indicating little diversity and high stand dominance.

Pielou evenness index (e) = H'/log(S) ……………………………………………………..(3)

S is the number of species, and H' is the Shannon Wiener Index. With potential values ranging from 0 to 1.0, strong values indicate good evenness.

Fisher's α diversity [162] was quantified in each site because it reduces the fluctuation of sample size between the two sites and works well on tropical forest vegetation [163]. The Biodiversity R package [164] in the R software version 4.2.1 was used to examine the diversity of species. The density-diameter distribution of tree species using DBH classes set at 10 cm intervals characterized the population structures of the two sites (BUCF and ZNP). The rarefaction curves were developed using the iNEXT package [165] in R software to evaluate the direct comparison of species richness between the two sites. Then, a species rank-abundance curve was developed to evaluate the species richness of the most abundant tree species [166]. Additionally, each species' Importance Value Index (IVI) was calculated by summing up each species' relative density, frequency, and dominance [167] (Table 3.1).

Table 3.1: Formulae for calculating IVI

Parameters	Formula
Importance Value Index	IVI = Relative density + Relative frequency + Relative dominance
Density of a species	De = Number of a species/Total area sampled
Frequency of a species	F = Area of plots in which a species occurred/Total area sampled
Dominance of a species	Do = Total basal area of a species/Total area sampled
Relative density of a species	RDe = Density of a species/Total density of all species*100
Relative frequency of a species	RF = Frequency of a species/Total frequency of all species*100
Relative dominance of a species	RDo = Dominance of a species/Total dominance of all species*100

The Shapiro-Wilk test determined the normality of the data before comparing stand structural features of economically significant and higher IVI species at BUCF and ZNP [168]. Since the dataset deviated from the normal distribution, the Wilcoxon rank sum test was used to compare dbh, basal area, and height between sites.

Nonmetric multidimensional scaling (NMDS) ordination in the R vegan package [169] examined tree species composition in 34 plots of three land classes in BUCF and ZNP. The sample plots were first arranged on the graph based on Bray Curtis distance measure. Then, the ordination graphs were fitted using permutation testing, significant species, and environmental factors. The Wilcoxon rank sum test compared environmental variables between the two sites. The Spearman rank correlation coefficients were used to quantitatively examine all sampling plots' stand structural characteristics and diversity along with environmental conditions (elevation, slope, distance to settlement, and roads).

3.3 Results

3.3.1 Stand structure and species diversity

The characteristics of 34 sampling plots were described (Table 3.2). ZNP had a higher tree density (322 individuals ha^{-1}) than BUCF, with a tree density of 306 individuals ha^{-1}. ZNP had a basal area of 20.6 m^2 ha^{-1}, whereas BUCF had 15.0 m^2 ha^{-1}. In ZNP, Simpson, Shannon, and Fisher diversity indices and Pielou's evenness were higher than in BUCF (Table 3.3). The secondary forests in ZNP had the highest tree density (338 individuals ha^{-1}) with the highest basal area (22.4 m^2 ha^{-1}) (Figure 3.4). The old-growth forest in BUCF had the most significant number of trees greater than 30 cm dbh (128 individuals ha^{-1}), followed by the secondary forest in ZNP (106 individuals ha^{-1}) (Figure 3.4). The species richness of all sampling plots and plot no. was investigated through rarefaction curves (Figure 3.5). The rarefaction curves for BUCF and ZNP demonstrated that, for the same number of individuals, the species diversity between them was comparable (Figure 3.6).

Table 3.2: Description of 34 sample plots with plot-level species diversity, elevation and logging level

Forest	Plot no.	Land class	Number of trees	Tree species richness	Fisher's α	Elevation	Logging level
ZNP	1	Secondary forest	63	14	5.530	703.848	low+
	2	Secondary forest	38	15	8.717	783.223	low+
	3	Secondary forest	33	16	11.036	774.303	low+
	4	Secondary forest	41	16	8.869	435.382	low+
	7	Secondary forest	56	22	12.009	812.641	low+
	8	Jungle forest	34	12	5.612	213.617	high+++
	10	Old-growth	42	19	10.786	596.825	low+
	11	Secondary forest	36	16	8.549	352.082	high+++
	24	Secondary forest	33	15	6.634	736.387	high+++
	25	Secondary forest	82	27	11.623	704.487	intermediate++
	26	Secondary forest	42	20	9.548	188.118	intermediate++
	27	Secondary forest	83	33	15.983	939.745	low+
	28	Secondary forest	87	15	4.605	532.638	low+
BUCF	5	Secondary forest	54	14	5.801	717.464	low+
	6	Old-growth	53	14	5.801	760.942	low+
	9	Old-growth	44	23	15.453	790.786	low+
	12	Secondary forest	52	21	10.892	376.989	intermediate++
	13	Secondary forest	39	22	14.386	673.089	low+
	14	Secondary forest	52	14	5.434	330.444	high+++
	15	Secondary forest	47	20	10.234	491.251	intermediate++
	16	Secondary forest	54	17	7.145	671.107	intermediate++
	17	Secondary forest	52	14	5.303	566.973	intermediate++
	18	Secondary forest	48	14	5.434	287.62	intermediate++
	19	Jungle forest	35	10	3.610	168.732	high+++
	20	Secondary forest	49	15	5.904	523.386	high+++
	21	Jungle forest	28	7	2.234	199.395	high+++
	22	Secondary forest	52	17	6.909	305.792	intermediate++
	23	Secondary forest	41	9	2.853	271.264	intermediate++
	29	Secondary forest	65	29	14.341	284.648	intermediate++
	30	Secondary forest	67	30	14.863	265.101	intermediate++
	31	Secondary forest	50	28	15.154	317.911	intermediate++
	32	Secondary forest	50	20	8.428	327.729	high+++
	33	Secondary forest	47	29	16.348	257.673	intermediate++
	34	Secondary forest	50	21	8.987	281.424	intermediate++

Note: ZNP= Zalon Taung National Park, BUCF=Banmauk unclassified forest, + = counts of cuttings and stumps < 3, ++ = counts of cuttings and stumps between 3 and 10, +++= counts of cuttings and stumps > 10

Table 3.3: Structure and diversity of BUCF and ZNP plots

Variables	BUCF	ZNP
Mean density (no. trees/ha)	306.00±11.90	322.00±35.50
Mean DBH (cm)	21.60±2.68	21.00±2.34
Maximum height (m)	23.60±5.82	26.50±9.51
Mean basal area (m^2)/ha	15.00±1.16	20.60±3.66
Simpson index	0.85±0.01	0.88±0.01
Shannon index	2.34±0.08	2.49±0.08
Pielou evenness	0.84±0.01	0.87±0.02
Fisher's α	24.45	25.37

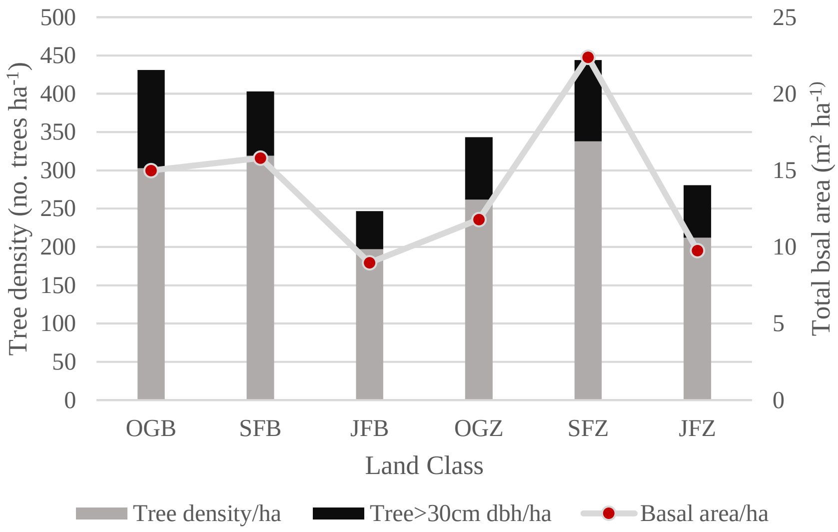


Figure 3.4: Tree density and basal area of three land classes in BUCF and ZNP

Note: OGB=old-growth forest in BUCF, SFB=secondary forest in BUCF, JFB=jungle forest in BUCF, OGZ=old-growth forest in ZNP, SFZ=secondary forest in ZNP, JFZ=jungle forest in ZNP

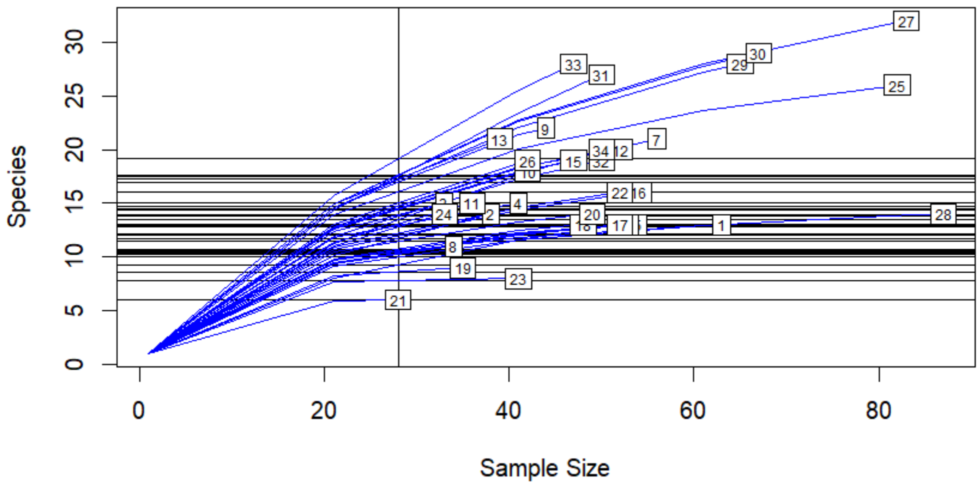


Figure 3.5: Rarefaction curve of species diversity in 34 sampling plots (the number represents each plot number)

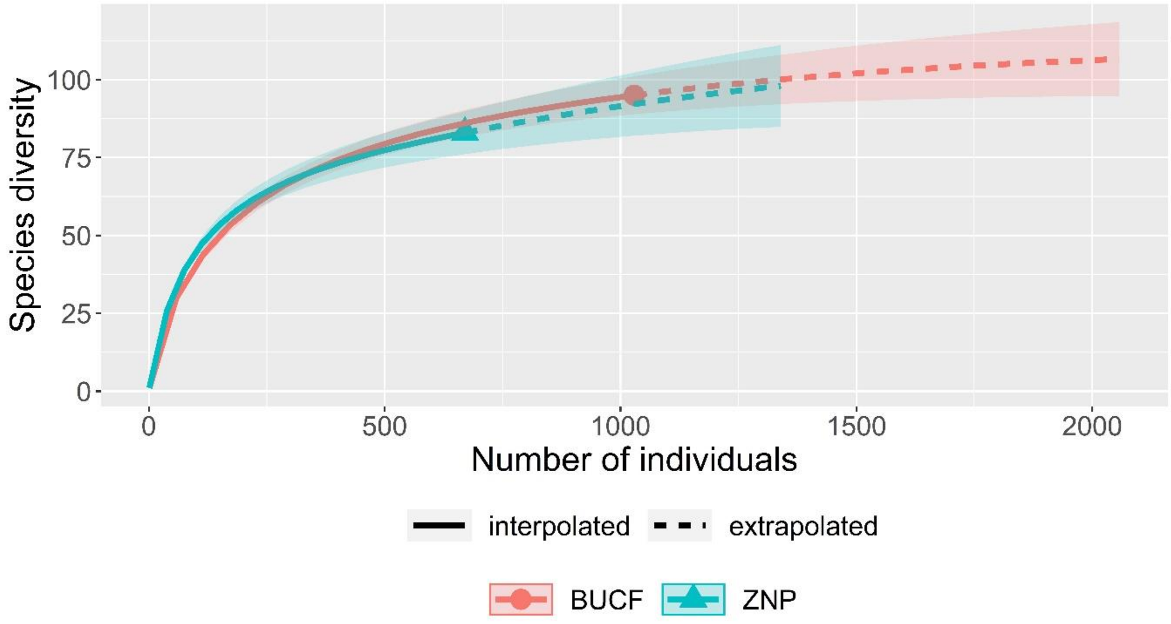


Figure 3.6: Rarefaction curve of species diversity in BUCF and ZNP

The population structure of BUCF and ZNP forests were analyzed using the density-diameter distribution (Figure 3.7). Most of the trees were between 10 and 15 cm dbh. Only a handful of the trees in each site were larger than 50 cm dbh. In contrast to BUCF, the ZNP plots showed a greater number of trees larger than 60 cm dbh. The tree population structures grew with increasing densities of lower diameter classes and lower densities of higher diameter classes (Figure 3.7).

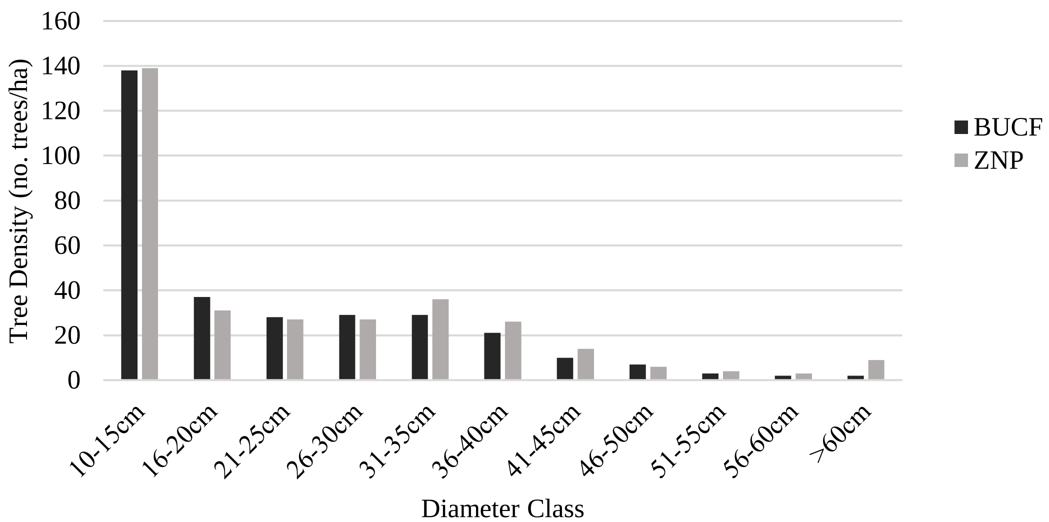


Figure 3.7: Population structure of BUCF and ZNP plots

3.3.2 Tree species composition, abundance, and importance value index (IVI)

A total of 1,699 individuals with dbh 10 cm and greater were counted in BUCF and ZNP, comprising 116 species from 87 genera and 48 families. In BUCF, 42 families represented 71 genera, 91 species, and 1,029 individuals. In ZNP, 43 families comprised 68 genera, 84 species, and 670 individuals. Table 3.4 lists the families that comprise more than 5% of the composition. In BUCF, the Verbenaceae family dominated, but in ZNP, it was the Euphorbiaceae family. IVI values indicate the ecological relevance of tree species in community structure (Table 3.5). With an IVI of 26.91%, *Protium serratum* (Burseraceae) was the most prominent species in BUCF, followed by *Dipterocarpus alatus* (Dipterocarpaceae), *Tectona grandis* (Verbenaceae), *Dillenia pentagyna* (Dilleniaceae) and *Schleichera oleosa* (Sapindaceae) with IVI of 19.83, 19.41, 16.29 and 16.25 %, respectively (Table 3.5). The most notable species in ZNP was *Dipterocarpus alatus* (Dipterocarpaceae), with an IVI of 18.39%, followed by *Xerospermum noronhianum* (Sapindaceae) (15.77%), *Protium serratum* (Burseraceae) (13.44%), *Baccaurea sapida* (Euphorbiaceae) (11.60%) and *Dracontomelon dao* (Anacardiaceae) (11.26%) (Table 3.5). These species are considered ecologically significant in a given habitat since the IVI value is more than 10 [168]. The IVI values of all species are provided in the Appendix.

Table 3.4: Families with a composition greater than 5% in BUCF and ZNP

BUCF			ZNP		
Family	Composition (%)	No. of species	Family	Composition (%)	No. of species
Verbanaceae	12.9	5	Euphorbiaceae	7.2	3
Burseraceae	9.9	2	Dipterocarpaceae	6.7	2
Dipterocarpaceae	9.9	4	Combretaceae	6.5	4
Combretaceae	8.6	4	Anacardiaceae	6.4	4
Sapindaceae	7.2	2	Sapindaceae	6.4	2
Euphorbiaceae	5.9	6	Fagaceae	6.1	4
Fagaceae	5.5	4	Burseraceae	5.8	1
Fabaceae	5.5	4	Moraceae	5.7	6
Dilleniaceae	5.3	1	Verbanaceae	5.0	2

Table 3.5: Total number, relative frequency, relative dominance, relative density, and importance value index of ten tree species in BUCF and ZNP

BUCF						ZNP					
Species	N	RF	RDo	RDe	IVI	Species	N	RF	RDo	RDe	IVI
Protium serratum	96	9.33	12.93	4.64	26.91	*Dipterocarpus alatus*	35	5.22	10.08	3.08	18.39
Dipterocarpus alatus	65	6.32	11.05	2.46	19.83	*Xerospermum noronhianum*	36	5.37	6.87	3.52	15.77
Tectona grandis	103	10.01	3.66	5.74	19.41	*Protium serratum*	39	5.82	4.10	3.52	13.44
Dillenia pentagyna	55	5.34	6.30	4.64	16.29	*Baccaurea sapida*	36	5.37	3.58	2.64	11.60
Schleichera oleosa	57	5.54	6.61	4.10	16.25	*Dracontomelon dao*	11	1.64	6.97	2.64	11.26
Terminalia crenulata	56	5.44	5.77	3.55	14.77	*Terminalia crenulata*	27	4.03	4.08	3.08	11.20
Dalbergia oliveri	51	4.96	3.53	4.64	13.13	*Dillenia pentagyna*	32	4.78	2.23	3.96	10.97
Quercus glauca	22	3.11	3.11	2.50	8.68	*Premna latifolia*	21	3.13	3.51	2.20	8.84
Aporusa roxburghii	34	3.30	1.62	2.73	7.65	*Cedrela serrata*	21	3.13	2.36	3.08	8.58
Shorea siamensis	25	2.43	2.98	2.19	7.60	*Decaspermum parviflorum*	16	2.39	2.52	2.20	7.12

The species rank abundance curve revealed an abundance of vegetation with variations in BUCF and ZNP (Figure 3.8). A steep gradient of the BUCF stand showed low evenness as high-ranking species have higher abundances than low-ranking species. On the other hand, the modest gradient of ZNP suggested good evenness since the abundances of various species are more consistent than in the BUCF (Figure 3.8).

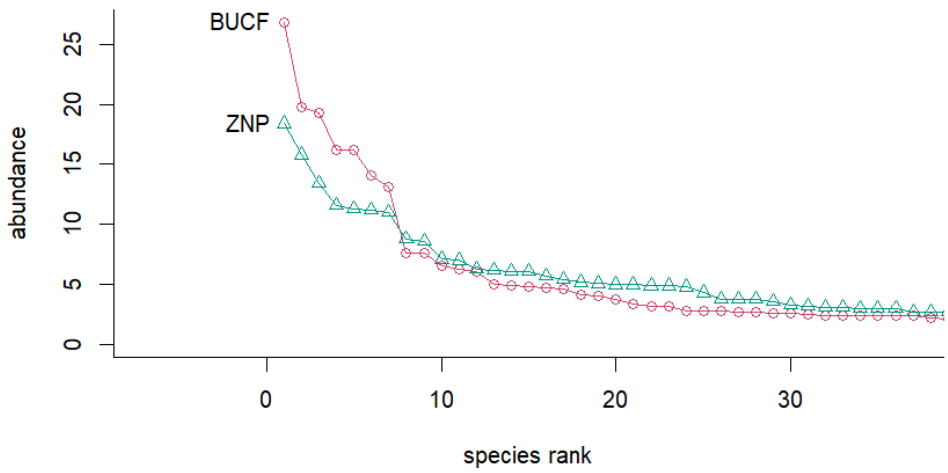


Figure 3.8: Species rank abundance curve

3.3.3. Stand structural characteristics of economically important tree species

The number of trees ha^{-1} (tree density), dbh, basal area ha^{-1}, and the height of five commercially significant wood species - *Dipterocarpus alatus, Dalbergia oliveri, Protium serratum, Tectona grandis and Terminalia crenulata* - were examined (Table 3.6 and Figure 3.9). *Dipterocarpus alatus* had the most excellent tree density, followed by *Protium serratum* in both BUCF and ZNP. *Dalbergia oliveri* of BUCF and *Tectona grandis* of ZNP had the lowest tree density. *Dipterocarpus alatus* had the most fabulous average diameter, basal area, and height in both sites, while *Tectona grandis* had the lowest except for the tree density in BUCF. The tree density of *Tectona grandis* was significantly different between BUCF and ZNP (W=104.5, $p<0.05$). The diameter and basal area of *Terminalia crenulata* were significantly different between the two sites (W=553.5, $P<0.05$). The height of *Protium serratum* was significantly different between the two sites (W=2510.5, $p<0.01$) (Figure 3.9).

Table 3.6: Mean and standard error value of structural characteristics of five species

	BUCF					ZNP				
	Da	Do	Ps	Tg	Tc	Da	Do	Ps	Tg	Tc
Tree Density ha^{-1}	37± 12	19± 4	35± 5	31± 3	27± 4	31± 6	17± 3	30± 4	13± 4	24± 7
DBH (cm)	29.40 ± 1.89	19.00 ± 1.30	26.10 ± 1.41	13.80 ± 0.60	23.10 ± 1.54	36.00 ± 2.86	19.10 ± 3.17	21.40 ± 1.74	12.40 ± 1.34	27.30 ± 1.74
Basal area (m^2 ha^{-1})	0.54 ± 0.06	0.22 ± 0.03	0.43 ± 0.04	0.11 ± 0.01	0.33 ± 0.04	0.77 ± 0.16	0.23 ± 0.07	0.28 ± 0.04	0.09 ± 0.02	0.41 ± 0.04
Height (m)	14.80 ± 0.74	9.84 ± 0.50	12.80 ± 0.52	8.36 ± 0.27	11.30 ± 0.62	17.20 ± 1.12	9.99 ± 1.31	9.81 ± 0.75	8.68 ± 0.63	12.10 ± 0.80

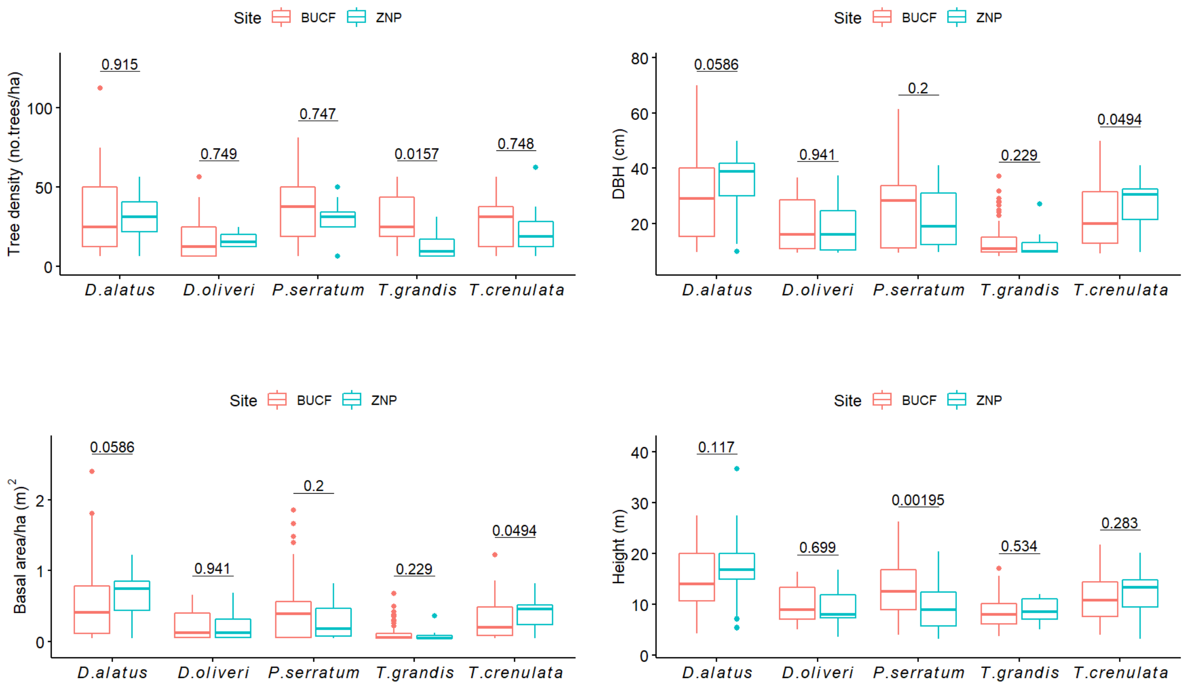


Figure 3.9: Tree density, dbh, basal area and height of five economically important tree species by Wilcoxon rank sum test (p-values are shown above the whisker plots)

3.3.4 Differences in species composition and environmental variables

The final stress value for the two-dimensional solution of the NMDS ordination analysis after 999 permutations was 16.61%, which is within an acceptable range of 20% for the statistical reliability of the NMDS ordination [170]. NMDS analysis revealed differences in the composition of tree species in BUCF and ZNP with three land classes. NMDS analysis showed that secondary forest plots were significantly composed of economically significant deciduous tree species such as *Tectona grandis*, *Dipterocarpus alatus*, and *Shorea siamensis* (Figure 3.10 and Table 3.7). The ZNP secondary forest plots favored the tropical moist forest habitats such as those occupied by *Dracontomelon dao*, *Malus*.spp, *Syzygium kurzii*, *Baccaurea sapida*, and medicinal plant species like *Millingtonia hortensis* and *Cinnamomum inunctum* (Figure 3.10 and Table 3.7). Elevation, logging level, and access to roads and villages appeared to be the most influential factors affecting tree species composition in BUCF and ZNP (Figure 3.11 and Table 3.8). In particular, the level of logging and distance to the road correlated with the secondary forest of BUCF (Figure 3.11 and Table 3.8). A higher elevation and a greater distance from the villages may favor the substantial composition of tree species, such as *Dracontomelon dao*, *Malus*.spp, *Morus alba*, and *Swintonia floribunda* in the secondary forest of ZNP according to the NMDS and Wilcoxon rank sum test (Figure 3.11 and Table 3.9). The Wilcoxon rank sum test revealed that elevation and distance to the village significantly differed, whereas slope, aspect, land classes, logging level, and distance to the roads were not significantly different between BUCF and ZNP (Table 3.9).

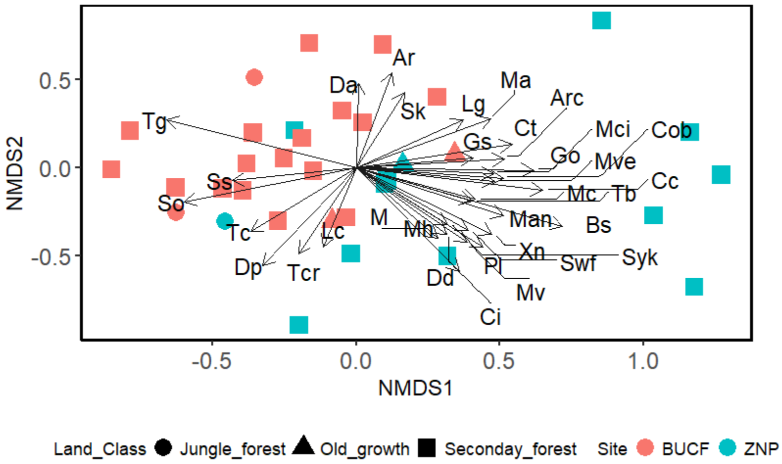


Figure 3.10: NMDS ordination of significant species

Note: Tg = *Tectona grandis*, Ss = *Shorea siamensis*, So = *Schleichera oleosa*, Tc = *Terminalia chebula*, Dp = *Dillenia pentagyna*, Tcr = *Terminalia crenulata*, Lc = *Lannea coromandelica*, M = *Malus*.spp, Mh = *Millingtonia hortensis*, Dd = *Dracontomelon dao*, Ci = *Cinnamomum inunctum*, Pl = *Premna latifolia*, Mv = *Machilus villosa*, Syk = *Syzygium kurzii*, Swf = *Swintonia floribunda*, Xn = *Xerospermum noronhianum*, Man = *Myristica angustifolia*, Bs = *Baccaurea sapida*, Mc = *Mangifera caloneura*, Tb = *Terminalia bellerica*, Cc = *Celtis cinnamomea*, Mve = *Miliusa velutina*, Go = *Gynocardia odorata*, Mci = *Millettia cinerea*, Cob = *Croton oblongifolius*, Gs = *Gardenia sootepensis*, Ct = *Castanopsis tribuloids*, Arc = *Artocarpus chaplasha*, Ma = *Morus alba*, Lg = *Lithocarpus grandifolia*, Sk = *Schima khasiana*, Ar = *Aporusa roxburghii*, Da = *Dipterocarpus alatus*

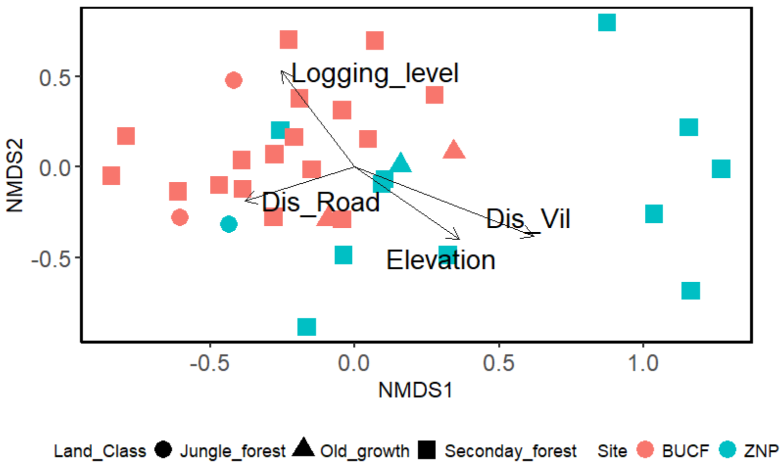


Figure 3.11: NMDS ordination of significant environmental variables

Table 3.7: NMDS scores of significant species variables

Variables	NMDS1	NMDS2	p-value	Variables	NMDS1	NMDS2	p-value
Tg	-0.69603185	0.26815787	0.001	Bs	0.71739058	-0.32149891	0.001
Ss	-0.41232026	-0.10011299	0.043	Mc	0.41662382	-0.16526151	0.031
So	-0.56436402	-0.20665331	0.002	Tb	0.40502089	-0.17997396	0.037
Tc	-0.34134782	-0.36691586	0.014	Cc	0.65185846	-0.10835249	0.001
Dp	-0.31340380	-0.56476761	0.001	Mve	0.48227540	-0.06323046	0.021
Tcr	-0.19001198	-0.48470993	0.006	Go	0.61740474	0.00877868	0.002
Lc	-0.11063047	-0.45432132	0.033	Mci	0.47986555	-0.01922995	0.023
M	0.27972265	-0.40814073	0.023	Cob	0.51353662	-0.04134883	0.011
Mh	0.31190539	-0.38333656	0.031	Gs	0.07242523	-0.43701499	0.034
Dd	0.36178355	-0.58436682	0.001	Ct	0.59246628	0.12546485	0.004
Ci	0.31190539	-0.38333656	0.031	Arc	0.51638375	0.06435238	0.007
Pl	0.43699282	-0.45633904	0.001	Ma	0.46983267	0.28921954	0.008
Mv	0.38140881	-0.42839178	0.001	Lg	0.41544319	0.27291349	0.016
Syk	0.31503950	-0.31214872	0.033	Sk	0.21492955	0.41970285	0.024
Swf	0.38823855	-0.36219381	0.002	Ar	0.13294825	0.53628319	0.003
Xn	0.46558492	-0.37516819	0.002	Da	-0.02393154	0.49260289	0.016
Man	0.52531797	-0.27657385	0.003				

Table 3.8: NMDS scores of environmental variables

Variables	NMDS1	NMDS2	p-value
Elevation	0.3584668	-0.42761819	0.002
Slope	-0.2444795	0.10440320	0.329
Logging level	-0.2534578	0.5300098	0.004
Aspect	-0.0691470	-0.11087101	0.764
Distance to village	0.6187588	-0.39816994	0.001
Distance to road	-0.3827346	-0.17037371	0.053

Table 3.9: Average value, standard error and p-value of environmental variables by Wilcoxon rank sum test

Variables	BUCF	ZNP	W value	P value
Elevation	422.00±43.3	598.00±65.90	77	0.036
Slope	12.50±1.58	13.20±2.02	127	0.749
Aspect (%)			38	0.560
South	14.29	15.38		
North	4.76	0		
East	4.76	23.08		
West	28.57	0		
Southeast	14.29	46.15		
Southwest	14.29	0		
Northeast	9.52	7.69		
Northwest	9.52	7.69		
Land class (%)			7	0.369
Jungle forest	5.88	2.94		
Old-growth	5.88	2.94		
Secondary forest	50.00	32.36		
Logging level (%)			7	0.383
High	14.71	8.82		
Intermediate	35.29	5.88		
Low	11.77	23.53		
Distance to village	2.78±0.25	5.32±0.52	40	0.001
Distance to road	2.20±0.24	1.55±0.37	186	0.082

3.3.5 Relationships between environmental factors, forest structure, and biodiversity indices

Spearman correlation analyses showed that the sample plots' basal area, maximum height, diversity, and evenness were affected by environmental factors such as elevation and distance to the village and road (Table 3.10). In all sample plots, elevation had a substantial impact on species diversity and evenness, while the distance to the village and the road significantly affected the structural features such as total basal area and maximum height (Table 3.10). Elevation exhibited positive correlations with average dbh (S=4694, p=0.105), total basal area (S=4500, p=0.072), and maximum tree height (S=6224.9, p=0.784) of the plots. In contrast, the slope had a negative relationship with the total basal area (S=7618, p=0.352) and maximum height (S=7871.3, p=0.250) of plots. Elevation had a significant positive relationship with Shannon diversity (S=3816, p<0.05), Simpson diversity (S = 2598, p<0.001), and Pielou's evenness (S=3742, p>0.05). Distance to the village showed a strong positive correlation with the total basal area (S=3690, p<0.01) and the Simpson diversity index (S=3492, p<0.01). The distance to the road also exhibited a strong positive correlation with Pielou's evenness index (S=3422, p<0.01) of the plots. On the contrary, the distance to the road showed a strong negative relationship with the maximum tree height (S = 91286, p<0.05) and showed a negative but insignificant relationship with the total basal area (S=8106, p=0.174) of the plots (Table 3.10).

The linear regression analyses revealed the relationship between the structural attributes (proportion of the number of trees >30cm dbh and the total basal area), diversity and evenness with the elevation (Figure 3.12). The regression was statistically significant for the increasing pattern of the percentage of trees greater than 30 cm dbh with increasing elevation (R^2 = 0.183, P <0.01) (Figure 3.12a). The total basal area of the trees in the sampling plots increased significantly with increasing elevation (R^2 = 0.0976, P <0.05) (Figure 3.12 b). The higher Simpson index (R^2 = 0.126, P<0.05) and Pielou's evenness (R^2 = 0.098, P<0.05) of the sample plots regarding increased elevation were also significant in the regressions (Figure 3.12 c and d).

Table 3.10: Spearman correlation coefficient of forest structure and tree species diversity of 34 sampling plots related with environmental variables

Parameter	Elevation	Slope	Distance to village	Distance to road
Average DBH (cm)	0.2828113	0.2186402	0.2073338	0.2748663
Total Basal Area (m^2)	0.3124523	-0.1639419	0.4362108**	-0.2385027
Maximum Height (m)	0.04890349	-0.2026439	0.2332085	-0.3947429*
Shannon Diversity	0.4169595**	0.036822	0.3191749	0.1792208
Simpson Diversity	0.6030558***	0.1446906	0.4664629**	0.3262032
Pielou’s Evenness	0.4282659**	0.1880825	0.281589	0.4771581**

Note: The correlation is considered significant at p<0.05 (*), p<0.01 (**) and p<0.001 (***).

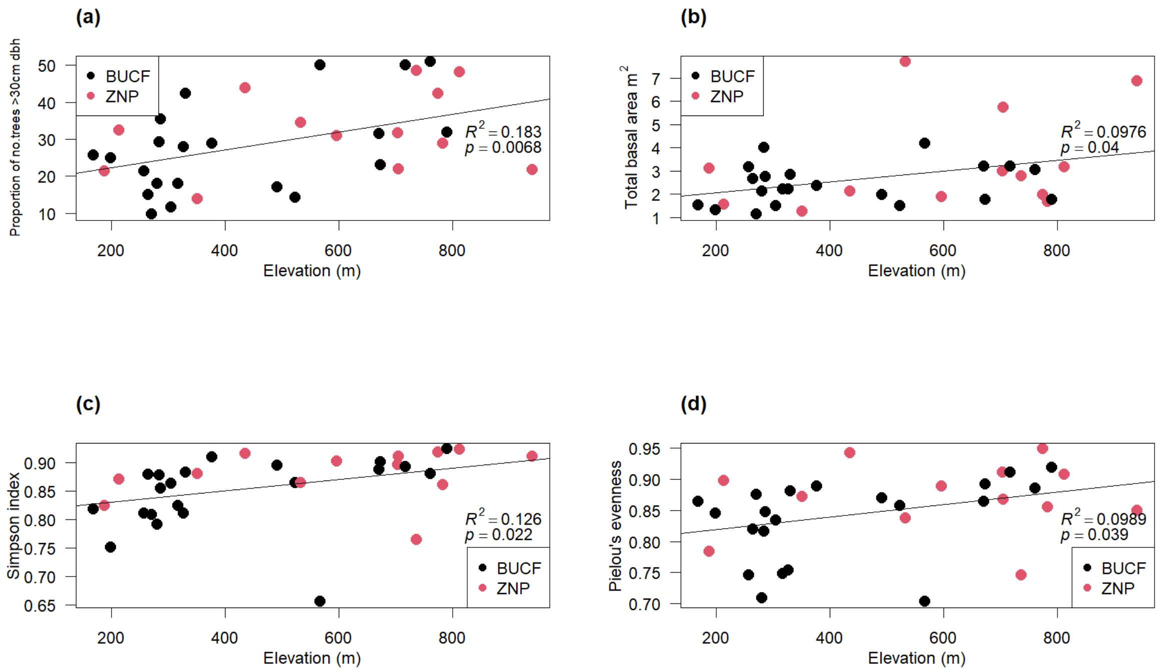


Figure 3.12: Linear regressions of (a) proportion of trees > 30 cm dbh, (b) total basal area, (c) Simpson index, and (d) Pielou's evenness with the elevation

3.4 Discussion

3.4.1 Do tree density, dominance, and diversity differ between BUCF and ZNP?

All 34 sample plots were located in the natural forest at altitudes ranging from 168 m to 812 m, dominated mainly by deciduous tree species, which characterizes the study forest as a tropical moist upper mixed deciduous forest [127]. Since all sample plots were in a continuous landscape accessible to nearby villages, local populations' dependency on them would likely be comparable. Tree density (306-322 individuals ha^{-1}) in BUCF and ZNP was lower compared to tree densities reported from Popa Mountain Park (604-957 individuals ha^{-1}) [141], the evergreen montane forest of Ywa Ngan Township (312-1372 individuals ha^{-1}) [142], and tropical deciduous forests of Gyobingauk Township (368 individuals ha^{-1}) [143] in Myanmar. However, the current research's tree densities were higher than that of a degraded forest (168 individuals ha^{-1}) in Oak-twin Township [27] and comparable to that of the reserved tropical forest (229 individuals ha^{-1}) reported from Seikphyu Township [143] in Myanmar. Although the ZNP plots have higher tree density and dominance than the BUCF plots, there was no significant difference between them. The dominance range (15.0-20.6 m^2 ha^{-1}) in this study was well comparable to the value reported for the human-disturbed forest (17.77-24.47 m^2 ha^{-1}) in Popa Mountain Park [141]. However, it was much lower than those recorded in the Alaungdaw Kathapa National Park (60.03 m^2 ha^{-1}) [27] and Natmataung National Park (55.63 m^2 ha^{-1}) [171], which have been protected since 1984 and 1994 in upper Myanmar.

Plant diversity indices provide more accurate measurements of species diversity and abundance in forests than species counts alone [172, 173]. ZNP had higher diversity indices and Pielou's evenness than BUCF, although not significantly. The steeper gradient rank abundance curve of the BUCF revealed unequal resource sharing (Figure 3.8), with *Protium serratum* and *Dipterocarpus alatus* having much greater relative dominance than neighbouring species (Table 3.5). The growing human demand for wood for housing and fuel causes the repeated exploitation of preferable tree species, which can alter the species composition in the BUCF, where the forest law does not strictly prohibit the exploitation of forest products.

The secondary forest plots had the highest species diversity, while the jungle forest plots had the lowest species diversity in rarefaction-based species richness (Figure 3.5). The limited diversity of woody species in the jungle forest today is due to the dominance of bamboo and shrubs, notably *Pseudostachyum polymorphum*, *Dendrocalamus strictus*, *Ziziphus oenoplia*, *Caryota mitis*, and *Arenga nana* after it was previously disturbed by heavy extraction of forest products as well as road and farmland invasion. The people's substantial dependence on unlawful access to forest resources may cause similar patterns of rarefaction-based species diversity in BUCF and ZNP (Figure 3.6). The study anticipated that the similar level of species richness in ZNP to the nearby unclassified forest (BUCF) was caused by previous heavy logging, the exploitation of forest products, and human intrusion. ZNP became a protected area (PA) in 2022. ZNP plots will evolve into excellent forest conditions if they are sufficiently protected under PA status. The large-diameter trees (dbh>60cm) considerably contribute to biomass; thus, the increasing frequency of these giant trees in ZNP (Figure 3.7) may increase structural variability and the forest's capacity to store carbon [174].

According to the distribution of the families, Verbenaceae (12.9%), Burseraceae (9.9%), and Dipterocarpaceae (9.9%) are the families with the highest representation in the BUCF. The family with the highest representation in the ZNP plots is Euphorbiaceae (7.2%), followed by Dipterocarpaceae (6.7%) and Combretaceae (6.5%). The highest abundance of Euphorbiaceae in ZNP mirrored a feature of tropical forests reported by the study of the tropical forest in the Congo [175]. However, Verbenaceae, Burseraceae, Dipterocarpaceae, and Combretaceae are distinctive families to the tropical mixed deciduous forests frequently disturbed by logging activities [143]. The abundance of Fagaceae and Fabaceae in some plots proves the old age or maturity of the forest [142]. Each forest lacked a few families. For example, Apocynaceae, Caesalpiniaceae, Convolvulaceae, Lecythidaceae, and Ulmaceae were found in BUCF but not in ZNP. Oleaceae, Capparaceae, Juglandaceae, Lythraceae, and Tetramelaceae did not appear in BUCF while present in ZNP. Elevation patterns, logging levels, and access to roads and settlements throughout the sample plots help to explain the compositional variances of different families (Figures 3.10 and 3.11).

The IVI gives a total picture of the social structure of species in a community and can be used to form an association of dominant species [176]. The results indicated that *Protium serratum*, *Dipterocarpus alatus*, *Tectona grandis*, *Dillenia pentagyna*, and *Terminalia crenulata* had the highest IVI (>15%), reflecting their relatively high ecological importance in the study area. However, compared to ZNP, BUCF revealed lower IVI and proportionately fewer trees per unit area for *Baccaurea sapida*, *Dracontomelon dao* and *Xerospermum noronhianum*. *Protium serratum*, *Dalbergia oliveri*, *Schleichera oleosa*, and *Tectona grandis* had lower IVI and densities in ZNP than in BUCF plots. Importantly, *Tectona grandis* (teak) had the high relative density in BUCF but severely decreased numbers in ZNP. The lower tree density of teak in ZNP may be due to the effects of previous extensive logging by the government before its declaration as a national park. Due to its better wood quality and higher demand than other species, overuse and overharvesting of teak causes deterioration of forests and biodiversity [174, 177]. The results highlighted that *Tectona grandis*, *Dalbergia oliveri*, and *Protium serratum* had been over-harvested in ZNP plots resulting in lower relative density and IVI. This finding suggested that the last logging activities significantly affected the abundance and dominance of certain commercially important tree species in ZNP. In ZNP, 23 species (27.38%) of all species exhibited the lowest IVI (<1%), while 32 species (35.16%) of those in BUCF did the same. The species with the lowest IVI ratings, including *Melastoma* spp. (Melastomataceae), *Atalantia monophyla* (Rutaceae), *Zanthoxylum* spp. (Rutaceae), and *Dalbergia* spp. (Fabaceae) are all tolerant to considerable shade. Due to their higher mortality, slower development, and reduced dispersion capacity, shade-tolerant species are more vulnerable to disturbance and fragmentation [178] than light-demanding species such as *Tectona grandis*, *Terminalia crenulata*, and *Dillenia pentagyna*, which showed greater IVI. It is necessary to control fragmentation-induced human activities and use specific silvicultural techniques, such as enrichment planting if these tree species can be conserved and managed to enhance their ecological value.

Variations in structural attributes (tree density, dbh, basal area, and height) were affected by many factors and varied between species [179]. The structural characteristics of woody vegetation were associated with forest types, land uses, human activities, and environmental factors such as elevation, slope, aspect, soil, and light conditions [180, 181]. The peculiarities of the habitat preferences and favored light conditions affect *Tectona grandis*'s much higher tree density in BUCF than in ZNP [172]. Human activities like logging and exploiting forest products leave gaps in the forests, which may help certain species respond positively to light conditions [182]. In ZNP, *Dipterocarpus alatus* performed slightly better than BUCF in tree density, dbh, basal area, and height. The dominance of *Dipterocarpus alatus* (IUCN endangered species) demonstrated its habitat preferences and the significance of its protection. *Dalbergia oliveri* (IUCN endangered species) showed lower tree density, dbh, basal area, and height than *Dipterocarpus alatus*, demonstrating its lower dominance in the tree community. The fact that the villagers favor *Tectona grandis*, *Dalbergia oliveri*, and *Terminalia crenulata* for housing, firewood, and income may help to explain the frequency and dominance of *Dipterocarpus alatus* in the study area (source: interview data in Chapter 4).

3.4.2 Do variations in species composition relate to environmental factors?

The logging intensity appears to be highly influential on tree species present in the jungle and secondary forest of BUCF (Figure 3.11). Logging operations favor light-demanding species such as *Tectona grandis*, *Aporusa roxburghii*, and *Dipterocarpus alatus* in the BUCF jungle and secondary forests since light influences the abundance and dominance of pioneer and light-demanding species [183, 184]. The dominance of *Dracontomelon dao* in ZNP's secondary forest seemed to be influenced by elevation (Figures 3.10 and 3.11). This endorsed the species' predilection for elevation up to 500 m above sea level in ZNP [185]. The prevalence of *Schleichera oleosa, Dillenia pentagyna* and *Terminalia chebula* in BUCF plots near roads may be owing to their less-desirable timber (Figures 3.10 and 3.11). Local populations use these two species for food and medicine, not for wood. The greater distance to the village affects the considerable composition of *Swintonia floribunda* (used as firewood) in the secondary forest of ZNP, presumably due to the species' lessened stress from being far away from populated areas. NMDS ordination indicated that BUCF plots clustered closely while ZNP plots were more dispersed (Figures 3.10 and 3.11). The presence of different species in each plot may help explain some of the dispersion seen in ZNP. In this study, I exclusively evaluated parts of ZNP that are accessible and are under significant human danger, restricting the species composition and richness of the species. Moreover, it is suggested that additional edaphic factors, such as soil properties and moisture, along with canopy openness, may affect changes in tree composition.

3.4.3 Do the stand structure and floristic diversity relate to environmental factors?

Higher altitudes, which are not easily accessible to gather forest resources, tended to have a significantly higher number of trees, more giant than 30 cm dbh, a larger basal area, and more diverse and evenly distributed tree species (Figure 3.12). Evidence suggests that human activities such as harvesting wood and forest products at lower elevations diminish the diversity of tropical forest tree species [186, 187]. The steeper slope has a favourable relationship with species diversity and evenness owing to difficult logging access. However, the steeper slope has a negative link with the stand basal area and height, which may be due to a natural process of loosening soil structure [188], which may influence the growth of trees (Table 10). There was a favourable relationship between tree species' dominance, diversity, and evenness and the distance of sample plots from the villages and roads (Table 10). Due to easy accessibility from the villages and road network, unlawful logging reduces tree species' dominance (basal area), diversity, and evenness. According to several studies, tree species' abundance, dominance, and diversity are all impacted by logging and the exploitation of forest products [189-191]. However, some studies claimed that logging creates gaps in the forest that allow shade-intolerant species to regrow and thrive, increasing their range and dominance [184, 192].

3.4.4 Consequences for conservation inside and outside of the protected area

Two of the 116 total species, *Dalbergia oliveri* and *Dipterocarpus alatus* (IUCN endangered species), were discovered in both BUCF and ZNP, demonstrating their moderate dominance and tree density per hectare. The remnant forests of BUCF (outside PA) had a high frequency and dominance of these two endangered species, suggesting its potential to boost biodiversity conservation. However, several studies have shown that protected areas promote greater abundance and dominance of endangered species, which contradicts this finding [149, 193, 194]. The studied forests provide ecological services and assist local economies by giving timber, firewood, medicinal plants, and food supplies. The profusion of high-quality timber species like *Tectona grandis*, *Dalbergia* spp., *Chukrasia velutina*, *Gmelina arborea*, *Quercus glauca* and *Shorea* spp. showed that these forests could be crucial seed sources for future regrowth. However, an efficient conservation approach is needed to reduce overexploitation, which puts these species' survival in peril, particularly in BUCF. The three prominent species in both sites, such as *Baccaurea sapida*, *Dracontomelon dao*, and *Dillenia pentagyna* provide the bulk of edible food supplies for surrounding local populations. *Cinnamomum obtusifolia*, *Millettia cinerea*, *Garcinia paniculata*, and *Millingtonia hortensis* were known to be medicinal and economically important species for local communities via the sale of these medicinal plant parts, yet they prevailed in ZNP.

This chapter showed that ZNP requires effective conservation compared to species richness in other protected areas in Myanmar [27, 140, 171]. However, the proximity of the sample plots to human-dominated areas may explain the restricted diversity of species. In addition, selective logging was widespread in ZNP before 2011, and local people's continuous harvest of forest products might affect the dominance and diversity of economically important species. It is suggested that ZNP would recover richer vegetation by the year after protection. The total part of ZNP is said to have various types of forest, including evergreen, deciduous, dry dipterocarp, low Indaing (a seasonally dry tropical forest), and native flora and wildlife [43], although official statistics are not available. The whole part of ZNP could contain more species diversity than current research. For instance, a recently discovered endemic plant species from Myanmar, *Sapria myanmarensis* (Rafflesiaceae), was only found in Kachin State and Sagaing Region, encompassing ZNP [195].

Many tree species recorded in the BUCF with a high dominance were commercially valuable timber species. It was mistakenly believed that the BUCF region has minimal conservation importance, as it is an open forest environment and is not officially protected as a reserved forest. This research indicated that while BUCF jungle forest plots have low basal area, old-growth and secondary forest plots are rich in economically relevant species. However, the

BUCF is imperiled by road development, human habitation, agricultural encroachment, and illicit logging. The uninterrupted fragmentation of the habitat of the BUCF will probably increase the disturbance to the nearby ZNP. Many studies reported that increased human disturbances quickly become problematic in conserving protected areas in Myanmar and tropical Asia [196-199].

For this reason, I urge the remaining forests of the BUCF to be acknowledged as an ecosystem of high conservation value to protect its biodiversity and economic viability. Community forestry ensures the participation of the local community in forest management by granting 30-year land use rights and removing forest products [57]. Establishing community forests in the BUCF's degraded forest land would propose to enable local engagement in forest management and potentially lessen stress inside ZNP.

3.5 Conclusion

Despite the human impact on the forests, the high richness and basal area of valuable timber species suggest that these forests remain of great importance for human well-being. Numerous medicinal plant species, including *Lannea coromandelica*, *Cinnamomum obtusifolia*, *Millettia cinerea*, *Garcinia paniculata*, and *Millingtonia hortensis*, are present in ZNP, demonstrating a high congruence of conservation values and meriting protection for both biodiversity and human security. The abundance of two endangered tree species, *Dipterocarpus alatus*, and *Dalbergia oliveri*, in BUCF, presents a high conservation value and demands special attention in conservation planning. The research found that even if the densities of commercially valuable tree species are declining in ZNP, maintaining their big-diameter trees is favorable. The establishment of permanent sample plots would be a helpful alternative for future evaluation to track the effectiveness of the protected area and assess the dynamics and natural regeneration of certain tree species in ZNP. Moreover, assisted natural regeneration and enrichment planting of valuable tree species should be promoted in degraded areas of ZNP.

Due to easy accessibility, unclassified forests are more prone to species compositional fluctuation and loss. Forest managers should take action to regularize the local exploitation of specific tree species in BUCF. Controlling firewood collection and illicit logging will be crucial in unclassified forest ecosystems. Encouraging fast-growing native tree species for firewood plantations in nearby villages might satisfy the people's fundamental demands for firewood and poles. The local populations who depend on and live close to forests know the potential of tree species diversity and the value of ecological sustainability [200]. I expect nearby communities to actively participate in forest management and conservation efforts to ensure long-term sustainability. Myanmar's biodiversity and protected areas legislation allows sustainable use of buffer zone [56]. Therefore, creating buffer zones outside ZNP may balance the competing interests of biodiversity conservation and socio-economic development. In the degraded and jungle forest areas of the BUCF, community forestry development might encourage local participation in forest management, therefore decreasing poverty and reliance on the park's core part. This chapter does not indicate that protected areas are unnecessary. Instead, the findings of this chapter suggest that if the remaining natural habitats in BUCF, where humans collect forest resources, are effectively managed to encourage native species to persist, it may gain enormous biodiversity both inside and outside the protected area.

Chapter 4. Forest-Related Income Contribution among Rural Households in Banmauk Township

4.1 Introduction

Many studies have shown the significance of forest resources for the livelihoods of rural communities across the globe [201, 202]. Two billion people, a third of the world's population, cook and heat using biomass fuels, mainly firewood, while billions utilize traditional medicines harvested from the forests [203]. According to an estimation, 20% of the global population is dependent on forest resources to meet their essential livelihood needs [204]. Though forests seldom offer a staple food, they give a variety of foods (such as fruits, vegetables, and bush meat), an extensive array of medicines, and other items that improve people's health and hygiene [202]. The forests of Myanmar are socially and economically significant because 70% of its 51.34 million people reside in rural areas and depend on forest resources for livelihoods and income [40]. In Myanmar, 24.8% of the total population falls under poverty, and poor people are 6.7 times higher in rural areas than in urban areas [205]. People traditionally living near reserved forests and protected areas in Myanmar depend on various forest resources for their livelihoods [127], although the law prohibits collecting these products [55]. However, it is possible to acknowledge these forest resources' vital role in meeting people's basic needs and reducing income inequality and poverty [206-208].

In tropical rural areas, income from the forest accounts for between 15% and almost 40% of total household income [209-212]. In Asia, forests provide over half of the annual household income for impoverished rural people [213]. Collecting forest products needs a few skills and technology, making an attractive and vital income opportunity for rural poor living near the forest [206]. Rural people in Myanmar mainly rely on forest products for their daily necessities, especially firewood which provides almost 70% of primary energy use of the country [214]. Households' dependency level on forest resources is determined by various elements, with the most significant being households' socio-economic and demographic factors [215, 216]. Several studies have reported that household characteristics (such as family size, age and sex of the household head, and education status), access to the forest, access to markets, institutional arrangements governing access to the forest and marketing channels, and off-farm employment opportunities all affect how much income households receive from the forest [207, 217, 218]. Considering that forest income helps reduce poverty and contributes to households' well-being, the success or failure to preserve and sustainably manage these forests will have significant consequences for millions of people dependent on them.

Banmauk's forests make up 42.54% of the total area of the township and 28.51% of the forest cover in the Katha District, which includes Banmauk Township administratively [2]. Indeed, the Zalon Taung National Park (ZNP) is the protected area in Banmauk Township, aiming to safeguard the native flora, fauna, water sources, the biodiversity and the cultural significance of the Zalon Taung Pagoda. On the other hand, there are various challenges to sustainably conserve and manage ZNP, as it has a lack of partner support, low funding, and insufficient human resources like the technicians to manage the park [196, 214]. Moreover, illegal logging, collection of plants and terrestrial animals, shifting cultivation and/or permanent agricultural field, and gold mining encroachment significantly impact Banmauk Township's forests [62, 63]. One option to assess the extent of human reliance on forest reserves and protected areas is to analyze the conditions and distributions of various forest products to local communities in the area so as to formulate specific conservation actions for this area [209].

An effective forest management needs to combine the multiple aspects of ecology, environment, economics and livelihoods of local communities. Forest management should consider the beneficiaries of forest resources within households' socio-economic circumstances to apply the proper strategies for balancing conservation and livelihoods [219, 220]. Some studies in Myanmar demonstrated the significant role of forest income to the livelihoods of rural households living in and around the reserved forests and protected area. For instance, forest income especially charcoal production only makes a contribution of over 40% of household’s total annual income for the communities living inside the reserved forests at Bago Township [221]. In the Natmataung National Park, the forests provide about 50% of total annual income to all households living around the park, demonstrating a high reliance of local people on the park’s forest resources [222]. Non-timber forest products were a major source of income for residents inside and around the Kyaikhtiyoe Wildlife Sanctuary in Mon State, making up 42.83% of the total annual income of households [223]. Forest resources are a vital source of livelihood, but its significance level changes in different geography, different periods and across various socio-economic groups [209, 224-226]. Understanding the relationships between households' characteristics and forest income in the specified region is crucial for developing sustainable forest management and conservation strategies for this region [227]. Policymakers, researchers, and professionals could use household forest reliance trends to create empirical approaches for sustainable resource utilization and biodiversity conservation [228].

The sustainable livelihood framework developed by DFID (1999) provides a tool for analyzing household livelihoods [229] and applies to both urban and rural livelihood strategies [230]. This study apply four capitals, including (1) human capital (e.g., household size, age and education of household head, number of adult labour and gold mining laborers per household), (2) natural capital (e.g., natural resource base that humans harvest for livelihoods), (3) financial capital (e.g., incomes from farming, salary jobs, mining and forest product collection, and total annual income of the household), and (4) physical capital (e.g., land holding amount, number of cattle, access to electricity and water) to examine the livelihoods of rural households.

The main objective is to assess how forest income contributes to the livelihoods of rural communities in Banmauk Township in Katha District, Sagaing Region in Myanmar. The specific goals are to

1. quantify the contribution of forest-related income to households' total annual income,
2. examine characteristics and factors influencing households' dependence on forest resources, and
3. measure the distributional impact of forest-related income for reducing household income disparities.

The findings of this chapter could inform policies aimed at promoting sustainable forest management and supporting rural livelihoods in the region.

4.2 Materials and Methods

4.2.1 Study area

Banmauk Township is situated between the latitudes of 24°10′N and 24°60′N and the longitudes of 95°15′E and 95°60′E, in Katha district, Sagaing Region in Myanmar (Figure 4.1). With a total population of 112,668, Banmauk Township includes three wards (in Banmauk town) and 47 village tracts [59]. There are 18,868 total households, of which 1,212 are in Banmauk town, and 17,656 are located in villages [59]. The region has a tropical monsoon climate with an average of 1,337 mm of annual rainfall, with June through September seeing the most rainfall [157]. It has a favourable environment and climatic conditions for growing crops [157], especially rice and groundnut. The local villagers are involved in commercial agricultural cultivation, gold mining, and gathering timber, fuelwood, and medicinal plants from the forests. The forest faces various anthropogenic forces in the form of gold mining, illegal logging, and extraction of non-timber forest products, which accounts for the reduced plant diversity [63].

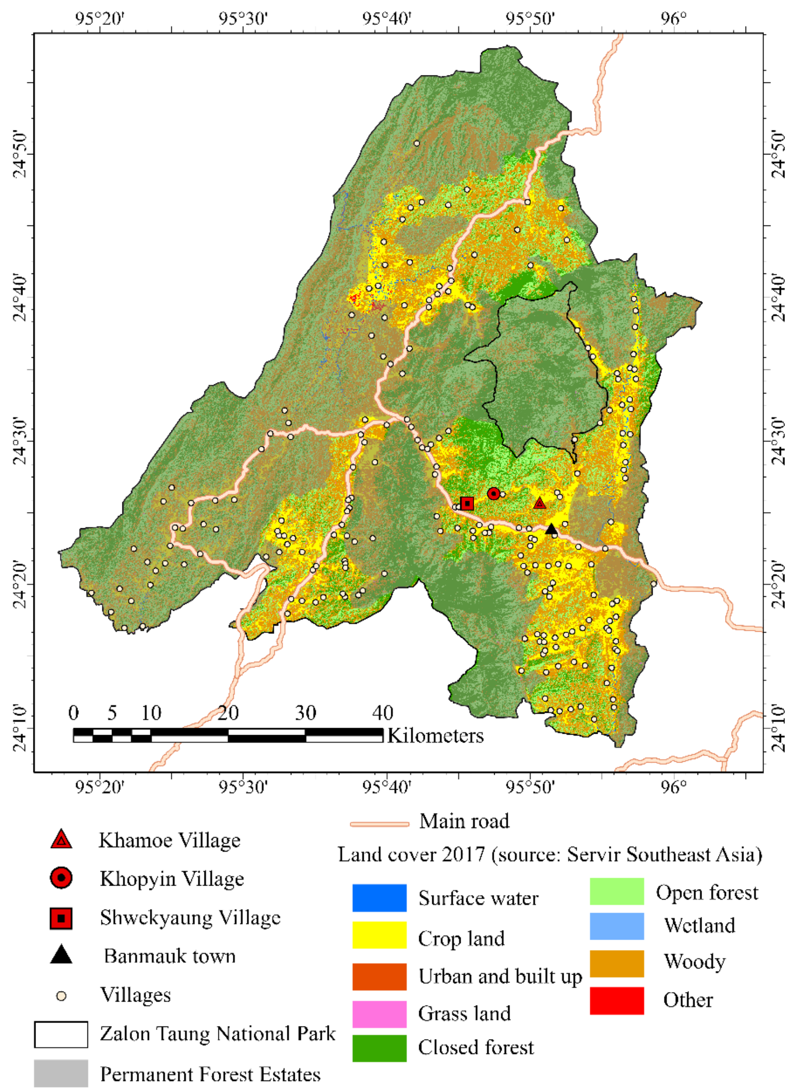


Figure 4.1: Location of study villages

4.2.2 Data collection

4.2.2.1 Selection of villages

Three villages, namely Khamoe, Khopyin, and Shwekyaung, located near the reserved forests and Zalon Taung National Park, were explicitly chosen for extensive research of the livelihood activities of rural residents who depend on the forest (Table 4.1). These villages were chosen based on five criteria: (1) their size (ranging from 50 to 110 households); (2) safety ground; (3) accessibility; (4) the commercial use of forest products for residents' livelihoods; and (5) their representativeness of the area around the reserved forests and a protected area. Ninety households from the three villages were randomly chosen for the household survey (Table 4.1). Field data were collected in the selected villages during April and May 2022 (Figure 4.2).

Table 4.1: Profile of study villages

Village Name	Village Tract	Total Households	Population	Sampled Households	Sampling Proportion (%)
1.Khamoe	Lay Thi	110	567	36	33%
2.Khopyin	Pin Hin Kha	49	326	28	58%
3.Shwekyaung	Pin Hin Kha	60	457	26	43%

4.2.2.2 Study design and approaches

The qualitative approach is a way to look into and understand the importance of individuals or groups connected to a social or human issue. Comparatively, the quantitative method entails testing objective theories by examining the correlations between variables [231]. This study used both qualitative and quantitative research methodologies. Field research is a methodological strategy for studying behaviour in the natural environment context [232]. Field observations provide additional data about the subject, such as community behaviours or environmental conditions [233]. Most field researches use two or three research methods; for instance, studies of household livelihood may combine quantitative surveys with qualitative key informant interviews and focus group discussions (FGDs) [209]. This study performed FGDs and household surveys in the sampled villages (Figure 4.2). FGDs were conducted with 5-8 participants in each village, including village leaders, the elders, forest department officials, survey team members, and the villagers. Data on the demographics, migratory patterns, economic status, land use, subsistence and commercial forest product, market prices, crop production seasonality, and livelihood activities were collected using FGDs. Household surveys were conducted using a semi-structured questionnaire developed with the assistance of professionals and literature, particularly the DFID framework for sustainable livelihoods (1999) [229]. The household survey gathered information such as family composition, age, education, land and livestock holdings, each family member's occupation, the types of forest products used for subsistence and commercial purposes, their sources and amounts extracted, their market prices, and the primary income sources. All respondents were asked to recall how much they had received, sold, and eaten from agricultural land and forests during the previous 12 months. The secondary data (books, figures, maps and data) were collected from the General Administrative Department and the Rural Development office in Banmauk Township and the Nature and Wildlife Conservation Division of Forest Department in Naypyitaw.

Figure 4.2: Focus Group Discussions (FGDs) (a and b) and household survey (c)

4.2.3 Data analysis

The econometric analyses used descriptive statistics, Kruskal Wallis tests, binary logistic regression, and ordinary least squares (OLS) regression models. The Gini coefficients and Lorenz curves were calculated and developed to assess the income disparity among rural households. R statistical software version 4.2.2 and Microsoft Office Excel were used for data analyses.

4.2.3.1 Income accounting

The sum of cash income from multiple sources (such as agricultural and livestock production, NTFP collection, and small-scale activities) and the monetary equivalent of a household's subsistence use of these sources' outputs is calculated as a household's total income [211]. The total household income was estimated on an annual basis. According to this research, a household's total income comes from four primary sources. They are (1) farm income; (2) off-farm income; (3) income from the forest; and (4) income from gold mining.

Agricultural income was calculated by multiplying the crop yields and prices. And inputs (fertilizers, hired labour, marketing costs) were deducted from total agricultural income [40]. Income from livestock was calculated by multiplying the amount of consumption and sale for the past twelve months by the prices, and inputs (feed value) were deducted from total income. The rural households in the study area mainly rear buffalos, pigs and chickens for biofertilizers and food. Farm income combined income from agriculture, livestock, and farm-related wage jobs.

Earnings from gold mining-related wage employment were calculated by multiplying the days worked for the past twelve months by the daily wage rate. The number of days worked, and daily wage rates were obtained from family members through the questionnaire survey. Income from other sources of employment, such as salaried jobs in government organizations, companies, and own businesses, was calculated by multiplying the salary amount by the working days during the past twelve months. In this study, off-farm income means income from non-agricultural, non-forest, and non-mining activities.

The estimated gross monetary value of the forest's revenue was calculated by multiplying all collected amounts over the previous twelve months by the price [234]. The household questionnaire survey was used to gather data on the categories of forest products, the quantity collected, sales, and market pricing. An annual consumption amount of firewood was predicted based on the respondents' estimated firewood usage during one rainy season (4 months) and three seasons for one year. The income from firewood was calculated by multiplying the amounts by the local market price. If households incur expenses for the extraction of firewood, the extraction costs (e.g., hiring a chainsaw) and transportation costs (hiring cattle and three-wheel motorbikes) were subtracted from the total revenue from firewood. When calculating the profits from timber and bamboo finished products, the production costs, such as the acquisition of bamboo culms and wood and the transportation expenses, were subtracted from the total income. While assessing the total income from all sources, the allowance for household-owned labour was not subtracted from the gross income.

4.2.3.2 Forest dependency analyses

Relative forest income was computed as a percentage of total income to measure household dependency on forest income [201]. Two regression analyses, such as binary logistic and ordinary least squares (OLS) regressions, examined the variables affecting household dependency on forest income. As some households were engaged more and some lesser in the forest product collection, determinants of more or less dependency on the forest were estimated using binary logistic regression analysis. Due to the nature of the binary logistic regression model, the response variable must be a dichotomous variable of the value to be 0 and 1. However, forest income is a continuous variable, and the value may not be 0 or 1. In this study, households with relative forest income of <30% in total annual income were considered less dependent households labelled with a value of 0, and households with forest income ≥30% were considered more dependent households with a value of 1 [25]. The logistic distribution function for identifying more or less dependency on forest income was defined as:

$P_i = 1 / (1+e^{Z_i})$ ………………………………………………………………….. (1)

Where, P_i is the probability of being household engaged in forest product collection activities for the i^{th} household and Z_i is the function of explanatory variable X_i.

Z_i can be stated as -

$Z_i = \beta_0 + \beta_i X_i$ …………………………………………………………………...... (2)

Where β_0 is the intercept and β_i is the estimated coefficient of explanatory variable X_i.

Since the P_i is the probability of being households engaged in forest product collection activities, the probability of being households do not engage in forest product collection will be $1-P_i$ which can be expressed as:

$1-P_i = 1 / (1+e^{-Z_i})$ ……………………………………………………………… (3)

Therefore,

$P_i/(1-P_i) = (1+e^{Z_i})/(1+e^{-Z_i}) = e^{Z_i}$ …………………………………………………….. (4)

And,

$1-P_i$ is the odd and $P_i/1-P_i$ is the odd ratio. Taking log to both side of equation,

$\ln (P_i/1-P_i) = \ln e^{Z_i}$ …………………………………………………………………. (5)

If the error term **U** is taken into account, the logistic model becomes

$Z_i = \beta_0 + \sum \beta_i X_i + U_i$ …………………………………………………………….. (6)

The characteristics and factors influencing households' dependency on forest income were estimated using an OLS (ordinary least square) regression. The income (monetary value) from forest was considered as the dependent variable and the socio-economic variables of the households were considered as the independent variables. The model can be stated as:

$Y = \beta_0 + \beta_1 X_i + U$…………………………………………………………………. (7)

Where, Y is forest income, β_0 is the intercept of the model, β_1 is the estimated coefficient of explanatory variable X_i and U is the error term.

When two or more independent variables in a model strongly correlate, multicollinearity arises. Multicollinearity among independent variables can cause unstable estimation and inaccurate variances in logistic regression modeling [41]. The multicollinearity testing via linear regression was calculated before logistic regression analysis to check each independent variable's variance inflation factors (VIFs) and tolerances. Table 4.2 presents the explanatory variables used to analyze the regression models. The native household head was coded as '1' and non-native one was coded as '0'. In Myanmar, primary school is for five years, middle school is for nine years, and high school is for eleven years. This research considered household heads with no formal education as educational year 0 and those with one year as educational year 1.

Table 4.2: Characteristics of explanatory variables

Factor	Assumption	Expected sign
Nativity of household head	The native household heads may involve in the extracting and selling forest products than non-native people.	+
Age of household head	Younger household heads may participate more in forest-based activities than older household heads.	-
Education of household head	The family dependence on forests would decrease with increasing years of schooling for the household head.	-
Family size	Forest product collection and revenue increase with family size.	+
Paddy (Acre)	The extraction of forest products would decline in households with sizeable agricultural land as the landholding size increases agricultural output and income.	-
Distance to the forest	The forest's ease of access increases the collection of forest products.	-
Agriculture income	Households earning more from their crops production would depend less on extracting forest products.	-
Wage employment income	Families with higher wage employment incomes would reduce the commercial extraction of forest products.	-
Own-business income	When households earn more income through their businesses, such as home businesses, transportation services like tricycle drivers, and market traders, they will depend less on the forest.	-
Income from salaried jobs	If households get regular income from the salaried employment, they are less reliant on forests as they have no time to get into the forests.	-
Gold mining income	Households involved in gold mining-related work and receiving regular income would depend less on forests.	-

4.2.3.3 Measuring economic inequality

Drawing a Lorenz curve is one method of representing the income distribution in a population. The Gini coefficient, based on inequalities in people's incomes, wealth, or other factors, is often used to evaluate inequality. The Gini coefficient value is between 0 (complete equality) and 1 (complete inequality). It is calculated by dividing the area between the Lorenz curve and the perfect equality line by the total area underneath the perfect equality line. The further the Lorenz curve is from the perfect equality line; the Gini coefficient will increase, and the more unequal the income distribution. The overall Gini coefficient for the total annual income with and without forest income was assessed separately to determine how forest income helps to reduce income disparity among the sampled households in the study villages.

4.2.4 Data reliability and validity

Reliability implies that the same thing is repeated or recurs under similar or comparable circumstances to provide correct, steady, or consistent effects [235]. Validity means how closely a concept matches reality. Validity asks how well the social reality evaluated by research fits the conceptions used to explain it [235]. This study conducted careful enumerations and data collection during household surveys. Data collection is fault-prone because people might acquire assistance recalling the exact quantities of products extracted from the forests. This memory recall bias may have underreported forest products with significant harvested amounts and economic contributions. However, there are no underreported categories of forest products since the types of extracted forest products vary across households.

Villagers are aware of forest product harvests and income since they rely on them. To avoid bias while recalling household income, the recall period was adjusted to the respondent's capacity [236]. Shorter intervals were used for wild edible vegetables, firewood, or bamboo. In contrast, more extended intervals were used for uncommon occurrences, such as timber extraction and hunting of substantial quantities of wildlife. Crop harvest quantities were recalled by cropping season, so the respondents could easily remember each crop production period [236]. Recalling events from the present back into the past rather than the past to the present improves memory. Thus, the respondents were first asked about their daily events on forest use to stimulate better recalls for past events.

4.3 Results

4.3.1 Households' demographic and socio-economic characteristics

Household socio-economic characteristics such as family size, agricultural land ownership, occupation and crop production calendar information were collected in the FGDs and household survey (Table 4.3, Figure 4.3). The average household heads' ages ranged from 47 to 48 (Table 4.4). The average number of academic years for household heads was three years for attending primary school. The average paddy land acreage owned by the families ranged from 1.86 to 3.58, and the average number of cattle was between 4 and 5. Khopyin and Shwekyaung villages are closest to the forest at 3-4 km, while Khamoe is approximately 9 km in distance. The planting and harvesting periods for rice and groundnut were the same among the three villages (Table 4.3). Khamoe village produced an average of 208 tin of rice (1 tin=20.87 kg) during the 2021-2022 cropping season, followed by Shwekyaung and Khopyin villages with 173 and 138 tin, respectively. Khamoe produced the least groundnut, 13 tin on average, while Shwekyaung and Khopyin produced 92 and 50 tin, respectively. In Khopyin village, 82% of respondents are Kadu, while in Shwekyaung village, 65% are Shan (Table 4.4).

Table 4.3: Seasonal calendar for households' livelihood activities

Activity		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agriculture	Rice planting						green	green					
	Groundnut planting	green					dark blue						green
	Rice harvesting										amber	amber	
	Groundnut harvesting				amber	amber		blue					
Forest product collection	Firewood	light blue	light blue	light blue							light blue	light blue	light blue
	Bamboo shoots						light green	light green	light green	light green			
	Mushroom						cyan	cyan	cyan	cyan			
	Medicinal plants	yellow	yellow	yellow	yellow	yellow	yellow				yellow	yellow	yellow
Other	Gold mining works	orange	orange	orange	orange	orange				orange	orange	orange	orange
	Farm-based employment				grey	grey	grey	grey			grey	grey	

Note: The dark blue color indicates groundnut planting and harvesting not for consumption and sale but for the next year's seeds.

(a)

(b)

(c)

(d)

Figure 4.3: (a) Shwekyaung village, (b) typical house design, (c) rice harvesting in Khamoe village (Source: ဗန်းမောက်မြို့ facebook page), and (d) groundnut planting in Shwekyaung village

Table 4.4: Profile of sample households in the study villages

HH's characteristics	Khamoe (n=36)			Khopyin (n=28)			Shwekyaung (n=26)		
	Mini	Maxi	Mean±SD	Mini	Maxi	Mean±SD	Mini	Maxi	Mean±SD
Age of HHH	25	66	48±11.0	32	65	47±8.2	30	63	47±9.3
Education (Yrs) of HHH	0	8	3±2.9	0	8	3±2.5	0	7	3±2.4
Family size	3	11	7±2.15	4	12	6±1.65	4	8	6±1.2
Paddy land (Acre)	0	6	3.6±1.9	0	5	1.9±1.7	0	6	2.2±0.9
No. cattle/HH	0	12	4±0.6	0	10	4±0.9	0	14	5±0.8
No. gold mine labor/HH	0	2	0.5± 0.7	0	3	1± 0.9	0	2	0.8± 0.6
Distance to forest (km)	4.3	16.1	9.1±3.2	1.2	4.8	3.0±1.3	2.2	14.5	4.0±2.3
Gross production of rice (tin)/year	0	350	208±118	0	400	138±126	0	370	173±88
Gross production of groundnut (tin)/year	0	50	13±15	0	120	50±45	0	250	92±45
Timber extracted amount (ton)/year	0	6	1.42±1.96	0	6	1.48±1.68	0	10	2.15±2.34
Firewood harvested amount (ton)/year	2.5	8.64	4.21±1.31	4.32	17.3	5.4±3.03	4.32	21.6	4.99±3.39
Ethnicity of HHH (%)									
Shan	36			18			65		
Kadu	44			82			35		
Burmese	20			0			0		
Nativity of HHH (%)									
Yes	75			82			85		
No	25			18			15		

Note: HH=Household, HHH=Household head, SD=standard deviation

4.3.2 Households' involvement in livelihood activities

Figure 4.4 displays the engagement of households in various livelihood activities. According to the study results, the livelihood strategies for rural households in the three villages were consisted of collecting forest products, livestock raising, agriculture, jobs related to gold mining, farm-based wage work, salaried jobs, and own-businesses (agricultural products trade, home shops, transportation work and vendors at Banmauk market).

Figure 4.4: Households' involvement in livelihood activities

4.3.3 Income status from income sources

Various livelihood activities were divided into four categories: farming, off-farm employment, forest product collection, and gold mining. Farm income included income from rice, groundnut, livestock and farm-based wages (Table 4.5). Farm income was the most significant income source for the Khamoe, Khopyin and Shwekyaung villages, accounting for 37%, 44% and 37% of the total annual household income (Figure 4.5). The average annual farm-related income per household generated approximately MMK 2,140,000 in Shwekyaung village, followed by MMK 1,960,000 in Khopyin village and MMK 1,560,000 in Khamoe village, respectively (Table 4.5). Khamoe village had the most excellent average annual household income from off-farm sources (MMK 120,000) (Table 4.5), accounting for 25% of total annual income (Figure 4.5). Shwekyaung village had the highest average annual revenue from gold mining operations per household (MMK 2,180,000), which accounted for the most considerable portion (38%) of the household's overall annual income.

Forest revenue was the third most important for Khopyin and Shwekyaung villages and least significant for Khamoe village. The average annual revenue per household from gathering forest products varied from MMK 588,000 to MMK 852,000 in the three villages, representing 14%, 16%, and 15% of the total household income in Khamoe, Khopyin, and Shwekyaung, respectively. Kruskal Wallis tests showed that farm income, off-farm income and gold mining income were significantly different within the three villages (farm income: Kruskal Wallis $X^2 = 10.0$, $p<0.01$; off-farm income: Kruskal Wallis $X^2 = 27.9$, $p<0.001$; gold mining income: Kruskal Wallis $X^2 = 9.98$, $p<0.01$). Post hoc comparisons using adjusted Bonferroni testing showed that Shwekyaung village had a considerably higher average annual farm and mining income per household than Khamoe village, and Khamoe had a significantly higher off-farm income than Khopyin and Shwekyaung villages (Figure 4.6).

Table 4.5: Income contribution of income sources in three villages

Main Income (,000 MMK/ HH/Yr)	Khamoe (n=36)			Khopyin (n=28)			Shwekyaung (n=26)		
	Mini	Maxi	Mean±SD	Mini	Maxi	Mean±SD	Mini	Maxi	Mean±SD
Net Farm income	230	3,020	1,560±604	48	3,560	1,960±777	293	4,320	2,140±839
Net rice income	0	2,000	1,060±646	0	1,740	638±573	0	2,040	1,070±551
Net groundnut income	0	355	75±95	0	1,050	440±398	0	2,370	854±439
Net livestock income	0	385	91±96	36	330	139±75.6	30	667	210±149
Farm-based wage income	0	2,520	327±680	0	2,880	747±832	0	0	0
Net Off-farm income	0	3,390	1,200±929	0	2,100	131±439	0	3,000	542±940
Salaried jobs income	0	3,060	524±958	0	2,100	75±397	0	300	332±864
Own-business income	0	3,390	672±820	0	960	55.7±210	0	1,800	210±532
Forest income	90	1,920	588±571	105	1,720	732± 531	99	2,180	852± 588
Raw bamboo income	0	90	14.83± 18.77	0	90	24.64± 27.75	0	60	15.11±15.12
Bamboo product income	0	300	28.33± 84.5	0	700	87.71± 208.5	0	300	20.19±70.3
Timber income	0	1,200	353±465	0	1,200	439±470	0	1,000	283±304
Timber product income	0	0	0	0	0	0	0	1,660	84.6±34.1
Firewood income	90	150	102± 24.1	90	490	149 ±90.5	90	1,200	204± 220
Thatch income	0	200	5.6± 33.3	0	150	22.9± 50.2	0	400	15.4± 78.5
Broom grass income	0	30	1.9±7.1	0	100	5.4±20.8	0	10	0.4±1.9
Wild vegetables income	0	400	29.4±68.5	0	70	2.5±13.2	0	150	6.15±29.4
Medicinal plants income	0	500	49.4±130	0	0	0	0	1,440	224±433
Bushmeat income	0	30	4.2± 9.1	0	30	1.1± 5.7	0	50	1.9± 9.8
Gold mining income	0	3,360	838±1100	0	6,240	1660± 1600	0	10,000	2,180± 2480

Note: 1 MMK = 21 JPY

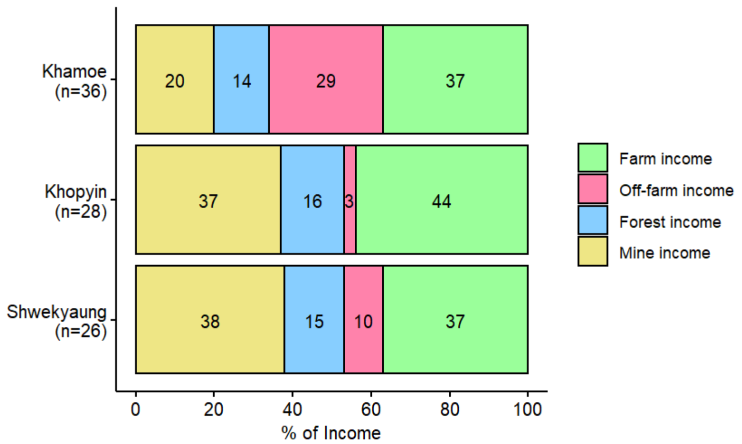


Figure 4.5: Income share of major income sources

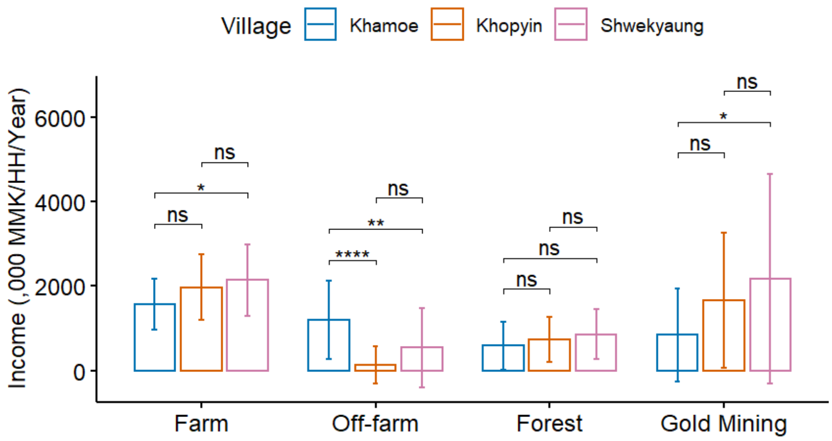


Figure 4.6: Income contribution of major income sources

4.3.4 Structure of forest income

The forests in the study area provided a wide range of goods, including timber and non-timber forest products, to help everyday life of the people. Sample households in three villages utilised timber, firewood, medicinal herbs, bamboo, thatch (*Imperata cylindrica*) (thetke grass used for roofing), wild vegetables, broom grass (*Thysanolaena maxima*), and bush meat (Figure 4.7). Firewood (97-100%), bamboo (83-92%), timber (42-62%), wild vegetables (4-47%), and medicinal plants (14-31%) were the main forest products most often harvested by families (Figure 4.8). Timber brings in the most excellent revenue due to its favourable pricing compared to other forest products (Figure 4.9). The villagers extracted timber for commercial and subsistence purposes and collected firewood for household use rather than for sale. The average annual timber revenue per household in three villages was roughly between MMK 353,000 and 439,000 for the year 2021-2022 (Table 4.5 and Figure 4.9). The reported tree species that were often collected for cash income were kyun (*Tectona grandis*), tamalan (*Dalbergia oliveri*), in (*Dipterocarpus tuberculatus*) and kanyin (*Dipterocarpus alatus*). The commonly gathered tree species for firewood included taung-thayet (*Swintonia floribunda*), htauk-kyant (*Terminalia crenulata*), kanyin (*Dipterocarpus alatus*), taw-thayet (*Mangifera caloneura*), thit-e (*Lithocarpus dealbatus*), sagat (*Quercus glauca*), in (*Dipterocarpus tuberculatus*) and gyo (*Schleichera oleosa*).

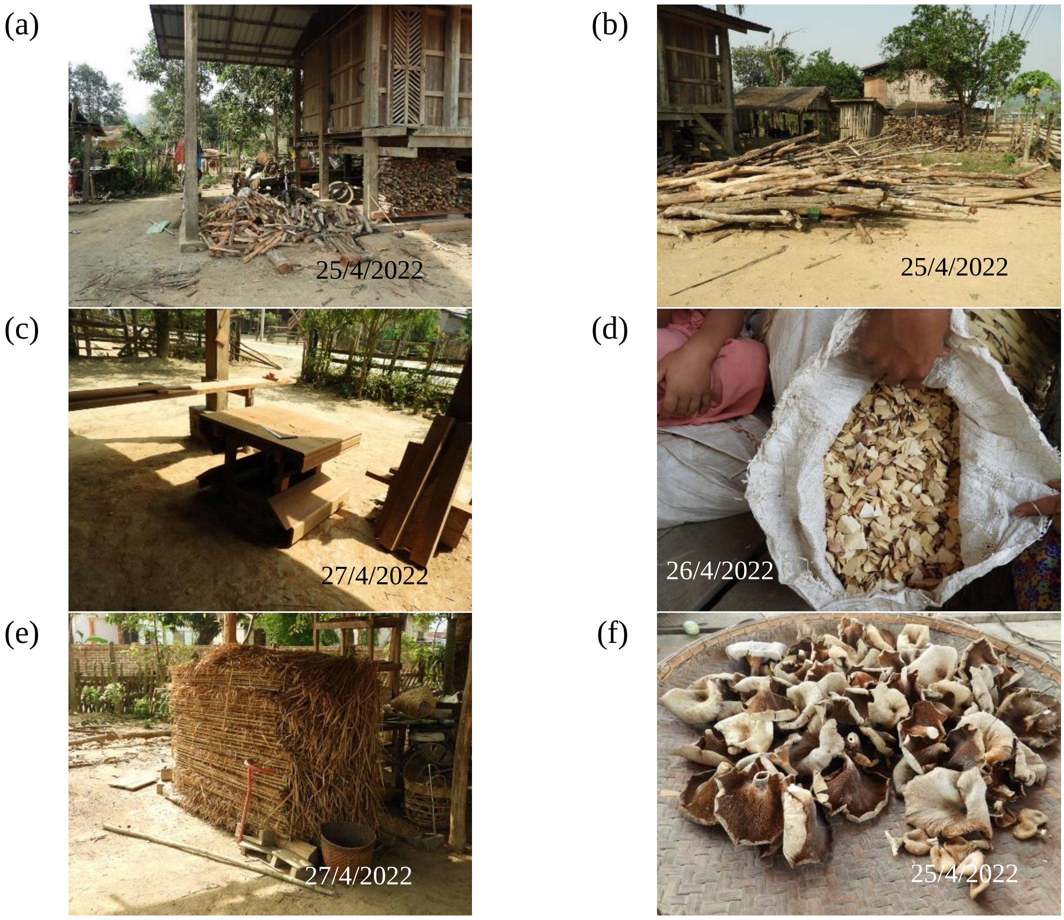


Figure 4.7: (a) and (b) Firewood, (c) timber, (d) medicinal plant parts, (e) thatch (thetke grass), and (f) mushroom

Income from medicinal plants is also worth mentioning. Medicinal plants outsold bamboo, thatch, broom grass, and most forest commodities except timber in Shwekyaung village (Figures 4.9 and 4.10). The women mostly gather medicinal plants for commercial purposes in response to market demand from the Zalon Taung Pagoda and Banmauk town. The roots, barks, leaves, and stems of medicinal plant species, including se-min gyi (*Millettia cinerea*), taw-malakar (*Psidium* spp.), Sanwin-yaing (*Curcuma comosa*), kyaung-sha (*Oroxylum indicum*), zadeik-po (*Myristica longifolia*), thayet-shwe (*Mangifera* spp.) and kyar-let-wah (NA) were mainly extracted notably from the Zalon Taung National Park. In Shwekyaung and Khamoe villages, the average annual household income from medicinal plants generated about MMK 224,000 and MMK 49,400, respectively (Table 4.5). However, there was no income from medicinal plants in Khopyin village between 2021-2022, where the villagers claimed to know little about medicinal plants (Table 4.5 and Figure 4.10). The rules of the village chiefs, as stated in FGDs and household surveys, prohibited residents from owning airguns to avoid shooting wildlife and, consequently, to prevent a decline in the wildlife population for the period between 2021-2022. As a result, the earnings from bushmeat were tiny and only contributed to the average annual household income of MMK 1,100 to 4,200 in the three villages (Table 4.5). Birds like the red jungle fowl (*Gallus gallus*) and silver pheasant (*Lophura nycthemera*), particularly for home consumption, were the most often gathered bushmeat. The income from bamboo includes raw bamboo and finished products like bamboo baskets used to store foods and bamboo walls for home construction materials, while the income from bamboo shoots is included in the category of wild vegetables. The respondents reported that theik-wa (*Bambusa tulda*), tin-wa (*Cephalostachyum pergracile*), wabo (*Dendrocalamus giganteus*), wa-net (*Dendrocalamus longispathus*) and bauk-wa (*Pseudostachyum polymorphum*) were among the bamboos that were often harvested.

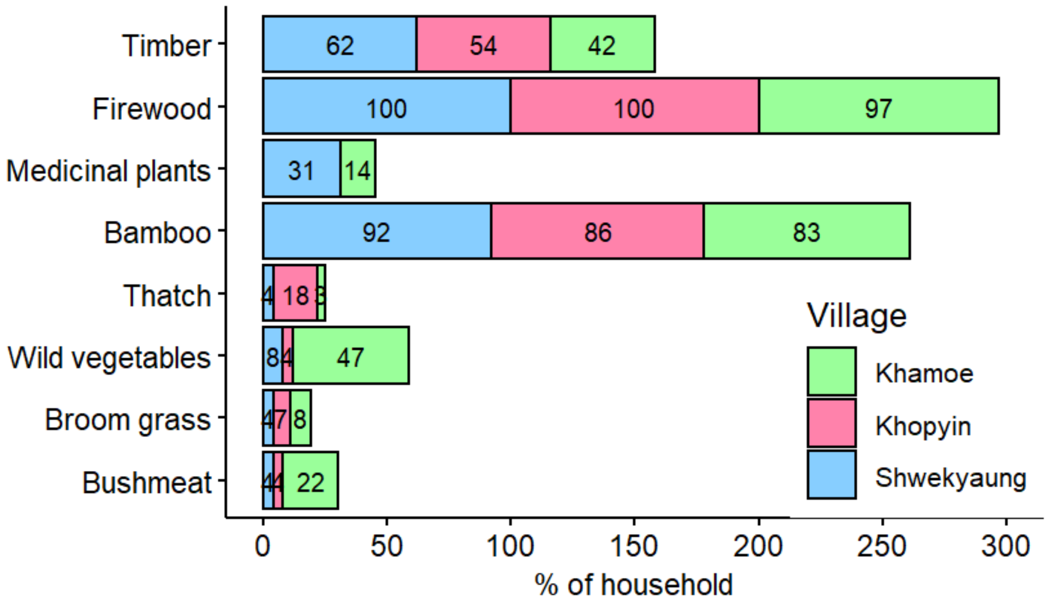


Figure 4.8: Households' involvement in forest product collection

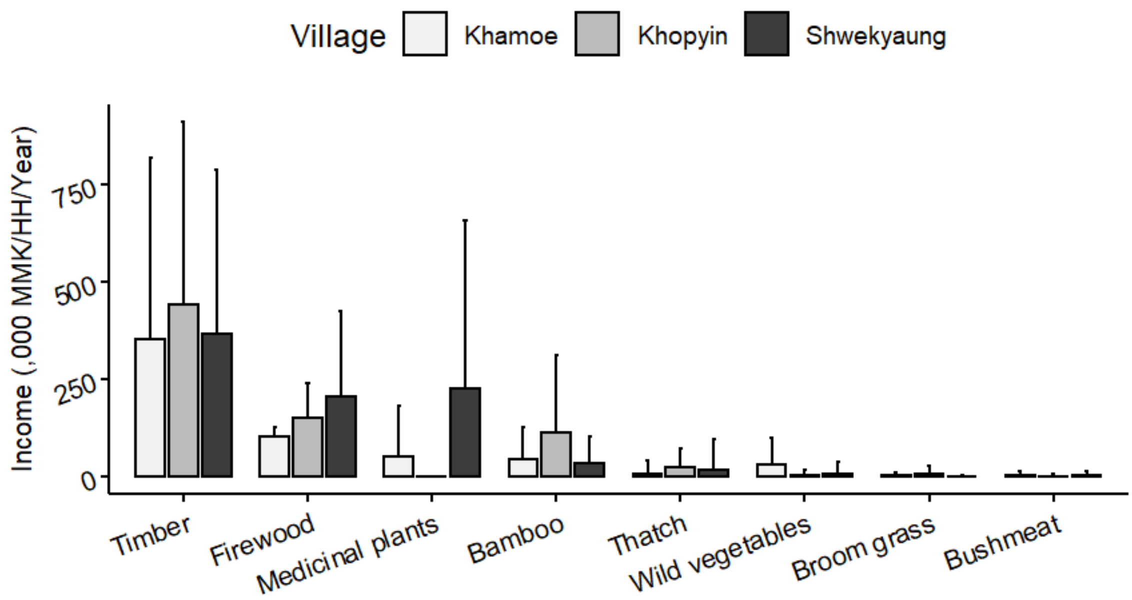


Figure 4.9: Income contribution of forest products

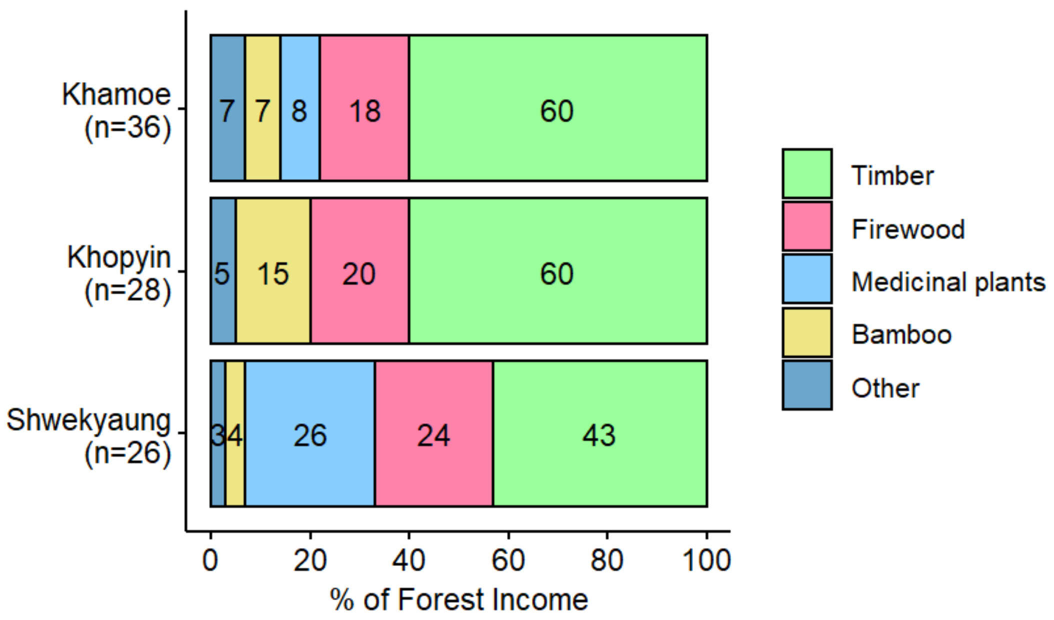


Figure 4.10: Income share of forest products

4.3.5 Forest dependence

4.3.5.1 Relative forest income

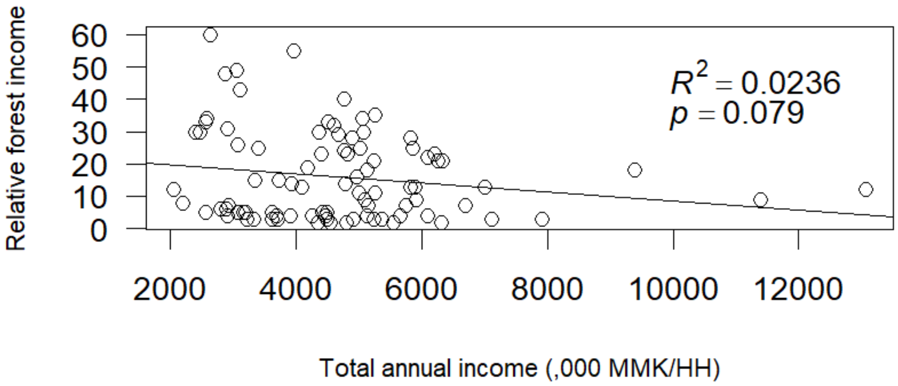


Figure 4.11: Relative forest income and total annual income

Figure 4.5 shows that the relative forest income was 14-16% for the three villages. The relationship between the relative forest income and the total annual income of the households was examined to understand the patterns and trends between them (Figure 4.11). The relative forest income was the proportion of a household's total annual income from the sale of forest products. The total annual income was a household's overall income from all income sources. There was a weak and non-significant correlation between relative forest income and total annual income (R^2 = 0.024, t value = -1.77, p=0.079). The plot showed a slightly descending relationship between the relative forest income and the total annual income of the households, indicating that the contribution of the forest income to total household income is higher in lower-income families with total annual incomes between 2,000,000 and 6,000,000 MMK than in high-income families with income ranges between 6,000,000 and 13,000,000 MMK. However, the p-value and low R^2 value argue for caution (Figure 4.11).

4.3.5.2 Relationship between forest dependency and households' socio-economic characteristics

Logistic regression is a technique to estimate the probability of a dichotomous or binary variable by a set of explanatory variables. No multicollinearity is anticipated when tolerance > 0.20 or VIF < 4 [109]. The tests revealed no collinearity among the seven explanatory variables; all VIF values were below four, and tolerances ranged from 0.46 to 0.96. (Table 4.6). Among seven explanatory variables, family size and distance to the forest were statistically significant at a 1% confidence interval (Table 4.6). The fitted model correctly predicted 76% of the observed values (Table 4.6).

Table 4.6: Binary logistic model for households' dependency on forests (N=90)

Explanatory variables	B	SE	Z value	Pr (>|z|)	Exp (B)	95% C.I. for Exp (B)		Toler-ance	VIF
						Lower	Upper		
Intercept	4.335	2.578	1.682	0.092	76.356	-0.717	9.388	-	-
Nativity of HHH	0.622	0.677	0.918	0.358	1.862	-0.705	1.949	0.962	1.038
Age of HHH	-0.009	0.039	-0.236	0.813	0.990	-0.086	0.068	0.470	2.123
Education of HHH	0.065	0.145	0.453	0.650	1.067	-0.218	0.350	0.462	2.164
Family size	-0.604	0.226	-2.668	**0.007**	0.546	-1.048	-0.160	0.644	1.550
Paddy (Ac)	0.204	0.180	1.133	0.257	1.226	-0.148	0.557	0.686	1.456
Distance to forest (km)	-0.296	0.104	-2.845	**0.004**	0.743	-0.500	-0.092	0.775	1.289
No. of gold mining labour	-0.629	0.466	-1.348	0.177	0.532	-1.544	0.285	0.775	1.289

Note: HHH=household head, SE=standard error, C.I=confidence interval, AIC=103.81, number of fisher scoring iteration=5, log likelihood= -43.91, df=8, X^2=18.7, P(> X^2) = 0.016, efficiency of fitted model=0.76, $p<0.01$ represents statistical significance at 1% level.

The younger and educated native household heads rely more on collecting forest resources (Table 4.6). Households with more paddy acreage but fewer gold mining laborers rely more on the revenue from forest goods. Households with fewer family members and a location nearer to forests rely more on gathering forest products than households with more family members and a location further away from forests (Table 4.6).

4.3.5.3 Socio-economic characteristics and factors influencing households' income from forest

The relationship between the income from forests and the socio-economic characteristics of households was examined using OLS regression analysis (Table 4.7). The value of R^2 (0.267) indicated 26.7% of the model's explanatory power. The test results showed that four variables of households' socio-economic characteristics including the income from agriculture, income from wage employment, income from salaried jobs and the distance to the forest showed negative and significant correlation with the forest income (Table 4.7). A household is closer to the forest if it obtains more subsistence and commercial forest income. If people earned more from other sources, they collected fewer forest products. Although collecting forest products wasn't usually a good idea, it was done since there were no other viable income options.

Table 4.7: Total annual forest income against households' socio-economic characteristics (N=90)

Explanatory variables	B	SE	t value	Pr(>|t|)
(Intercept)	1.814	2.483	7.307	0.000
Family size	-4.921	3.755	-1.311	0.193
Paddy (Ac)	6.460	5.394	1.198	0.234
Agriculture income	-2.739	9.567	-2.863	**0.005**
Wage employment income	-2.587	1.028	-2.517	**0.013**
Salary income	-1.778	7.424	-2.394	**0.018**
Own-business income	-3.248	9.763	-0.333	0.740
Gold mining income	-4.899	3.449	-0.142	0.887
Distance to forest (km)	-7.238	1.800	-4.022	**0.000**

Note: Multiple R^2=0.3325, Adjusted R^2=0.2666, F=5.043, p-value = 0.000, $p<0.05$, $p<0.01$ and $p<0.001$ represent statistical significance at 5%, 1% and 0.1% level, respectively.

4.3.5.4 Forest income and economic inequality

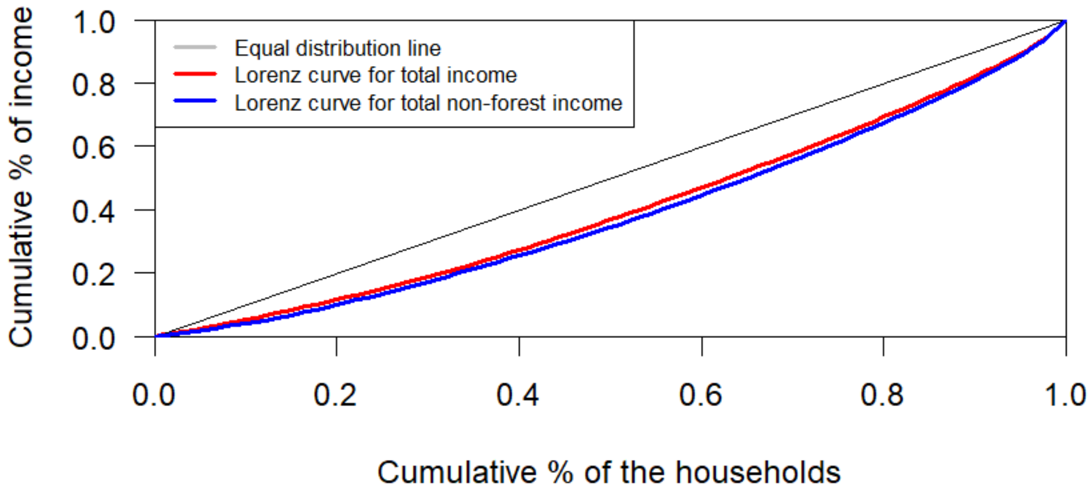


Figure 4.12: Lorenz curve

The overall computed Gini coefficient of total income with forest revenue was 0.19. However, it increased to 0.23 without forest income, indicating that the exploitation of forest resources may help to lessen economic inequalities. According to Lorenz curves, the total annual household income including forest income reduced income inequality and improved household well-being (Figure 4.12). The results generally imply that using forest resources reduces economic inequality as the Lorenz curve came close to equality.

4.4 Discussion

4.4.1 Impact of farming and gold mining on households' economy

People in the study villages used a variety of livelihood activities, including agriculture, wage work related to the gold mine, salaried employment, own business, and the gathering of forest products, such as timber and non-timber forest products. All sampled households gathered forest products, which played a significant role in livelihood activities (Figure 4.4). However, the revenue from the forest varies across the three sampled villages. The forest income share is higher than off-farm income but lower than farm and mining income in Khopyin and Shwekyaung villages. Khamoe village is a base camp for visitors worshipping the Zalon Taung Pagoda. It has sparked the growth of off-farm employment, including transportation and home food stores, which have become considerable income sources for the villagers. Khamoe village is also near Banmauk town, where most residents trade agricultural items at Banmauk market seasonally. The dependency on the forest has decreased because of these occupations. Consequently, forest income has the lowest income share among the four primary sources of income in Khamoe village.

Farming was the most crucial income source contributing 37 to 44 % of the total annual income of households for the production year 2021-2022 (Figure 4.5). This result is consistent with a number of studies conducted in Asia and Africa, which found that agricultural revenue made up the greatest proportion of families' total annual income (45-48%). Households acquire their daily food consumption through their crop production in which 61-92% of households were involved (Figure 4.4). The common crops included rice and groundnut. According to the answers from FGDs and household surveys, the productivity of agricultural products was satisfactory, and households received both home consumption amount and market sale. Agricultural practices are well established, and farming is often the most established livelihood activity in most rural communities in Myanmar. The households stated that rice and groundnut are more market-oriented than other crops, including local and regional markets, allowing them to get better prices for their products. The villagers have traditionally used cows and buffalo to prepare paddy fields for planting. However, due to the increasing use of hand tractors for agricultural field ploughing, some households reported that they only use cow and buffalo dung as bio-fertilizer for rice farming. The locals grow and harvest rice and groundnuts traditionally using labours. The daily wage for one worker varies from 6,000 to 10,000 MMK in the study villages. Meanwhile, Shwekyaung village does not get any revenue from farm-based wage employment (Table 4.5). This is because Shwekyaung village families assist each other to cultivate and harvesting crops without compensation but provide meals to those who labour all day, as stated in FGDs and household surveys.

Mining income accounted for the second largest share in Khopyin and Shwekyaung villages and the third largest in Khamoe village, respectively. In all three villages, mining income was higher than forest income, providing 20 to 38% of the total household annual income (Figure 4.5). The high demand for labour in the gold mining business and the abundance of gold mining sites in Banmauk Township may make wage employment in the gold mining industry more accessible than other livelihoods. Gold mining is a physically demanding and risky job that requires specialized skills and experience. As labour leaders trained new hires on how to work in the gold mines, the respondents reported that every adult male in the villages had the skills and expertise to do so. The average wage rate for gold mining-related wage employment is 7,000 Kyats/day, which is not much compared to other income sources. However, year-round operation in the gold mining industry may provide a more dependable and consistent source of income than forest-based livelihoods, which may be seasonal or face more uncertainties and risks due to market fluctuations and constrained by Forest Law and regulations. In the study villages, gold mining supports the livelihoods of 41-82% of households (Figure 4.4). This result is analogous to research in northern Guinea, where 78% of households were engaged in artisanal and small-scale gold mining [237]. While gold mining is a significant part of the economy of Myanmar and a substantial source of income for local people [76], it has a tremendous impact on the environment, causing arsenic, cyanide, and mercury contamination of the air, soil, and water [238]. 'Recently, the mining companies started testing gold even in the creek near the village. We are worried that harm to the creek's water flow would eventually prevent the agricultural lands from producing crops,' a farmer in Shwekyaung village said. The high price of gold made it feasible to mine in sites like streamlets near villages and inside reserved forests that were previously off-limits (see Chapter 2). Although gold mining is often temporary and only takes up a little space, its pollutants, and sediments move far via streams and tributaries, harming water quality and restricting access for people, fish, and other species [239]. A recent study in Nantkyin reserved forests in Banmauk Township showed high concentrations of heavy metals in the soil of several mining sites, which can cause adverse health effects in the mining community [79]. The Planning and Statistics Division of the Forest Department reported that water samples taken from some of the gold mining sites in Banmauk Township had color values higher than the WHO drinking water standards [94].

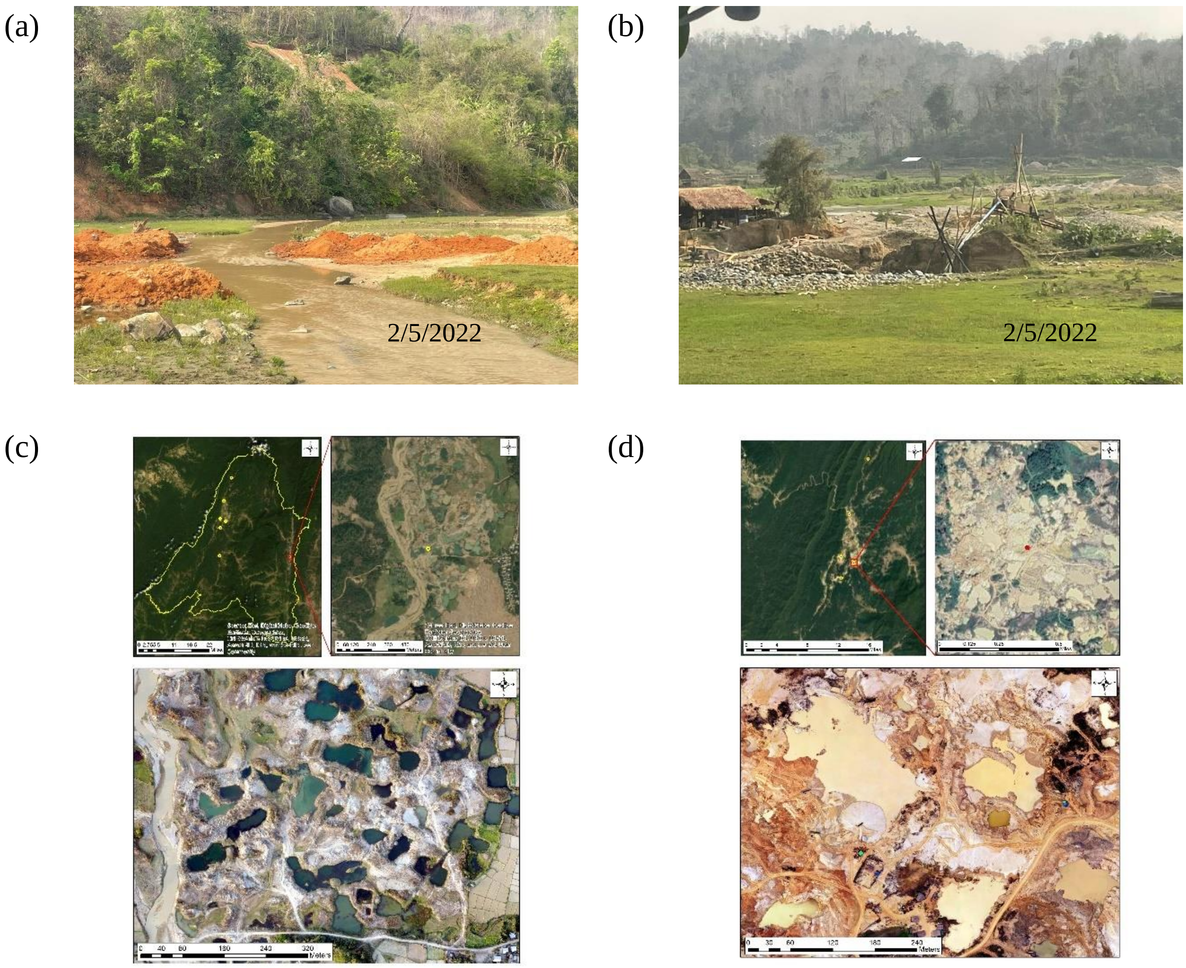


Figure 4.13: New gold mining testing sites near Shwekyaung village (a and b), gold mining sites in Banmauk Township (c and d)

(Source of c and d: Planning and Statistics Division of Forest Department, 2020)

Due to increased demand and prices of gold, new mining activities have been started in the low-land agricultural fields of the study villages (Figure 4.13 (a and b)). A family in Shwekyaung village reported that 'We leased 1 acre of our paddy field to the gold mining company for 10,000,000 MMK for one year. After the one-year lease expires, the company will renovate the land so we can cultivate the rice again there'. According to various studies, the growth of surface mining often results in the permanent loss of farmland, which causes the expansion of shifting cultivation in forest land [77, 115]. Aye and Shibata (2023) found that gold mining displaced paddy fields on 533 hectares north of Banmauk township between 2000 and 2021, confirming the substitution of agricultural land for gold mines [62]. Although mining development benefits the economies of the villagers, its associated increase in illicit logging, illicit mining activities, and shifting cultivation may harm ecosystem services, biodiversity conservation, and quality of life [119]. Some remote and well-maintained reserved forests in the Sagaing Region [74] and the Banmauk township [62] are increasingly damaged by deforestation driven by gold mining. The Myanmar Mining Enterprise, under the Ministry of Natural Resources and Environmental Conservation, grants mining licenses to companies for various fixed durations. The minimum land size for gold mining is 20 acres (about 8 hectares) [49]. The study suggested effective regulation and law enforcement on current mining activities to reduce environmental harm, balance mining and local livelihoods, and stop unsustainable resource use. The government and relevant organizations should monitor and regulate mining activities near settlements to avoid harm to rivers, streams, and the social environment.

4.4.2 Contribution of forest resources to household’s economy and implications for forest conservation

Local communities use forest resources primarily for domestic use in all sampled households, demonstrating that all households participate in the gathering of forest products. With a contribution of 14–16% of the household's total annual income, the forest income was a significant income source (Figure 4.5). Nonetheless, the communities' farming and gold mining revenue exceeds the forest's revenue. Hence, there is little proof that the most important source of living in this area is forest revenue. This study's lower forest income share contrasts previous research in Myanmar that found forest income generated the largest income share (37%-44%) of families' total annual income in villages near reserved forests and protected areas [25, 26, 221, 240]. However, this research aligned with a prior study in the Katha district, which found that the least income proportion of families' overall income came from forest revenue (1–7%) [97]. Other studies in Malawi and the Philippines also reported that forest revenue accounted for the lower income share, 15% and 13.5% of total household income [241, 242].

Among eight categories of forest products that the local communities mostly used, the largest income share was from timber, which accounted for 43–60% of all annual forest income (Figure 4.10), and 42–62% of households were engaged in timber extraction from adjacent forests (Figure 4.8). This result is consistent with the previous research conducted in the Katha district, which found that most families (96%) engaged in timber extraction from the forests [97]. Timber had the most significant income share among forest products due to the high market price of teak (*Tectona grandis*) and tamalan (*Dalbergia oliveri*), which are popular in the local and foreign markets and predominate in nearby forests around the study villages (see Chapter 3). Increased wood harvest from natural forests may damage forest quality and sustainability as timber demand and price grow. Many studies reported that tropical forests are suffering from accelerated human disturbances through logging, hunting, forest fire, and so on, which make sustainable management of tropical forest complex and difficult [243-246]. Myanmar's Forest Law allows locals to use forest products from the public forests and buffer zones exclusively for subsistence. This chapter confirmed that locals gathered wood from nearby forests for commercial and subsistence needs. The establishment of community forestry in the degraded forest land may help to maintain natural forests by integrating locals in forest management and allowing them to dispose of forest products. Reduced illegal logging in the gazette-reserved forests could be possible with the appropriate use of community forestry in Myanmar [247].

Firewood accounted for the second-highest income share (18-24%) of households' income derived from the forests (Figure 4.10). A significant percentage of households (97-100 %) engaged in firewood collection, illustrating firewood's importance as a primary energy source. This result is consistent with the previous research in the Thayarwaddy District in Myanmar, which reported that firewood was the second-largest source of revenue, accounting for roughly 18% of families' total forest income [25]. Households reported gathering firewood from nearby unclassified and reserved forests using knives, while others claimed to do so using chainsaws. Khamoe and Shwekyaung villages have access to additional energy sources like electricity, whereas Khopyin village solely uses firewood for daily cooking as it has no access to electricity. Bamboo is another valuable forest resource, providing 4–15% of total forest revenue and supporting a significant portion of households (83–92%). Bamboo is used as a building material to create houses, walls, baskets, and fences on houses and farms. Some households reported that they get regular income from making and selling bamboo products such as bamboo baskets, bamboo walls for housing, and fences. It is necessary to systematically manage the natural bamboo stocks if the market demand for bamboo is consistently growing. Dransfield and Widjaja (1995) claimed that regular and systematic exploitation boosts bamboo stock production [248]. On the other hand, bamboo forest vegetation management, like density control of bamboo culms and fertilizing, is required to maintain the coexistence of bamboo and trees [249]. Establishing private bamboo farms is one alternative strategy to reduce unauthorized bamboo harvesting from reserved forests. One of the fastest-growing plants on the planet, bamboo has been utilized to boost the economy, preserve the environment, and generate employment. As several studies have shown how bamboo has a vast potential to reduce rural poverty in many nations [250, 251], the government and aid agencies should train and transfer technology to small-holder bamboo product producers on managing bamboo plantations, harvesting, post-harvest handling, processing, and systematic felling and new planting to sustain bamboo and firewood for local use.

In addition to bamboo and timber, the locals depend on medicinal plants for commercial purposes, accounting for the second-largest income share (26%) of the total annual forest income in Shwekyaung village (Figure 4.10). Hence, boosting this industry might help underprivileged local populations and raise their standard of living. Mountainous locations, like the Zalon Taung National Park, have less accessible topography and slower urban development. However, the locals, notably Shan women, have much traditional knowledge about using different medicinal plants. The visitors to the Zalon Taung Pagoda and the residents of the adjacent towns provide a market for the medicinal plants. The bark, roots, stems, as well as other plant parts of medicinal plants are chopped and sold as raw materials (Figure 4.7d). The population of some highly sought-after medicinal plants in the wild may be under severe stress due to overharvesting because of the rising demand for plant-based pharmaceuticals [252]. A collector of medicinal plants in Khamoe village said, 'Nowadays, medicinal plants are getting rarer, and we have to go in the depth of the forests to collect them.' Due to their sluggish rates of growth, low population densities, and constrained geographic ranges, medicinal plant species are more susceptible to extinction [253]. In addition to serving the current market, cultivation may aid in preserving the wild genetic variation of medicinal plants [252]. Agroforestry offers a helpful strategy for their development and preservation since many medicinal plant species prefer to flourish in forests. The agricultural organizations and research facilities should assist people who collect medicinal herbs to cultivate such plants by providing proper cultivation techniques.

4.4.3 Determinants of households' dependency on forest income

The relative forest income of the household trends slightly downward as total income rises (Figure 4.11). The study's findings (Table 4.6) indicated that having a household head who is a native of the study region was positively correlated with household income from the forest. This result aligns with research from Ethiopia and India that found a good correlation between native status and daily revenues from forest products [254, 255]. The age of the household head was negatively correlated with the income from the forest (Table 4.6), suggesting that as the household heads aged, they suffered reduced ability to cut wood and bamboo. This result is in line with the previous research in Thayarwaddy District and Taungoo District in Myanmar, which stated the inverse relationship between household head age and income from forest products [25, 240]. The logistic regression model provided an unanticipated prediction about the association between the household head's education (years of education) and forest revenue (Table 4.6). Conventional expectations are that families with improved access to education will rely on something other than collecting forest products for survival. This contradicts other research in Africa and Myanmar that found a negative correlation between forest revenue and household head education [26, 216, 240, 256]. Nevertheless, Masozera (2002) [257] and Moe and Liu (2016) [25] found a positive association between household head education and forest income in the Nyungwe Forest Reserve in Rwanda and the Tharyarwaddy District in Myanmar. Some elderly household heads in the research region did not have any formal education, while middle-aged and young people tended to attend primarily elementary and middle schools. Hence, more educational access may be associated with nearly elementary schooling and may not thus indicate other alternative means of support, such as salaried jobs. This may be the reason why higher education affects greater dependence on forests. The walking distance to the forest was negatively and significantly correlated with the income from the forests. That is not surprising since I anticipated households closer to forests would be relatively more dependent on forest resources than other households (Table 4.2). This result is consistent with other research conducted in Asia and Africa, which discovered that families' reliance on forests is negatively and significantly impacted by their proximity to forests [256, 258, 259].

The people have paddy land but also profit from the forest during the market season. For instance, locals with a traditional understanding of medicinal plants will often harvest them with market demand and a reasonable price. Thus, there was a positive correlation between paddy land (Acre) and forest revenue (Tables 4.6 and 4.7). This finding contradicts previous research conducted in Myanmar, which found that families with more agricultural land relied less on forest income [26, 221, 240]. This finding, however, is consistent with that of Aung et al. (2015), which found a positive correlation between the area of agricultural land and the household's revenue from the forests in Natmataung national park in Myanmar [222]. As agriculture is the primary source of income in the study villages, sample households have an average of 2 to 3 acres and a maximum of 5 to 6 acres of paddy land. In the household survey, a farmer from the Khamoe village said, "My farm cannot produce groundnut because the soil is not favorable for it; only rice can be grown. I, therefore, made less money from agriculture". Another farmer from Khamoe village said, "My paddy field is roughly 5 acres. But since I am elderly, I cannot work as hard as I once could. Thus, I leased my paddy field to the lessor, who is entitled to get half of the profit". A larger paddy land area would only sometimes mean more extensive crop production or profitability as crop productivity declines with lousy weather, less labor force, and natural disasters like drought and floods, insects, pests, and diseases [260].

Households with more income from farm and off-farm activities showed a negative relationship with household income derived from forest-based activities (Table 4.7). This result is in line with research from Myanmar's Natmataung and Popa national parks, which suggested that other sources of revenue reduce human reliance on the forest [26, 222]. If households earned more income from other livelihood activities such as wage employment, salaried jobs, and own-business, they were less interested in forest product collection. The study anticipated that forest product collection was only sometimes a favorable vocation, but it was taken up in the absence of regular sources of income. These results align with the studies in tropical countries, which reported that agriculture and off-farm income showed a significant and inverse relationship with the income from forest products [240, 256, 261]. However, this study's results differ from the study in Bangladesh, which found that household incomes from forest increase as the wage incomes from households increase [217]. Such disparities may be due to different wage types, wage rates and location characteristics, and the respondents' nature.

The negative correlation between households' forest income and income from gold mining suggested that households with higher gold mining income depend less on forests (Table 4.7). However, there was no sufficient evidence for this conclusion. When more family members in a household work in gold mines, fewer persons are available to gather forest products, resulting in lower forest income. Deforestation and environmental deterioration are additional risks associated with gold mining, which lowers the availability of and revenue from forest resources [262]. The local people work in the gold mining sites during the off-cropping season and then return to their paddy fields during the cropping season. The study argued that gold mining's effect on forest revenue is uneven and seasonal, resulting in an insignificant correlation.

In general, this chapter confirms the important role of forests in securing livelihoods among rural households. When forest income was removed from total income, the Gini coefficient rose from 0.19 to 0.23, with a slight change (0.04) in the context of the sampled households. This result is comparable to the increase of 0.06 found in Uganda [263] but lower than that of 0.11 found in the Congo [264]. Although there is variation from case to case, the general trend indicates that forest resources have considerable potential for reducing income inequality among rural households, and the present study supports this.

4.5 Conclusion

A better understanding of different socio-economic characteristics and factors of households living adjacent to forests is crucial for designing conservation and alternative income development initiatives in the area. In the study villages, 14-16% of households' annual income comes from collecting forest products. This investigation, therefore, supports the substantial use of forest resources by nearby local communities. Also, this research suggests that severely restricting access to forests will harm the livelihood of the local people, who depend on forest products for survival and income. The results from the regression analyses reflect the significant socio-economic characteristics and factors that influence the nature of ethnic communities living near forests. The policy planners should consider measures to improve agricultural production and support the region's education sector to develop alternative salaried employment to reduce the communities' dependence on forest product collection and enhance conservation.

Further ethnobotanical research is required to chronicle the herbal medicinal plants utilized and the associated traditional knowledge of herbal medicine in the communities since the local population depends on extracting medicinal plants from ZNP. From the conservation perspective, the designation of a buffer zone would divide village land from ZNP to help prevent encroachment and other unlawful activities within ZNP. This chapter recommended establishing community forestry in the designated buffer zone and the adjacent unclassified forest area to address the needs of local communities for timber and non-timber forest products and create job opportunities and income. The findings of this chapter will help develop the management of ZNP and adjacent forests by providing a better knowledge of the relationship between local livelihoods and forest products.

4.6 Limitations of the Study

The questionnaire survey data was collected based on the recall period of one year for calculating household income. The problem of respondents' recall, accuracy, and intentions may be subject to various biases.

4.7 Ethical Concerns

Before conducting the survey, the respondents were fully informed about the purpose, intent, and potential use of data and data collection methods. However, I did not share information between participants, protect the data and names of the participants and use the collected information only for the study's intended purpose.

Chapter 5. General Discussions and Conclusion

5.1 General Discussions

Banmauk Township, Katha District in Sagaing Region, is a part of Myanmar's crucial forest management plan for timber production and conservation due to its extensive natural forest cover with economically valuable tree species. This study focused on the township's forest cover, forest structure and tree species composition affected by various human activities and socio-economic impacts of local communities to inform interventions for optimum forest management while maintaining its social and natural assets. All assessments for the three components of the research (Chapters 2, 3, and 4) included a comprehensive literature review, satellite imagery analysis, field observations, vegetation survey, and structured interviews with the local communities. In Chapter 2, Landsat satellite imagery analyses in the forest landscape north of Banmauk Township between 2000 and 2021 showed that gold mining and its effects, such as shifting cultivation and bare land formation, were the primary causes of deforestation. After observing the visible signs of land-cover changes, Chapter 3 focused on evaluating the forest structure, tree species diversity, and composition affected by various human activities and the socio-economic reliance of local communities. However, vegetation assessment cannot be carried out in some parts of the township (including the Chapter 2 site) owing to the risky ground conditions imposed by the ongoing armed conflicts since 2021. Thus, Chapter 3 assessed the forest structure, tree species diversity, and composition inside and outside the newly established Zalon Taung National Park (ZNP) in the middle part of Banmauk Township. ZNP was also concerned with assessing forest conditions impacted by human disturbances for many years before its declaration as a PA. The results showed that the tree density, diameter, and IVI of economically valuable species, notably teak (*Tectona grandis*), which had been extracted as the target species to fulfill the national revenue target for a long time were significantly lower inside ZNP than outside.

The results from Chapters 2 and 3 highlighted the increasing human activities on the forest land together with the unsustainable forest management and weak law enforcement, resulting in forest cover loss and degradation, which may pose a growing threat to the natural environment and the livelihoods of rural people in Banmauk Township. Chapter 4 analyzed the local livelihoods strategies and the determinants of rural households’ dependency on forest for their subsistence and income. Although agricultural and gold mining incomes were higher than forest income, all sampled households use firewood, timber, bamboo, and medicinal plants for energy, shelter, and safe of life, showing the significant role of forest products for rural communities. The local government and forest managers should use the analytical findings from this study to create effective land-use plans for minimizing deforestation and balancing resource use and conservation to reach sustainable forest management in Banmauk Township.

5.1.1 Forest cover and tree species composition affected by gold mining and logging

The expansion of the gold mining industry depletes the forest resources in Banmauk Township's production forests (Chapter 2), and excessive legal and illegal logging degrades the forest quality, reducing the tree density of economically targeted tree species (Chapters 3 and 4). According to the MCRB report on gold mining in Myanmar, forest clearing for mining sites, logging for mine shaft construction, burning limestone for gold processing, and using large amounts of forest timber for charcoal and firewood in mining sites cause significant forest cover loss [49]. The results of Chapter 2 confirmed that mining-related bare land formation, shifting cultivation, and settlement growth were all related to deforestation. In addition to the deforestation issue, the results of Chapter 2 and national land-cover data of Banmauk Township [23] represented the high percentage of the land-cover shift from the closed forest to open forest during the past years. The significant forest degradation in the timber production forests is a reaction to decades of unsustainable forest management and excessive timber extraction, primarily of teak and other economically valuable hardwoods, either legally or illegally.

Following nationwide log export and logging bans in 2014 and 2016, timber harvesting resumed in 2017. Katha District, which includes Banmauk Township, has since emerged as one of the primary timber extraction regions due to its vast natural forest resources [265]. According to the Katha District forest management plan for 2016-2025, teak and other hardwoods have been planned to harvest in considerable quantities from the production forests of Banmauk Township (including Chapter 2's site). At ZNP, MTE harvested 5,207.852 tons of kanyin trees (*Dipterocarpus* spp.) in 2005 and 2,439.546 tons of teak trees (*Tectona grandis*) between 2008 and 2010 as the last legal timber extraction before designation as a PA. Previous selective logging activities significantly reduced the tree density of the mostly targeted and extracted tree species, notably teak (*Tectona grandis*), revealing its severely decreasing numbers in ZNP (Chapter 3). Treue et al. (2016) noted that the reserved forests (RFs) had been routinely over-logged for decades, with a heavy focus on export-oriented timber exploitation and a considerable exceed of AAC [36]. The analytical results of Chapter 3 also confirmed that teak had been harvested at a rate that may have consistently exceeded the estimated AAC in the past decades.

Another economically valuable and IUCN endangered species, tamalan – Myanmar rosewood (*Dalbergia oliveri)* has been intensively harvested legally and illegally both inside and outside ZNP, leading to the commercial extinction. Springate-Baginsky et al. (2014) noted that *Dalbergia oliveri,* one of the most traded timber species over the China-Myanmar border through a vast illegal trade, was intensively logged to market extinction [266]. However, the logging practice has lessened the burden on other hardwoods, including *Dipterocarpus alatus, Protium serratum*, *Xerospermum noronhianum*, *Dillenia pentagyna, Schleichera oleosa* and *Terminalia crenulata,* showing the high IVI in both inside and outside ZNP. The over-exploitation of marketable tree species may open up opportunities for other lesser-used and light-demanding tree species to grow more abundantly, possibly leading to changes in the forest's overall composition and structure. Promoting the use and sustainable exploitation of various tree species may preserve the resilient forest ecosystem and improve forest management. With the easy accessibility to the roads and villages, over-harvesting and illegal logging would decrease tree species diversity, evenness, and dominance (Chapter 3). The over-extraction of wood is closely tied to land use change and shifting dense forests to open forests and sometimes to degraded forests (Chapters 2 and 3). Buffer zone demarcation and law enforcement are necessary to reduce the over-exploitation of wood and protect the core area of ZNP.

5.1.2 Rural households' forest dependency and its consequences on forest management

Despite having various energy sources, like hydro-power and natural gas, Myanmar has one of the lowest commercial per capita energy consumptions in Southeast Asia due to the low per capita income and insufficient energy infrastructure, with the total electrification rate of only 26% for the whole country [267]. Useful tree species for timber and firewood are suffering from accelerated human disturbances through logging and over-exploitation which make sustainable management of forest complex and challenging (Chapter 3). Some studies in Myanmar pointed out that the amount of fuel wood harvested from the forests has steadily been increasing with population growth and is higher than timber extraction [10, 268]. According to the results of Chapter 4, the quantity of firewood that households in the study villages harvested each year was estimated to be between 4.2 and 5.4 tons (in raw weight), compared to an average of 1.4 to 2.2 tons of timber, suggesting that the amount of extracted firewood was 2-3 times more than the amount of timber (Table 4.4) (Figure 5.1).

The average annual firewood consumption (4.2–5.4 tons) per household in this study was higher than the estimated annual firewood consumption (2.5 tons) per household described in Katha District forest management plan [58]. Due to the underestimation of domestic timber and fuel requirements, home wood demands become mostly illegal and unplanned, which undermines the sustainability of forests. Banmauk Township has planned to establish 760 acres

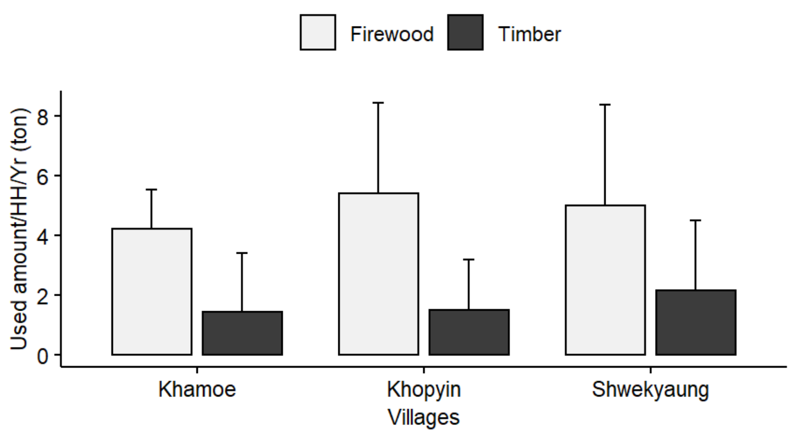


Figure 5.1: Average annual harvested amount of firewood and timber

of fuelwood plantation between 2020–2025 under the forest management plan. This will help to fulfill local fuel and firewood needs to some extent while reducing extraction from the natural forests. However, an extensive management plan is required before and after plantation establishment since the failures of plantations have resulted in forest loss and degradation [269].

Bamboo is a multifunctional forest resource used in the study villages for housing and making domestic products like utensils, fences, and baskets. If the market demand for bamboo is consistently increasing, it is necessary to systematically manage the natural bamboo stocks and support establishing private bamboo farms. Since the Phetswet Research Station in Katha Township has established research trial plots for various bamboo species in Sagaing Region since 1966 [270], it could provide extension services to local communities who want to establish private bamboo plantations with suitable bamboo species, bamboo seedlings, and cultivation techniques. The indigenous Shan people of Khamoe and Shwekyaung villages harvested medicinal plants from ZNP for the local sale. The collection of medicinal plants in the wild will rise if the demand for herbal medicines rises steadily, and overharvesting might affect their growth and survival in the natural forest. The research institutions must assist local communities in growing medicinal plants from seeds or vegetative propagation techniques, which have been effective in tree breeding and forest plantations.

5.2 Suggestions to Improve Banmauk Township's Forest Management

All forest land in Myanmar is state-owned and the government controls the country's forests. But the government has complex problems to manage all forests effectively, and has low investment for rehabilitation work. With the increased population and interest in gold extraction with reliable economic benefits, gold mines are increasing rapidly in the lowland agricultural fields with a high possibility of gold occurrence in Banmauk Township. As a result, gold mines substituted paddy fields in the lowland, and people expanded shifting cultivation in the upland forest. In the shifting cultivation cycle, the long fallow period regenerates the forest and soil nutrients necessary to ensure sustainability [44, 271]. However, due to rising land scarcity driven by population growth and socio-economic constraints, fallow periods are becoming shorter in many places, resulting in the transition of permanent agricultural fields, which causes deforestation and biodiversity loss [45]. Participatory forest management and the development of community forestry have shown to be a drive to create land use models for resolving the issues of forest conservation and local livelihoods to prevent shifting cultivation in the natural forests of Myanmar [200, 272]. The CFI (2019) supports entrepreneurial growth and enables the community forest user groups to profit from timber and non-timber forest products. Community forestry, which improves local community engagement in forest management, is one of the potential strategies for adequately restoring the damaged forest area in the township.

Once gold mining was complete, the land was left as the waste land with no vegetation cover. Local people often enter these waste lands, and make gold mining activities illegally. According to the Mining law and regulations, mining companies are responsible for the reclamation of the land and the establishment of plantations following mining. To effectively regulate existing mining companies to conduct restoration and replanting of native tree species after mining with scientific knowledge of species characteristics, more efforts and law enforcement are required. The Mining Law (2015) is the main piece of legislation governing the mining and minerals sector, setting out the mining licensing as well as penalties for non-compliance with the law [53]. However, given the ongoing armed conflict and the resulting limitations on the scope of government control of some areas, the formalization of the mining sector may need to be improved further. Land-cover analysis found the mining activities operating in and near waterways was seen to lead to unsustainable water-based mining practices in Banmauk Township. The use of mercury and cyanide in the waterways for the gold extraction often led to water pollution and the depletion of fish stocks. Local people in the surveyed villages also expressed concerns about soil and water contamination of gold mining in the streams near the village's paddy fields. The government and relevant organizations must monitor and regulate mining activities near settlements and agricultural fields to avoid harm to rivers, streams, soil and the socio-economic environment of the local communities. Also, the Forest Department must continuously monitor, manage, and execute laws and regulations on illegal mining in the forest area to lessen damage to the forest ecosystem and halt the unsustainable use of resources.

As part of the country's reforestation and rehabilitation program (MRRP), the Forest Department targeted to restore almost 1 million hectares of degraded and deforested lands within PFE all over the country between 2017 and 2026. MRRP calls for establishing plantations, community forestry, assisted natural regeneration, and enrichment plantings of existing forests, all carried out in Banmauk Township. Furthermore, the Forest Department establishes seed production areas, clonal seed orchards, and hedge gardens, tests and selects seed sources using provenance trials, and maintains improved seeds and seedlings for reforestation programs [6]. Since 1978, field trials for various provenances of teak (*Tectona grandis*), padauk (*Pterocarpus macrocarpus*), and yemane (*Gmelina arborea*) have been conducted at Phetswet Research Station in Katha Township to support information regarding reliable seed sources for reforestation [270]. Such data should be used to choose appropriate seed sources and seedlings for reforestation activities in Banmauk Township. Clonal seed orchards and hedge gardens for teak (*Tectona grandis*) and tamalan (*Dalbergia oliveri*) should also be developed in the township to preserve the species' genetic integrity and support the sustainable production of planting stock for reforestation under MRRP and by the gold mining companies [6].

Improving forest management to retain carbon stocks while maintaining timber production is of utmost importance for timber producing countries like Myanmar, where timber exports are a crucial source of national income. The impact of logging on the forest and soil is one of the crucial factors to be considered in SFM, even if this research could not evaluate it owing to the temporary suspension of logging activities due to risky ground conditions. In Myanmar, the government agency MTE and, sometimes, the subcontracted agents who adhere to MTE's standards handle logging activities in the natural forests. MTE employs a combination of animal and mechanical power for timber extraction operations which include felling trees, log stumping, skidding, logging road construction and log transportation [273]. In order to save budget and reduce environmental damage, elephants have been used to skid logs from stumps to the log landing site in the logging operations under MSS [273]. Nowadays, the bulldozer or other machinery is frequently and unavoidably used for skidding especially when the logs are too big to be hauled by elephants or buffaloes. Khai et al. (2020) observed that elephant skidding produced minor ground disturbance, but employing machinery for skidding resulted in a significant proportion of disturbed land in the timber production forests of Katha District [265]. Reduced impact logging (RIL) has been implemented worldwide to achieve sustainability in wood extraction operations [274], and MTE has embraced RIL guidelines to support SFM and the forest certification process [275]. The logging operations in Banmauk Township should use RIL and animal skidding to minimize environmental damage to the natural forest, which already had pressures from over-exploitation, agriculture, and gold mining expansion. Future research should conduct post-harvest assessments to inform forest managers and crews on the impacts of logging operations on the forest, soil, and environment to assist in optimum forest management of the township.

To reduce the pressure on forest resources and promote socio-economic well-being, alternative livelihood opportunities should be developed for local communities. These opportunities may include the promotion of non-timber forest products, eco-tourism, or value-added agricultural products. By diversifying their income sources, local communities can become less reliant on forest resources, and more resilient to environmental and economic changes. Policymakers should consider developing other income sources that don't hurt the environment and forest resources. Gaining access to formal and informal education may increase the people’s prospects of finding other work and lessen their reliance on the forest for survival. To encourage agriculture-based professions, government organizations and research institutions should support modern and environmentally gentle agricultural technologies and advanced interventions for cultivation to traditional farmers. A prosperous agriculture-based economy would be one substitute for exploiting forest resources. Since most of the population is skilled at producing finished bamboo products for home construction and derives income from bamboo, bamboo craft training course should be provided to the local people by the support of government or aid groups. Nature-based ecotourism should be promoted in and around ZNP to provide an alternative source of income to local people instead of harvesting forest resources and engaging in gold mining activities that are environmentally irresponsible.

After the designation of ZNP as a protected area, environmental education programs and public talks are necessary to raise local awareness of forest conservation, ecosystem services, and biodiversity. Together with the community forestry establishment, the government and aid agencies should provide capacity-building programs to empower local communities and equip them with the necessary skills to manage their resources sustainably. On the other hand, by incorporating local people's traditional wise use of forest resources into the township's restoration initiatives, forest managers could improve forest resilience and biodiversity of the restored forests more effectively. This study suggested that participatory forest management strategies might preserve natural forests and local livelihoods by giving access to crucial forest products and progressively developing income options outside the forest.

5.3 Conclusion

The optimization of forest management in Banmauk Township appears to be challenging since it needs to deal with the expansion of legal and illegal gold mining and exploitation of forest products, which depend on the government policy, laws, regulations, political conditions, and the socio-economic background of the local communities. The expansion of the gold mining industry and over-exploitation of commercially important tree species cause forest cover loss and degradation, impacting Banmauk Township's sustainable forest management. The favourable timber species extracted by the local communities for domestic use and sale included teak (*Tectona grandis*) and tamalan (*Dalbergia* spp.) which are regarded as reserved tree species by Forest Law and regulations. Long-term over-extraction of these species, legally and illegally, could bring them close to extinction in the natural forest. The local government should implement a time-limited logging ban for damaged tree species, mainly teak (*Tectona grandis*), and tamalan (*Dalbergia* spp.), to support their natural regeneration and survival in the natural forest. Law enforcement is necessary to prevent illegal logging, arrange for systematic land restoration, and establish plantations once gold mining ceases. As a limitation of the study, the continuous armed struggle between the national military and the local armed groups since 2021 prevented the vegetation survey and household survey on the current and post-mining forest area. Future research should focus on detecting revegetation after gold mining, including the re-establishment of the soil, to identify whether there is a tendency to return to the original forest site (i.e., close to the original) as fast as possible to improve the township's reforestation and rehabilitation work. The research findings could help forest managers and policy planners to develop appropriate policies and management interventions for mining industries with significant land use impacts on the forests. The results can be used as baseline data for future assessment of the effectiveness of protected area establishment in tropical developing countries. Moreover, the findings of this study may serve as a database for future landscape management plans that balance resource utilization and conservation to promote forest management in Banmauk Township.

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Appendix

IVI (%) of Tree Species in Zalon Taung National Park (ZNP)

No.	Species	Family	Local Name	Relative Frequency	Relative Dominance	Relative Density	IVI
1	*Dipterocarpus alatus*	Dipterocarpaceae	Kanyin	5.223881	10.07772	3.0837	18.3853
2	*Xerospermum noronhianum*	Sapindaceae	Thit-nyo	5.373134	6.873061	3.524229	15.77042
3	*Protium serratum*	Burseraceae	Thadi	5.820896	4.097131	3.524229	13.44226
4	*Baccaurea sapida*	Euphorbiaceae	Kanaso	5.373134	3.582451	2.643172	11.59876
5	*Dracontomelon dao*	Anacardiaceae	Ngar-bauk	1.641791	6.971972	2.643172	11.25693
6	*Terminalia crenulata*	Combretaceae	Htauk-kyant	4.029851	4.082225	3.0837	11.19578
7	*Dillenia pentagyna*	Dilleniaceae	Zin-byun	4.776119	2.226705	3.964758	10.96758
8	*Premna latifolia*	Verbanaceae	Sate-hnan	3.134328	3.506509	2.202643	8.843481
9	*Cedrela serrata*	Meliaceae	Taung-tama	3.134328	2.364814	3.0837	8.582843
10	*Decaspermum parviflorum*	Myrtaceae	Taung-thabye	2.38806	2.524494	2.202643	7.115197
11	*Syzygium kurzii*	Myrtaceae	Thabye-nyo	2.089552	1.823508	3.0837	6.996761
12	*Mangifera caloneura*	Anacardiaceae	Taw-thayet	1.641791	2.748499	1.762115	6.152405
13	*Castanopsis tribuloids*	Fagaceae	Gon	1.641791	2.727311	1.762115	6.131217
14	*Myristica angustifolia*	Myristicaceae	Myauk-ma-kun-thwe	2.686567	1.665779	1.762115	6.11446
15	*Ficus glomerata*	Moraceae	Ye-thapan	2.686567	1.259297	1.762115	5.707979
16	*Gynocardia odorata*	Flacoutiaceae	Kalaw	2.537313	1.07416	1.762115	5.373588
17	*Lannea coromandelica*	Anacardiaceae	Nabe	2.537313	1.775907	0.881057	5.194278
18	*Machilus villosa*	Lauraceae	Tha-but-thein	2.089552	0.80445	2.202643	5.096646
19	*Shorea obtusa*	Dipterocarpaceae	Thit-ya	1.492537	1.767522	1.762115	5.022174
20	*Tectona grandis*	Verbanaceae	Kyun	1.940299	0.419648	2.643172	5.003118
21	*Schima khasiana*	Theaceae	Laukya	1.492537	3.006044	0.440529	4.93911
22	*Lithocarpus grandifolia*	Fagaceae	Thit-cha	1.492537	1.189986	2.202643	4.885167
23	*Fraxinus* spp.	Oleaceae	Se-kha	0.447761	3.951615	0.440529	4.839905
24	*Dalbergia oliveri*	Fabaceae	Tamalan	1.641791	0.935486	1.762115	4.339392
25	*Miliusa velutina*	Annonaceae	Thabut-gyi	1.940299	0.516306	1.321586	3.778191
26	*Lithocarpus dealbatus*	Fagaceae	Thit-e	1.791045	1.097942	0.881057	3.770044
27	*Quercus glauca*	Fagaceae	Sagat	1.19403	1.67858	0.881057	3.753667
28	*Terminalia bellerica*	Combretaceae	Thit-seint	1.19403	0.597645	1.762115	3.553789
29	*Tetrameles nudiflora*	Datiscaceae	Baing	0.597015	2.369436	0.440529	3.40698
30	*Terminalia chebula*	Combretaceae	Phan-kha	0.895522	0.643766	1.762115	3.301403
31	*Garcinia paniculata*	Hypericaceae	Metlin	1.044776	0.392403	1.762115	3.199294
32	*Pterospermum semisagittatum*	Sterculiaceae	Nagye	0.895522	0.880286	1.321586	3.097395
33	*Schleichera oleosa*	Sapindaceae	Gyo	1.044776	0.707631	1.321586	3.073993
34	*Swintonia floribunda*	Anacardiaceae	Taung-thayet	0.597015	1.570296	0.881057	3.048368
35	*Aporusa roxburghii*	Euphorbiaceae	Ye-mein	1.044776	0.669503	1.321586	3.035865
36	*Gardenia sootepensis*	Rubiaceae	Yin-gat	0.895522	0.770216	1.321586	2.987324
37	*Tetrameles nudiflora*	Tetramelaceae	Baing	1.044776	1.006532	0.881057	2.932365

38	*Lagerstroemia villosa*	Lythraceae	Zaungbale	0.895522	0.963032	0.881057	2.739611
39	*Colona floribunda*	Tiliaceae	Phet-waing	0.447761	0.95685	1.321586	2.726197
40	*Schima wallichii*	Theaceae	Pan-ma	0.447761	1.32459	0.881057	2.653408
41	*Mahonia nepalensis*	Berberidaceae	Ta Khaing Lone Kway	0.746269	0.361094	1.321586	2.428948
42	*Antiaris toxicarius*	Moraceae	Hmya-seik	1.343284	0.178286	0.881057	2.402627
43	*Artocarpus chaplasha*	Moraceae	Taung-peinne	0.746269	0.241951	1.321586	2.309806
44	*Michelia champaca*	Magnoliaceae	Saga	0.895522	0.945212	0.440529	2.281263
45	*Croton oblongifolius*	Euphorbiaceae	Thetyin-gyi	0.746269	0.178612	1.321586	2.246466
46	*Morus alba*	Moraceae	Posa	0.447761	0.446081	1.321586	2.215428
47	*Malus* spp.	Rosaceae	Taw-Panthee	0.746269	1.015627	0.440529	2.202424
48	*Sterculia angustifolia*	Sterculiaceae	Shaw	0.746269	0.087551	1.321586	2.155406
49	*Millettia cinerea*	Fabaceae	Se-min-gyi	0.746269	0.08719	1.321586	2.155045
50	*Cinnamomum obtusifolium*	Lauraceae	Na-lin-gyaw	0.447761	0.815857	0.881057	2.144676
51	*Ficus altissima*	Moraceae	Nyaung-peinne	0.298507	0.93283	0.881057	2.112394
52	*Ziziphus rugosa*	Rhamnaceae	Zi-ganauk	0.746269	0.423189	0.881057	2.050515
53	*Stereospermum grandiflorum*	Bignoniaceae	Thande	0.597015	1.001351	0.440529	2.038894
54	*Cinnamomum glanduliferum*	Lauraceae	Seik-nan	0.447761	0.680164	0.881057	2.008982
55	*Cratoxylum pruniflorum*	Hypericaceae	Sa-thange-ohnauk	0.597015	0.580586	0.440529	1.61813
56	*Millingtonia hortensis*	Bignoniaceae	Akayit	0.447761	0.712412	0.440529	1.600702
57	*Elaeocarpus bracteatus*	Elaeocarpaceae	Thit-phwe	0.447761	0.526555	0.440529	1.414845
58	*Ficus rumphii*	Moraceae	Nyaung	0.149254	0.586791	0.440529	1.176573
59	*Adina cordifolia*	Rubiaceae	Hnaw	0.298507	0.436483	0.440529	1.175519
60	*Juglans regia*	Juglandaceae	Thitkya	0.597015	0.122068	0.440529	1.159611
61	*Terminalia tripteroides*	Combretaceae	Thanpe	0.447761	0.257831	0.440529	1.14612
62	*Psidium guajava*	Myrtaceae	Taw-malaka	0.298507	0.232321	0.440529	0.971357
63	*Grewia tiliifolia*	Tiliaceae	Ta-yaw	0.298507	0.202228	0.440529	0.941264
64	*Hibiscus rosasinensis*	Malvaceae	Pan-swe-le	0.149254	0.287527	0.440529	0.87731
65	*Dioscorea wallichii*	Dioscoreaceae	Kadat	0.298507	0.040338	0.440529	0.779374
66	*Diospyros ehretioides*	Ebanaceae	Aukchinsa	0.298507	0.035513	0.440529	0.77455
67	*Sterculia foetida*	Sterculiaceae	Letkok	0.149254	0.164711	0.440529	0.754493
68	*Elaeocarpus floribundus*	Elaeocarpaceae	Thitpwe	0.149254	0.123716	0.440529	0.713498
69	*Dalbergia cultrata*	Fabaceae	Yin-daik	0.149254	0.119939	0.440529	0.709721
70	*Sideroxylon burmanicum*	Sapotaceae	Thit-cho	0.149254	0.115083	0.440529	0.704865
71	*Dalbergia stipulaceae*	Fabaceae	Thit-mar	0.149254	0.080708	0.440529	0.670491
72	*Bombax ceiba*	Bombacaceae	Letpan	0.149254	0.059296	0.440529	0.649078
73	*Rinorea bengalensis*	Violaceae	Taw-okshit	0.149254	0.059296	0.440529	0.649078
74	*Eurya acuminata*	Theaceae	Taw-laphet	0.149254	0.0388	0.440529	0.628582
75	*Diospyros burmanica*	Ebanaceae	Te	0.149254	0.030929	0.440529	0.620711
76	*Sageraea listeri*	Annonaceae	Kalaw	0.149254	0.030657	0.440529	0.620439

77	*Crateva magna*	Capparaceae	Taung-gadat	0.149254	0.026944	0.440529	0.616727
78	*Dalbergia kurzii*	Fabaceae	Thit-poak	0.149254	0.026944	0.440529	0.616727
79	*Cinnamomum inunctum*	Lauraceae	Kara-way	0.149254	0.020238	0.440529	0.610021
80	*Uvaria cordata*	Annonaceae	Thabut-new	0.149254	0.017576	0.440529	0.607359
81	*Atalantia monophylla*	Rutaceae	Shauk	0.149254	0.017576	0.440529	0.607359
82	*Polyalthia simiarum*	Annonaceae	Thabut	0.149254	0.017244	0.440529	0.607027
83	*Dichrostachys cinerea*	Mimosaceae	Ta-pay	0.149254	0.016866	0.440529	0.606649
84	*Melastoma* spp.	Melastomataceae	Shar-mae	0.149254	0.016517	0.440529	0.606299

IVI (%) of Tree Species in Banmauk Unclassified Forest (BUCF)

No.	Species	Family	Local Name	Relative Frequency	Relative dominance	Relative density	IVI
1	*Protium serratum*	Burseraceae	Thadi	9.329446	12.93273	4.644809	26.90698
2	*Dipterocarpus alatus*	Dipterocarpaceae	Kanyin	6.316812	11.05378	2.459016	19.82961
3	*Tectona grandis*	Verbanaceae	Kyun	10.00972	3.661275	5.737705	19.4087
4	*Dillenia pentagyna*	Dilleniaceae	Zin-byun	5.344995	6.303373	4.644809	16.29318
5	*Schleichera oleosa*	Sapindaceae	Gyo	5.539359	6.614345	4.098361	16.25206
6	*Terminalia crenulata*	Combretaceae	Htauk-kyant	5.442177	5.773196	3.551913	14.76729
7	*Dalbergia oliveri*	Fabaceae	Tamalan	4.956268	3.532702	4.644809	13.13378
8	*Quercus glauca*	Fagaceae	Sagat	3.109815	3.107013	2.459016	8.675845
9	*Aporusa roxburghii*	Euphorbiaceae	Ye-mein	3.304179	1.618434	2.73224	7.654853
10	*Shorea siamensis*	Dipterocarpaceae	Ingyin	2.429543	2.983873	2.185792	7.599209
11	*Decaspermum parviflorum*	Myrtaceae	Taung-thabye	2.623907	1.822388	2.185792	6.632087
12	*Terminalia chebula*	Combretaceae	Phan-kha	1.846453	1.718025	2.73224	6.296718
13	*Xerospermum noronhianum*	Sapindaceae	Thit-nyo	1.749271	1.626335	2.73224	6.107847
14	*Lithocarpus truncata*	Fagaceae	Thit-e	1.846453	1.190721	1.912568	4.949742
15	*Careya arborea*	Lecythidaceae	Bambwe	1.846453	1.106894	1.912568	4.865915
16	*Sideroxylon burmanicum*	Sapotaceae	Thit-cho	1.263362	1.85515	1.639344	4.757856
17	*Sterculia foetida*	Sterculiaceae	Letkok	1.263362	1.460046	1.912568	4.635977
18	*Elaeocarpus floribundus*	Elaeocarpaceae	Thitpwe	1.166181	1.026215	1.912568	4.104964
19	*Syzygium kurzii*	Myrtaceae	Thabye-nyo	0.874636	2.054552	1.092896	4.022084
20	*Vitex glabrata*	Verbanaceae	Tauksha	1.360544	1.059515	1.36612	3.786179
21	*Schima wallichii*	Theaceae	Pan-ma	1.166181	1.514491	1.092896	3.773568
22	*Ficus auriculata*	Moraceae	Sin-chaw	0.874636	0.65251	1.912568	3.439714
23	*Pterospermum semisagittatum*	Sterculiaceae	Nagye	1.263362	0.585042	1.36612	3.214524
24	*Shorea obtusa*	Dipterocarpaceae	Thit-ya	0.971817	1.688312	0.546448	3.206578
25	*Mangifera caloneura*	Anacardiaceae	Taw-thayet	0.680272	1.064718	1.36612	3.11111
26	*Lannea coromandelica*	Anacardiaceae	Nabe	0.971817	0.922686	1.092896	2.9874
27	*Terminalia tripteroides*	Combretaceae	Thanpe	1.166181	1.054121	0.546448	2.76675
28	*Tetradium glabrifolium*	Rutaceae	Kyet-maok	0.874636	0.160622	1.639344	2.674602
29	*Myristica angustifolia*	Myristicaceae	Myauk-ma-kun-thwe	0.680272	0.615128	1.36612	2.66152

30	*Albizia lucidior*	Mimosaceae	Thanthat	0.680272	1.13281	0.819672	2.632754
31	*Albizia procera*	Mimosaceae	Thit-pyu	0.777454	0.473751	1.912568	2.617325
32	*Erycibe citriniflora*	Convolvulaceae	Eikhmwe	0.680272	0.750675	1.092896	2.523843
33	*Ficus rumphii*	Moraceae	Nyaung	0.485909	1.389485	0.546448	2.421841
34	*Berrya mollis*	Euphorbiaceae	Phet-wun	1.263362	0.332005	0.819672	2.41504
35	*Gardenia sootepensis*	Rubiaceae	Yingat	0.777454	0.261039	1.36612	2.404613
36	*Baccaurea sapida*	Euphorbiaceae	Kanaso	0.58309	0.441367	1.36612	2.390577
37	*Ficus hispida*	Moraceae	Kha-aung	0.680272	0.606927	1.092896	2.380095
38	*Dracontomelon dao*	Anacardiaceae	Ngar-bauk	0.194363	1.507139	0.546448	2.24795
39	*Lithocarpus dealbatus*	Fagaceae	Thit-e	0.485909	0.802378	0.819672	2.107959
40	*Premna latifolia*	Verbanaceae	Sate-hnan	0.485909	0.409535	1.092896	1.988339
41	*Hisbiscus grewiaefolius*	Malvaceae	Thitsho	0.485909	0.633811	0.819672	1.939392
42	*Bombax ceiba*	Bombacaceae	Letpan	0.291545	0.758977	0.819672	1.870195
43	*Gmelina arborea*	Verbanaceae	Yamane	0.485909	0.773821	0.546448	1.806177
44	*Garuga pinnata*	Burseraceae	Gyi Chote	0.58309	0.345324	0.819672	1.748087
45	*Tectona hamiltoniana*	Verbanaceae	Dahat	0.58309	0.253042	0.819672	1.655805
46	*Azadirachta indica*	Meliaceae	Tama	0.291545	0.798121	0.546448	1.636114
47	*Schima khasiana*	Theaceae	Laukya	0.485909	0.553936	0.546448	1.586293
48	*Ziziphus rugosa*	Rhamnaceae	Zi-ganauk	0.680272	0.181399	0.546448	1.408119
49	*Hunteria zeylanica*	Apocynaceae	Myinlaban	0.388727	0.174182	0.819672	1.382581
50	*Michelia champaca*	Magnoliaceae	Saga	0.58309	0.511155	0.273224	1.36747
51	*Dalbergia stipulaceae*	Fabaceae	Tamalan-new	0.388727	0.15658	0.819672	1.364979
52	*Grewia tiliifolia*	Tiliaceae	Tayaw	0.291545	0.095823	0.819672	1.20704
53	*Colona floribunda*	Tiliaceae	Phet-shat	0.291545	0.298434	0.546448	1.136427
54	*Hibiscus rosasinensis*	Malvaceae	Pan-swe-le	0.291545	0.289138	0.546448	1.127131
55	*Aporusa villosa*	Euphorbiaceae	Thit-sat	0.485909	0.31922	0.273224	1.078352
56	*Spondias mangifera*	Anacardiaceae	Gway	0.388727	0.118845	0.546448	1.05402
57	*Ficus glomerata*	Moraceae	Ye-thaphan	0.291545	0.192751	0.546448	1.030744
58	*Artocarpus chaplasha*	Moraceae	Taung-peinne	0.291545	0.175134	0.546448	1.013127
59	*Swintonia floribunda*	Anacardiaceae	Taung-thayet	0.097182	0.634289	0.273224	1.004695
60	*Celtis cinnamomea*	Ulmaceae	Kha-baung	0.485909	0.193062	0.273224	0.952194
61	*Diospyros ehretioides*	Ebanaceae	Aukchinsa	0.291545	0.361117	0.273224	0.925886
62	*Gynocardia odorata*	Flacoutiaceae	Kalaw	0.194363	0.348034	0.273224	0.815622
63	*Terminalia bellerica*	Combretaceae	Thit-seint	0.194363	0.067186	0.546448	0.807997
64	*Albizia odoratissima*	Mimosaceae	Thit-magyi	0.194363	0.063804	0.546448	0.804616
65	*Miliusa velutina*	Annonaceae	Thabut-gyi	0.194363	0.060419	0.546448	0.801231
66	*Dipterocarpus tuberculatus*	Dipterocarpaceae	In	0.194363	0.040043	0.546448	0.780855
67	*Mangifera indica*	Anacardiaceae	Thayet	0.097182	0.40338	0.273224	0.773786
68	*Antidesma bunius*	Euphorbiaceae	Kinbalin	0.194363	0.028653	0.546448	0.769464
69	*Tetrameles nudiflora*	Datiscaceae	Baing	0.194363	0.286408	0.273224	0.753996
70	*Morus alba*	Moraceae	Posa	0.194363	0.236862	0.273224	0.704449
71	*Malus* spp.	Rosaceae	Taw-Panthee	0.194363	0.236862	0.273224	0.704449
72	*Adina cordifolia*	Rubiaceae	Hnaw	0.291545	0.122871	0.273224	0.687641

73	*Diospyros burmanica*	Ebanaceae	Te	0.194363	0.157734	0.273224	0.625321
74	*Zanthoxylum acanthopodium*	Rutaceae	Thabye-sintpwar	0.097182	0.254081	0.273224	0.624487
75	*Cratoxylum pruniflorum*	Hypericaceae	Sa-thange-ohnauk	0.097182	0.200177	0.273224	0.570583
76	*Machilus villosa*	Lauraceae	Tha-but-thein	0.097182	0.157065	0.273224	0.527471
77	*Stereospermum grandiflorum*	Bignoniaceae	Thande	0.097182	0.155095	0.273224	0.525501
78	*Castanopsis tribuloids*	Fagaceae	Gon	0.194363	0.029228	0.273224	0.496815
79	*Uvaria cordata*	Annonaceae	Thabut-new	0.097182	0.110678	0.273224	0.481084
80	*Chukrasia velutina*	Meliaceae	Yinma	0.097182	0.068704	0.273224	0.439109
81	*Rinorea bengalensis*	Violaceae	Taw-okshit	0.097182	0.068704	0.273224	0.439109
82	*Dalbergia obtusifolia*	Fabaceae	Wun-byaung	0.097182	0.053764	0.273224	0.424169
83	*Syzygium grande*	Myrtaceae	Thabye-pinpwa	0.097182	0.036689	0.273224	0.407095
84	*Mahonia nepalensis*	Berberidaceae	Ta Khaing Lone Kway	0.097182	0.018794	0.273224	0.389199
85	*Caesalpinia crista*	Caesalpiniaceae	Met-lin	0.097182	0.018794	0.273224	0.389199
86	*Mucuna pruriens*	Fabaceae	Khwele-ya	0.097182	0.018794	0.273224	0.389199
87	*Croton oblongifolius*	Euphorbiaceae	Thetyin-gyi	0.097182	0.015532	0.273224	0.385938
88	*Melanorrhoea usitata*	Anacardiaceae	Thitsi	0.097182	0.014917	0.273224	0.385323
89	*Stereospermum suaveolens*	Bignoniaceae	Kywe-ma-gyo-lein	0.097182	0.014635	0.273224	0.385041
90	*Zanthoxylum* spp.	Rutaceae	Tazat	0.097182	0.014614	0.273224	0.38502
91	*Melastoma* spp.	Melastomataceae	Shar-mae	0.097182	0.014018	0.273224	0.384423