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The role of agroforestry-based community forests in curbing agricultural encroachment in state forests in Myanmar

Using an integrated approach for evaluation

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KURZFASSUNG

In Myanmar hat die Expansion der Landwirtschaft zu erheblichen Entwaldungen und zum Verlust von Waldbesitzrechten geführt, was permanenten Änderungen der Landnutzung zur Folge hat und die Wiederaufforstung erschwert. Zur Bewältigung dieses Problems führte die Regierung im Jahr 2013 eine politische Intervention ein, die die Einrichtung agroforstbasierter Gemeinschaftswälder (ACFs) in von Landwirtschaft beanspruchten Staatswaldgebieten vorsieht. Diese ermöglicht es den Landwirten, Agroforstwirtschaft zu betreiben und gleichzeitig ihre Landnutzungsrechte im Rahmen der bestehenden Verordnungen zu sichern. Trotz schwieriger Rahmenbedingungen wurde die landesweite Umsetzung der Politik ohne vorherige Evaluation oder wissenschaftliche Begleitung schnell vorangetrieben. Ziel dieser Dissertation ist es daher, die Wirksamkeit dieser forstpolitischen Maßnahme mit Schwerpunkt auf die Etablierung von ACFs in landwirtschaftlich genutzten Gebieten des Distrikts Taungoo in Myanmar zu evaluieren, wo Waldökosysteme als stark gefährdet gelten. Die Steuerung landwirtschaftlicher Expansion und Wiederaufforstungsmaßnahmen betrifft zahlreiche Akteure und ist mit vielfältigen sozialen Fragestellungen verbunden, insbesondere im Kontext der Subsistenzlandwirtschaft. Dies führt zu einer komplexen Problemlage, die über den rein forstwirtschaftlichen Bereich hinausgeht. Zur Evaluation wurde ein integrierter methodischer Ansatz gewählt, der Fernerkundungstechniken, Waldinventurmethoden sowie sozialwissenschaftliche Analysen umfasst.

Zunächst wurde der Einfluss der politischen Intervention auf landwirtschaftliche Nutzung und Waldflächenentwicklung auf Landschaftsebene mittels Landbedeckungsänderungsanalysen auf Basis von LANDSAT-Bilddaten aus den Jahren 2010, 2015 und 2020 sowie ergänzenden Wahrnehmungsanalysen unter Anwendung sozialwissenschaftlicher Methoden untersucht. Im Anschluss erfolgte die Erhebung von Daten im Bezug zur Teilnahme der Landwirte an der Umsetzung der ACFs mittels Fragebogenerhebung sowie die Bewertung der Wirksamkeit verschiedener ACF-Praktiken anhand der Messung von 42 Stichprobenflächen. Abschließend wurden die von den Landwirten wahrgenommenen Ökosystemleistungen der ACFs analysiert und deren tatsächlicher Beitrag durch Waldinventurdaten bewertet.

Die Waldbedeckungsanalyse zeigte einen kontinuierlichen Rückgang der Waldflächen im Untersuchungsgebiet von 62,8 % im Jahr 2010 auf 58,2 % im Jahr 2015 und 51,9 % im Jahr 2020. Gleichzeitig nahm die landwirtschaftlich genutzte Fläche von 9,5 % (2010) auf 14,5 % (2015) und 18,5 % (2020) zu. Diese Befunde deuten darauf hin, dass die politische Intervention keine wirksame Reduktion der landwirtschaftlichen Expansion oder der Entwaldung bewirken konnte. Zudem gaben 91 % bzw. 97 % der Befragten an, dass die Politik nicht dazu führte, dass sie ihre landwirtschaftlichen Praktiken veränderten noch Rodungen oder Neuansiedlungen verringerte. Insgesamt erwies sich die Politik als ineffektiv in der Eindämmung der Entwaldung auf Landschaftsebene.

Der zweite Teil der Studie zeigte eine geringe Beteiligung der Landwirte an den ACFs, wobei nur 79 % der Befragten diese umsetzten. Entscheidende Einflussfaktoren für die Beteiligung waren die Betriebsgröße sowie das Wissen über ACFs. Im Untersuchungsgebiet wurden vier Hauptpraktiken identifiziert: (i) Grenzbepflanzung, (ii) Bepflanzung von Waldparzellen, (iii) Anreicherungspflanzungen in degradierter Waldparzellen sowie (iv) Schutz degradierter Waldparzellen. Die Gestaltung und Artenauswahl wurde maßgeblich von der Forstbehörde (FD) bestimmt und die Einbeziehung der Landwirte war gering. Die Waldinventurergebnisse zeigten, dass die Baumdichte in den ACF-Parzellen das von der FD angestrebte Ziel von 150 Bäumen pro Acre (375 Bäumen pro Hektar) nicht erreichte.

Der abschließende Teil der Studie unterstrich die dringende Notwendigkeit, die Versorgungsleistungen der ACFs zu verbessern, da diese trotz hoher Relevanz für die Landwirte aktuell nur unzureichend erbracht werden. Zur Förderung der aktiven Beteiligung der Landwirte wird empfohlen, Mehrzweck- sowie kurzfristig einkommensgenerierende Baumarten anzubieten, um die Ökosystemleistungen entsprechend der Interessen der Landwirte zu maximieren. Zudem sollten Beratungsdienste und Plattformen zur Wissensvermittlung gestärkt werden. Abschließend empfiehlt die Studie, dass zukünftige Forschung einen integrierten multidisziplinären Ansatz verfolgt, wie etwa mit Fernerkundung, zusammen mit forst- und sozialwissenschaftliche Methoden, da sich dieser Ansatz für die Bewertung politischer Maßnahmen als besonders wirkungsvoll erwiesen hat.

ABSTRACT

In Myanmar, agricultural expansion has caused major deforestation and forest land title loss, leading to irreversible land-use changes that hinder reforestation. To address this issue, the government introduced a policy intervention in 2013. It includes establishing agroforestry-based community forests (ACFs) in encroached state forest areas, allowing farmers to practice agroforestry while securing their land tenure under existing community forestry regulations. Since then, despite questionable conditions for its success, the nationwide implementation of the policy has accelerated without evaluation or scientific evidence. Therefore, this dissertation aims to evaluate the policy focusing on ACF establishment in agricultural encroachment areas in Taungoo district in Myanmar, where forest ecosystems are critically endangered. Managing agricultural expansion and reforestation involves numerous stakeholders and associated social issues, particularly in the subsistence farming context, leading to a complex situation beyond the scope of forestry alone. An integrated approach was adopted for evaluation, involving remote sensing techniques, forest inventory methods, and social research analysis.

Firstly, the study assessed the impact of the policy intervention on agricultural encroachment and forest cover dynamics at the landscape level through land cover change analysis using LANDSAT images from 2010, 2015, and 2020, combined with perception analysis, including social research methods. Secondly, it assessed farmers' participation in ACF implementation using a questionnaire survey and evaluated the performance of different ACF practices by measuring 42 sample plots. Lastly, the study examined farmers' perceived importance of various ecosystem services from ACFs and evaluated their actual contributions through forest inventory data.

The land cover change analysis revealed a consistent decrease in forest cover in the study area over the study period, declining from 62.8% in 2010 to 58.2% in 2015 and 51.9% in 2020. Meanwhile, the agricultural area increased from 9.5% in 2010 to 14.5% in 2015 and 18.5% in 2020. These results indicate that the policy did not effectively reduce agricultural expansion or deforestation, despite variations in land cover change patterns. Additionally, 91% and 97% of respondents reported that the policy neither changed their farming practices nor reduced land clearing or new settlement. Overall, the policy was ineffective in controlling deforestation from agricultural encroachment at the landscape level.

The second part of the study showed low farmer participation in ACFs, with only 79% of respondents implementing them and key factors influencing participation were farm size and knowledge related to ACFs. In the study area, four main ACF practices were identified: (i) boundary planting; (ii) woodlot planting; (iii) planting trees in degraded forest remnants; and (iv) protection of degraded forest remnants. The Forest Department (FD) strongly influenced design and species selection, with low farmer inclusion. Forest inventory results revealed that tree densities in ACF plots did not meet the FD's target of 150 trees per acre (375 trees per hectare).

The final part of the study highlighted an urgent need to enhance the provisioning services of ACFs, given their currently low contributions despite being perceived as highly important by farmers. To encourage active farmer participation, the study suggested offering multipurpose and short-term income-generating tree species to maximize ecosystem services based on farmers' interests, alongside strengthening extension services and knowledge dissemination platforms. The study also recommended that future research adopt an approach integrating diverse disciplinary methods such as remote sensing, forestry, and social research methodologies, which has proven highly beneficial for policy evaluation.

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LIST OF ACRONYMS

ACF	Agroforestry-based community forest
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization
FD	Forest Department
MEA	Millennium Ecosystem Assessment
MONREC	Ministry of Natural Resources and Environmental Conservation
MoALI	Ministry of Agriculture, Livestock and Irrigation
NDC	Nationally Determined Contributions
NTFP	Non-Timber Forest Products
PPF	Protected Public Forests
REDD	Reducing Emissions from Deforestation and Forest Degradation
RF	Reserved Forests
ROI	Region of Interest
UNFCCC	United Nations Framework Convention on Climate Change

1 GENERAL INTRODUCTION

1.1 Background

Deforestation has been an urgent issue worldwide due to its negative consequences for human well-being and biodiversity (Faria et al. 2023). It impacts human livelihoods not only through the loss of tangible benefits but also in intangible ways. More importantly, deforestation has caused irreversible loss of biodiversity and forest ecosystem services, which are crucial for the sustainability of life (Chakravarty et al. 2012; Faria et al. 2023). It also impedes achieving Sustainable Development Goals (SDGs), especially for SDG 13 (Climate Action) and SDG 15 (Life on Land). According to the Food and Agriculture Organization (FAO), a total of 178 million ha of forest has been lost globally since 1990 (FAO 2020). From 2015 to 2020, the rate of deforestation was as high as 10 million ha per year (FAO 2020). Among them, the most serious deforestation is concentrated in tropical areas where 45% of global forests exist, and it occupied more than 90 % of total forest loss with an annual rate of 9.28 million ha per year in 2015–2020 (FAO 2020). In 2022 alone, the forest loss in the tropical domain was as high as more than 11 million ha (World Resources Institute 2023). Meanwhile, tropical forests are biodiversity hotspots, enriched with the most diverse and important species, playing crucial roles in various related ecosystems and the livelihoods of many indigenous and forest-dependent rural communities (Brandon 2014a). Therefore, the loss of forests in tropical regions has caused serious negative consequences on biodiversity, society, economy, and the environment over decades (Brandon 2014a; Hoang and Kanemoto 2021).

Therefore, many studies have been conducted to analyze the drivers and root causes of deforestation in tropical regions (Hosonuma et al. 2012; Jayathilake et al. 2021). Although they can vary according to the context of the countries, the major common proximate drivers of deforestation are agricultural expansion, mining, infrastructure extension, and urbanization, while political, social, economic, and technical conditions can affect deforestation as underlying factors (Kissinger et al. 2012; Hosonuma et al. 2012; Jayathilake et al. 2021). Among them, agricultural expansion is the most significant and common driver of deforestation worldwide, especially in tropical countries (Hosonuma et al. 2012; Curtis et al. 2018; Han and Huang 2021).

Agricultural expansion includes clearing forests for commercial-scale commodity production, livestock farming, and subsistence farming (Kissinger et al. 2012; Curtis et al. 2018; Acheampong et al. 2019; Han and Huang 2021). Based on the national data from 46 tropical and sub-tropical countries from 1990 to 2010, commercial agricultural expansion and subsistence agricultural expansion were major drivers of deforestation, accounting for 40% and 33% of deforestation, respectively (Hosonuma et al. 2012). Other studies have similarly identified commercial and subsistence agriculture as major drivers of deforestation (Curtis et al. 2018; Jayathilake et al. 2021). Specifically, Kissinger et al. 2012 identified commercial agriculture as a main driver of deforestation in Latin America, while both commercial and subsistence agriculture account significantly for deforestation in Africa and tropical and sub-tropical Asia. From 2010-2020, Southeast Asia alone experienced an annual deforestation rate of 941,000 ha per year and suffered a 15% decline in total forest cover from 1990 to 2019 (FAO 2020; Turner and Snaddon 2023). Crop production, including shifting cultivation, was again identified as a significant driver of deforestation from 1980 to 2010 (Imai et al. 2018). In summary, deforestation due to subsistence agriculture has been pronounced in regions of Africa and Southeast Asia.

On the other hand, subsistence agricultural expansion often involves poor and landless people encroaching on forests, making it challenging for governments to prioritize strict enforcement of rules over addressing their livelihoods (Colchester 2006). As a consequence, many governments, especially in Southeast Asia and Africa, have been struggling to resolve the issue of encroached agricultural areas and settlements in state forests, where a dilemma exists between meeting the socioeconomic needs of marginalized communities and ensuring the sustainability of forests (Iftekhar and Hoque 2005; Arowosoge Oluwayemisi Grace 2015; Yurike et al. 2021; Phiri et al. 2023). Colchester (2006) already pointed out that relying solely on the law enforcement approach is insufficient to address the issue.

Despite the complexity and significance of the issue, studies on different approaches to coping with the issue are still very limited. Therefore, the study attempts to evaluate an approach implemented by Myanmar, a Southeast Asian country, to handle the agricultural expansion or encroachment in state forests. Since 2013, Myanmar has been establishing agroforestry-based community forests (ACFs) in agricultural encroachment areas in state forests for that purpose (FD 2013a). In this strategy, farmers practicing rain-fed dryland agriculture, locally known as 'Ya', in the state forests are required to plant a minimum of 150 trees per acre (375 trees per ha) in their encroached agricultural land. These planted areas are designated as community forests and granted to farmers with 30-year land use rights.

To evaluate Myanmar's approach, the study used integrated interdisciplinary methods at multi-level forest management, focusing on the landscape, community forest, and individual levels, aiming to assess the approach's outcome and extract lessons of this approach in curbing agricultural encroachment in forests. The study employed land cover change analysis using Landsat imagery, quantitative and qualitative analysis of household survey data, and stand characteristics, above-ground biomass, and vegetation cover calculation derived from forest inventory data. The study also adopted the theoretical framework of ecosystem services, integrating both ecological and socio-economic perspectives on the benefits of ACFs, and considered the relevance of achieving the Sustainable Development Goals (SDGs).

1.2 Objectives

1.2.1 General objective

The main objective of the study was to evaluate Myanmar's approach to establishing ACFs in areas of agricultural encroachment within the state forests. Based on the analysis results, the study aimed to provide recommendations to policymakers for improving current agricultural encroachment management and to ensure both ecological and socio-economic benefits from ACFs.

1.2.2 Specific objectives

The specific objectives were as follows:

i. To evaluate the policy intervention on agricultural encroachment dynamics at the landscape level (see Chapter 4)

ii. To understand the farmers' perspective on participation and local implementation of ACFs (see Chapter 5), and

iii. To assess farmers' perceived importance of ecosystem services and the actual benefits of ACFs (see Chapter 6)

1.3 Structure of the thesis

The structure of the dissertation consists of eight main chapters and appendices. Chapter 1 introduces the background of the research, the rationale and objectives of the study, and the structure of the dissertation. Chapter 2 presents the state-of-the-art of the study, while Chapter 3 outlines the general methodology of the research and provides an overview of the study area. Chapters 4, 5, and 6 are the analytical chapters linked to the objectives outlined in Section 1.2.2, and their associated publications are listed in Table 1.1. Additional publications work during this research project, but are not essential working packages of the dissertation, are summarized in Table 1.2. Chapter 7 provides the synthesis of the results from specific objectives from the analytical chapters, and Chapter 8 concludes and gives an outlook on the research. Supplementary information essential to the research findings is included in the Appendices after that.

Table 1.1: Authorship and specific contributions

Author and title	Journal	Status of publication	Specific contribution of the thesis author
San, S. M., Kumar, N., Biber-Freudenberger, L., & Schmitt, C. B. *Policy Evaluation and Monitoring of Agricultural Expansion in Forests in Myanmar: An Integrated Approach of Remote Sensing Techniques and Social Surveys.* https://doi.org/10.3390/land13020150	Land, 13(2), 150	Published, 2024	• Lead author • Development of ideas and research design • Data compilation and analysis • Writing and revision of the manuscript
San, S. M., Kumar, N., Biber-Freudenberger, L., & Schmitt, C. B. *Agroforestry-based community forestry as a large-scale strategy to reforest agricultural encroachment areas in Myanmar: ambition vs. local reality.* https://doi.org/10.1186/s13595-023-01191-x	Annals of Forest Science, 80(1), 27.	Published, 2023	• Lead author • Development of ideas and research design • Data compilation and analysis • Writing and revision of the manuscript
San, S. M., Kumar, N., Biber-Freudenberger, L., & Schmitt, C. B. *Toward successful implementation of Agroforestry-based Community Forests in Myanmar: Using the ecosystem services approach to include farmers' perception*	Tree, Forests, and People	Submitted, 2025	• Lead author • Development of ideas and research design • Data compilation and analysis • Writing and revision of the manuscript

Table 1.2: Additional publications work during this project, but are not essential working packages of the dissertation

Author and title	**Journal/Book/Report**	**Status of publication**	**Specific contribution of the thesis author**
Oo, T. N., Hlaing, E. E. S., Aye, Y. Y., Chan, N., Maung, N. L., Phyoe, S.S., Thu, P., Pham, T.T., Maharani, C., Moeliono, M., Gangga, A., Dwisatrio, B., Kyi, M.K.M., **San, S.M.** *The context of REDD+ in Myanmar: Drivers, agents and institutions*. https://doi.org/10.17528/cifor/007556	CIFOR Occasional Paper No. 205.	Published, 2020	• Development of ideas • Writing and revision of the manuscript
San S. M., Quartucci F., and Oluoch W. A. *Forest land degradation and restoration: lessons from historical processes and contemporary advances.* https://doi.org/10.1016/B978-0-12-823895-0.00017-8	In: G.S. Bhunia, U. Chatterjee, Kashyap, P.K. Shit (eds.): Land Reclamation Restoration Strategies for Sustainable Development: Geospatial-Based Technology Approach	Published, 2021	• Development of ideas and research design • Data compilation and analysis • Writing and revision of the manuscript
Poscher, B., & **San, S. M.** Forest cover dynamics and community forest management in the Himalayan and dry zone region of Myanmar: a SWOT analysis. https://doi.org/10.1201/9781003268383-21	In: Parida, B. R., Pandey, A. C., Behera, M. D., & Kumar, N. (eds.): Handbook of Himalayan Ecosystems and Sustainability, Volume 1, 317-340	Published, 2022	• Development of ideas and research design • Data compilation and analysis • Writing and revision of the manuscript

2 STATE OF THE ART

2.1 Deforestation in Myanmar

Myanmar had a total forest coverage of 2.85 million hectares, which is equivalent to 42.19% of the country's total area in 2020 (FAO 2020). However, between 2010 and 2020, Myanmar lost 290,000 hectares of forest annually, making it the 7th highest deforested country in the world (FAO 2020). Similar to other tropical countries, many studies identified agricultural expansion as the most significant driver contributing to the high rate of deforestation (Lim et al. 2017; Oo et al. 2020; Naing Tun et al. 2021). It was pointed out that around 74% of the total lost forested areas were transformed into agricultural land during 1988-2017 (Yang et al. 2019). A recent study analyzed the land cover change in Myanmar during 2000-2020 and revealed that most areas (67%) of total cropland expansion occurred in the deciduous broad-leaved forest (Wang et al. 2023).

Many studies have highlighted large-scale agricultural concessions related to agricultural-driven deforestation in Myanmar (Woods 2015; Oo et al. 2020). Wood (2015) mentioned that there was an increase of 170% in agricultural concession areas during 2010-2013 (Woods 2015). One main reason behind this was due to the goal of the Ministry of Agriculture, Livestock and Irrigation (MoALI)'s Master Plan for the Agriculture Sector (2000-01 to 2030-31) to expand 10 million acres of agricultural land for increasing production of rubber, oil palm, paddy, pulses, and sugarcane (Oo et al. 2020). Often, the agricultural concession areas were allocated in heavily forested areas of Myanmar (Donald et al. 2015). However, it was noted that those areas were frequently subjected to logging without being converted to agricultural use (Woods 2015). For example, less than 25% of total concession areas were converted into agricultural land during 2012-2013 (Woods 2015). Therefore, attention should be directed not only towards large-scale agricultural concessions but also towards the expansion of smallholder agriculture in forests, which contributes to deforestation causing permanent land cover change to agriculture. In 2016, Chan et al. mapped shifting cultivation areas at the country level and 100,311 ha were detected (Chan et al. 2022). However, it was a cross-sectional study and did not reflect temporal dynamics (Chan et al. 2022; Chen et al. 2024). Most studies related to agricultural-driven deforestation, with detailed analysis of small and large-scale commercial agriculture, were conducted at regional and local levels (Win et al. 2009; Shimizu et al. 2017a; Myint 2018; Chen et al. 2024). Apart from that, specific studies related to the contribution of small-scale or subsistence agriculture to deforestation are limited, especially at the country level.

2.2 Forest classification in Myanmar

All forest land in Myanmar is considered formally under state property (NEPCon 2013). The Forest Department (FD), which operates under the Ministry of Natural Resources and Environmental Conservation (MONREC), is the responsible state agency for managing forests (FD 2020a). However, not all forested areas fall under the management of the FD. According to the forest law (2018), the FD holds legal rights to manage only forested areas under the categories of reserved forests (RF) and protected public forests (PPF) (MONREC 2018). RFs are strictly regulated, and the public has no right to harvest forest products unless specifically permitted by the government. In contrast, in PPFs, the public may be allowed to harvest certain forest products under regulated conditions (MONREC 2018; FD 2020a). The total areas of state forest managed by the FD can be seen in Table 2.1. Additionally, protected areas are established for biodiversity and ecosystem conservation purposes and also fall under the authority of the FD. Those strictly protected areas include wetlands, lakes, and other important habitats for biodiversity and can exist within or outside of RFs and PPFs. Apart from areas authorized by the FD, the remaining forest-covered areas are referred to as "public forests" or "unclassified" forests (MONREC 2018). In 2017, forest cover areas outside the state forests were estimated as 211,977 km^2 (around 31% of the country's area) (Lwin et al. 2020). Usage rights for these areas can be acquired by other government departments, organizations, or individuals, enabling them to convert forests for alternative land uses (von der Mühlen 2018).

Table 2.1: Extent of state forests (Permanent Forest Estate) areas in Myanmar (FD 2020a)

Type of forests	Area (ha)	Percentage of the country
Reserved Forests (RF)	12,020,011.8	17.8%
Protected Public Forests (PPF)	5,224,273.5	7.8%
Total RF & PPF (State forests)	17,244,285.3	25.6%

In this dissertation, the term 'state forests' will be used to denote areas comprising both RF and PPF for clarity and to distinguish them from "public" or "unclassified" forests.

The effectiveness of forest management in state forests compared to unclassified forests at the country level has been highlighted by a lower deforestation rate within state forests than outside of them during 2006-2017 (Lwin et al. 2020). Given the significance of delineating state forests to safeguard against forest conversion for other land uses, the Myanmar FD has prioritized efforts to expand state forests. Not only in the country's national-level agenda (FD 2024), but also in international commitments, such as in Nationally Determined Contributions (NDC) submitted to the United Nations Framework Convention on Climate Change (UNFCCC), Myanmar has targeted to expand state forests up to 30% of the country's area (FD 2020a; UNFCCC 2023).

2.3 Legal framework and policy for agricultural encroachment management

According to the forest law (2018), any kind of encroachment, including settlements and clearing the forests for agricultural activities, is strictly forbidden in state forests. Under 'Chapter XII: Offences and Penalty' of the forest law, encroaching and domesticating animals in state forests is punishable with imprisonment not exceeding 1 year or with a fine not exceeding 300,000kyats (~220 USD) (MONREC 2018). However, forests have been gradually cleared and changed into different land uses for decades, especially during the military regimes, as a consequence of weak law enforcement and unclear land use policies among different sectoral departments (von der Mühlen 2018). Between 2010 and 2013, numerous disputes emerged between farmers' land use rights and forest conservation interests, causing debates in parliament (Ananda 2012). Based on the debate related to land tenure conflicts in the Parliament, the FD developed a policy intervention (President's Office 2013). The first action of the policy intervention was to review the encroachment status in state forests through a countrywide survey. The survey results in 2013 showed that around 7401 km^2 of the state forests had been encroached on and changed into different land use categories (FD 2013a). Based on the survey results, the FD handed over village areas, along with their paddy fields, and religious and communal areas to relevant departments such as the General Administration Department and Department of Agriculture, Land Management and Statistics (FD 2013a). The rest of the area, categorized as rain-fed dry farms (locally known as 'Ya'), spanning around 344,989 ha, was planned to be reforested through ACF establishment (FD 2013a).

2.4 Concept of agroforestry-based community forests (ACFs) in Myanmar

The implementation of ACFs in Myanmar involves two key concepts: agroforestry and community forestry. Agroforestry represents a planting practice, while community forestry serves as a governance strategy.

The Centre of World Agroforestry originally adopted the definition of agroforestry, which is "Agroforestry is a collective name for land-use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land-management unit. The integration can be either in a spatial mixture or in a temporal sequence. There are normally both ecological and economic interactions between the woody and non-woody components in agroforestry" (Leakey 1996). It was pointed out that agroforestry should be viewed as more than a set of distinct prescriptions for land use because of its potential to mitigate deforestation and reduce land degradation, and poverty alleviation (Leakey 2017). It was proposed to consider agroforestry as "*a dynamic, ecologically based, natural resource management system that, through the integration of trees in farm and rangeland, diversifies and sustains production for increased social, economic, and environmental benefits*"(Leakey 2017). Sinclair (1999) highlighted that agroforestry practices should not be restricted to the integration of woody and non-woody components due to the ambiguity of labelling between trees and crops, as some agricultural species can themselves be plantation tree crops. The definition of agroforestry has been formulated in various ways and discussed throughout the past decades (Lundgren and Raintree 1983; McAdam et al. 2008; Nair 2013; Atangana et al. 2014a; Leakey 2017). Although various definitions can differ in many aspects, agroforestry can simply be conceptualized as a practice where perennial trees are introduced or managed in different spatial or temporal arrangements on the farm (Atangana et al. 2014a). Understanding the general concept of agroforestry is more important than defining the term exactly (Nair et al. 2017). Based on the general agroforestry concept, Myanmar's reforestation of agricultural encroachment areas can be viewed as introducing agroforestry practices in agricultural areas.

In the ACF implementation, the agroforestry areas in state forests are governed and managed according to the community forestry instructions. In Myanmar, community forestry instructions serve as a fundamental framework for establishing community forests (FD 1995; Lin 2005). Under community forestry instructions, a community forest user group must be formed for each community forest with the participation of interested local households (FD 2018). In the context of ACFs, community forest user groups are formed with encroaching farmers. The collective agroforestry areas of each farmer are recognized as community forests, even though the individual farmers manage their separate agroforestry plots. After forming user groups, the members have to develop a management plan outlining how to establish and utilize the benefits of ACF areas (FD 2018). The ACF management committee, organized by some members of ACFs and local FD, is responsible for the management and monitoring of the ACFs. Upon successful application to the FD, local user group members receive a certificate that allows them to manage and use the designated area of ACFs for 30 years, with the possibility of extension (FD 2018). Through this means, the FD intends to enable communities to retain their user rights and land tenure. On the other hand, agricultural encroachment areas in state forests are expected to be reforested through agroforestry practices.

2.5 Rationale and implementation status of ACFs in Myanmar

In Myanmar, of all the total forested areas of the country (42.19%), only 25.49 % of the country's total area has been entitled to state forests till 2020, while the rest of the forests are not under the management of the FD (MONREC 2020). Therefore, the FD is currently putting effort into meeting the NDC target of increasing state forest areas up to 30% of the country. Since encroachment in forests caused not only forest cover loss but also threatened forest land titles, the FD prioritized implementing reforestation in agricultural encroachment areas, introducing ACFs (FD 2013a, 2020b).

In the procedures of establishing ACFs in agricultural encroachment areas, the FD issued one additional instruction to the current community forest instructions (FD 2018) that farmers have to plant at least 150 trees per acre (~375 trees per hectare) in their encroachment areas (FD 2013a). Apart from that, all procedures and instructions are the same of the previously existing community forest establishment. However, the nature of ACFs in agricultural encroachment areas differs from the usual community forests in many aspects. One of the important aspects is that the management of forests in encroachment areas is mainly individual-based rather than community-based, as agricultural encroachment areas have already been demarcated informally into individual ownerships (San and Hlaing 2019). Moreover, within ACFs, farmers are required to integrate trees into their farms, potentially leading to trade-offs in their annual income. This differs from conventional community forests, typically situated on communal degraded or non-degraded forested lands, where their agricultural income and crop production remain undisturbed. Lastly, contradicting the nature of community forests, which is usually based on farmers' motivation and interest, encroaching farmers are obligated to establish ACFs to avoid legal consequences, reflecting a top-down approach.

Despite the numerous potential issues associated with policy implementation in encroachment areas, particularly concerning participation, the FD has been implementing it at a nationwide scale since 2013 without evaluating the current approach or outcomes. During 2014-2019, 129,200 hectares were registered as ACF implementing areas covering 19% of the total encroached area in state forests. Those ACF areas represent 55% of total community forest establishment from 1995 to 2019 (Figure 2.1).

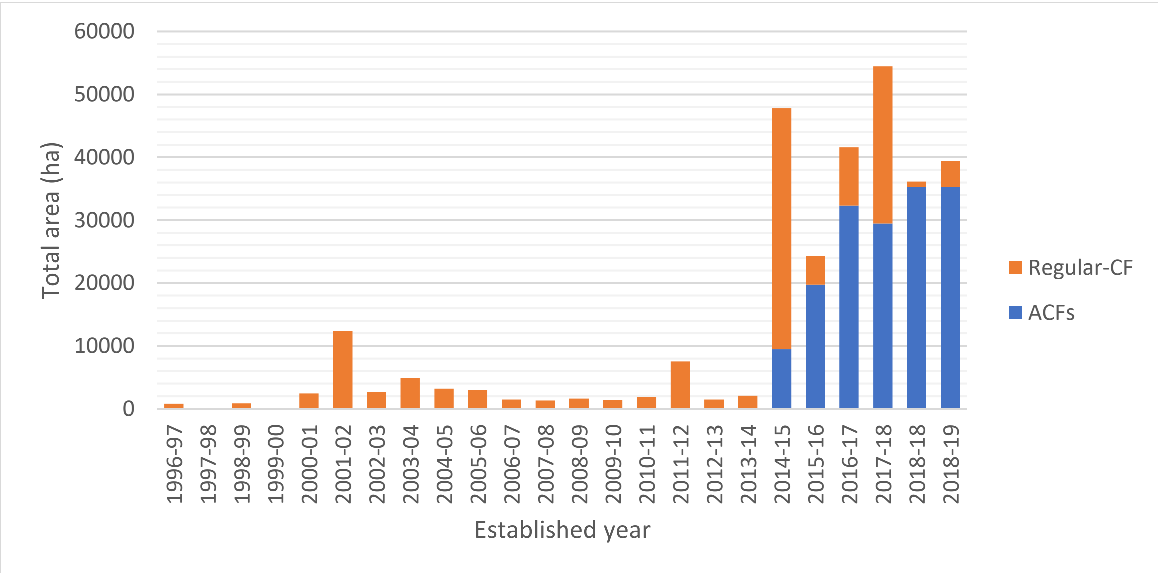

Figure 2.1: Yearly establishment areas of community forests in Myanmar (FD 2020b). (Regular-CF: community forests following normal procedures, ACFs: Agroforestry-based community forests in agricultural encroachment areas)

3 GENERAL METHODOLOGY

3.1 Study Area

3.1.1 Description of the study area

The study was conducted in Taungoo district, which is situated as part of the Bago mountain range (Bago-Yoma) in the Bago region in central Myanmar. This study area was selected due to the high rate of deforestation due to agricultural encroachment, the dependency of local people on forests, and its ecological significance. The district is located between 18°8′ and 19°20′ N and 95°50′ and 96°45′ E. The district includes a lowland plain in the center, which is surrounded by mountain ranges, and hence, the elevation ranges from 5 to 1884 m above the mean sea level (Figure 3.1).

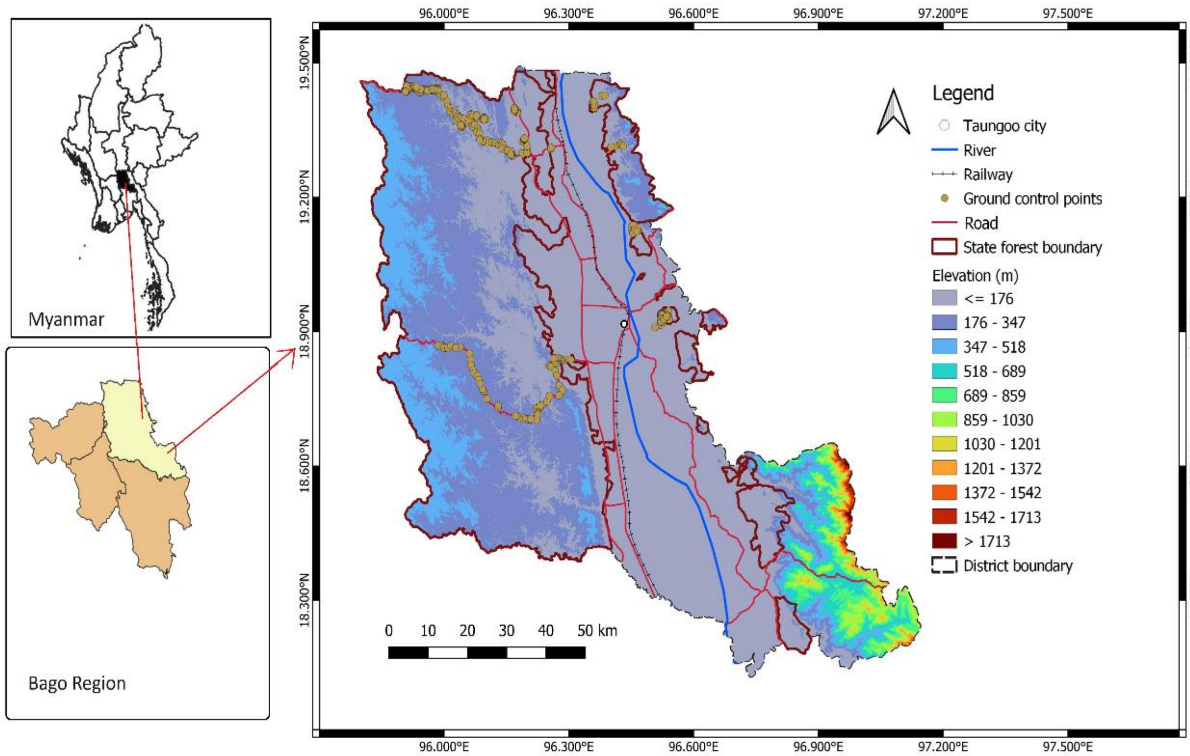

Figure 3.1: Location of the Taungoo District and the study area (State Forests) (Source: FD 2020, State Forest boundary, unpublished); see also in (San et al. 2024).

The study area has a tropical monsoon climate characterized by heavy seasonal rainfall during May and October considered the rainy season. The rest of the year, between November and May, is considered a dry period and experiences high temperatures. The temperature of the district ranges between 21°C and 32°C with average annual precipitation between 2500 mm and 3000 mm (FD 2015). The soil in the study area is categorized as yellow-brown forest soil and yellow-brown Indaing soil (Mon 2016).

Land uses

The total area of the district is 1,067,700 ha, and around 52.4% of the district area is state forests managed by the FD (FD 2015). Forested areas are located in the mountainous part of the districts, while the lowland plain is mainly occupied by agricultural land and settlements. As the study focuses on the ACF establishment in encroached agricultural areas in state forests, the analysis areas of the study will cover only state forest areas by excluding the areas of the district outside the state forests. In the state forests, different land uses, including forest plantations, shifting cultivation, encroached agricultural areas, fallow agricultural areas, and settlements, can still be found in addition to degraded and primary natural forests (Mon 2016; Chan et al. 2016; Thet and Tokuchi 2020).

Forest types

The forest types in Bago Yoma include upper moist and dry mixed deciduous forests according to forest type classification by Myanmar FD (FD 2015; Biswas et al. 2020). Meanwhile, they are also categorized as semi-evergreen forests, referring to they are primarily deciduous with some occurrence of evergreen elements (Kress et al. 2003; Murray et al. 2020). It is also known as the 'Home of Teak' as it was originally predominated by naturally grown Teak trees (Kyaw et al. 2020). Other commercially important hardwood tree species, such as *Xylia xylocarpa* R., and *Pterocarpus macrocarpus* K.*,* are also native to the study area (FD 2015). Bamboo widely occurs along with native species throughout the region, especially in areas of degraded forests and fallow land (Thein et al. 2007; Chan et al. 2016; Murray et al. 2020).

Livelihoods and resource dependency of local people

In 2015, the total population in the district was approximately 1.1 million (FD 2015). Among them, the majority, around 79.4% live in rural areas while the rest 20.6 % reside in urban areas (Department of Population 2017). According to the 2014 census data in Myanmar, the primary source of employment for around 38% of households in the district was categorized under the agriculture, forestry, and fishing sector (Department of Population 2017). The common agricultural practice in the district, particularly in the lowland areas, is paddy rice farming.

Regarding the forestry sector, households in the district have a high dependency on forests. It was reported that a majority, 72%, of total households depend on firewood, while 16% rely on charcoal for cooking (Department of Population 2016). Rural households in the study area, particularly those settling within the state forests, have a high dependency on non-timber forest products (NTFPs) for their livelihood, especially through charcoal making and bamboo harvesting (Soe and Yeo-Chang 2019a). Collecting other NTFPs such as bamboo shoots, medicinal plants, roofing materials, and Elephant Yam (*Amorphophallus paeoniifolius*) is also very common and essential for rural forest-dwelling households (Khaine et al. 2014).

Status of forests and their ecological significance

The study area played an important role in supplying timber to the state; the total legal harvested amounts between 2006-07 to 2015-16 were as high as 191,949 cubic tons from 134,887 Teak trees and 907,183 cubic tons from 634,751 hardwood trees (FD 2015). Due to intensive legal logging followed by illegal logging, the area suffered from high forest degradation (Kant et al. 2014). Therefore, legal timber harvesting in Bago Yoma has been banned for 10 years, starting from the government fiscal year of 2016-17 (Shimizu et al. 2017a); however, illegal logging continued (Frontier 2023). The annual deforestation rate of Bago Yoma was estimated at around 0.5% per year during the last decades (Kant et al. 2014). Illegal logging (59.8%), water invasion due to dams (14.6%), encroachment due to farming (10.4%), forest clearance for the establishment of plantations (8.4%), and settlements (6.8%) were found as the main disturbance agents of forest change in Bago-Yoma during 2000-2014 (Shimizu et al. 2017a). As logging was mainly done by selective logging with elephants or buffalo, it contributed to forest degradation; however, flooding by the dam, agricultural encroachment, and settlement caused deforestation and permanent forest cover loss. While agricultural expansion was claimed as the main driver of deforestation in the study area (Kant et al. 2014), 8759 ha of agricultural encroachment areas (dry farms excluding paddy fields) were reported at the FD in 2016. Of these, around 4479 ha have been registered and appear to be reforested as ACFs according to the registry data from the FD (FD 2020b).

In addition to high deforestation, the above-mentioned human disturbances have extensively degraded the primary forests of Bago Yoma, resulting in dense bamboo regrowth that limits the establishment of primary tree species (Murray et al. 2020). This degradation threatens the existence of the Bago Yoma forest ecosystem, which still supports small populations of large mammals such as the Leopard (*Panthera pardus*), Sambar (*Cervus unicolor*), Gaur (*Bos gaurus*), Banteng (*Bos javanicus*), and Asian Elephant (*Elephas maximus*) (Hein et al. 2020; Murray et al. 2020; Varma et al. 2024). As a result, the Bago Yoma forest ecosystem was classified as a critically endangered ecosystem in Myanmar on the Red List of the International Union for Conservation of Nature (IUCN) in 2020, highlighting its ecological importance and deteriorating condition (Murray et al. 2020).

3.2 Research methods

The study adopted the theoretical framework for analyzing the sustainability of social-ecological systems developed by Ostrom (2009). The framework analyzes at different resource management levels, focusing on resource systems, resource units, governance systems, and users as main components, and also investigates interactions among different components and outcomes (Ostrom 2009). Following the framework, the study applied a multi-level evaluation approach that integrated various disciplinary methods for both data collection and analysis to achieve the overall objectives of the dissertation. Multi-level studies provide a holistic perspective with appropriate solutions for each analytical level (Clement 2008; Ostrom 2009; Kadam 2022; Hess 2022). Therefore, the study began with analysing the landscape level (Chapter 4), then focuses on the community forest level (Chapter 5), and concludes with an exploration of farmers' perceptions at an individual level (Chapter 6).

In addition, the benefits of interdisciplinary analysis have been proven in other studies, as it helps address complex research questions and broad issues, providing comprehensive results by integrating perspectives from different disciplines (Klein 1990; Graw 2015). In the context of curbing agricultural encroachment in state forests, it involves various biophysical and socio-economic aspects, creating a complex situation. Therefore, for each analytical level of the study, different disciplinary methods were integrated to incorporate diverse perspectives and provide detailed explanations (Table 3.1). The dataset supporting the findings of this study is available at DOI: 10.5281/zenodo.17877188 and DOI: 10.5281/zenodo.8005342.

Table 3.1: Summary of the research methods of data collection and analysis used in the dissertation

Chapter	Data sources	Analysis methods	Chapter section
4	Landsat Images, Household survey	Quantitative and qualitative (Land cover change analysis, descriptive statistics)	4.3.
5	Household survey, Forest Inventory	Quantitative and qualitative (Binary logistic regression, stand characteristics calculation, descriptive statistics)	5.3.
6	Questionnaire survey, Forest Inventory	Quantitative and qualitative (Partial proportional odds model, descriptive statistics, co-occurrence analysis, above-ground biomass calculation, vegetation cover analysis)	6.3.

4 POLICY EVALUATION AND MONITORING OF AGRICULTURAL EXPANSION IN FORESTS IN MYANMAR: AN INTEGRATED APPROACH OF REMOTE SENSING TECHNIQUES AND SOCIAL SURVEYS

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4.1 Abstract

Agricultural expansion is the main driver of deforestation in Myanmar. We analyzed the effectiveness of a national policy intervention on agricultural encroachment in state forests in Taungoo District in Myanmar from 2010 to 2020. The policy aims to stop agricultural encroachment and reforest encroached areas through farmers' participation in an agroforestry community forestry. We applied an integrated approach that involved a land cover change analysis together with a household survey about encroachment behavior. The remote sensing analysis for the years 2010, 2015, and 2020 showed the land cover change pattern and an increase in agricultural encroachment from 9.5% to 18.5%, while forests declined from 62.8% to 51.9%. The survey showed that most farmers (91%) believed that the policy intervention did not lead to a change in their encroachment behavior or farm size. The main reasons that incentivized encroachment were stated to be livelihood needs, immigration due to marriage, and increased accessibility due to road construction. The main reason for reducing encroachment was plantation establishment, leading to a loss of land for encroaching farmers. In conclusion, the integrated approach showed that the policy intervention did not decrease encroachment, whereas other factors influenced encroachment behavior. We recommend solving interministerial conflicts of interest related to encroachment in Myanmar and using an integrated approach for future studies.

Keywords: deforestation; encroachment; perception; land cover change; forest policy

4.2 Introduction

Deforestation and forest degradation are among the major global challenges contributing to biodiversity loss and climate change. At the same time, forests are relevant for human well-being, particularly in many countries of the Global South, where local communities are directly dependent on the benefits of forest ecosystems, including the provisioning of timber and non-timber products, as well as many regulating services, such as flood protection and climate regulation. Addressing deforestation is therefore not only relevant to Sustainable Development Goals (SDGs) 15 (Life on land) and 13 (Climate Action) but to the sustainability agenda overall. The drivers of deforestation and forest degradation can be diverse and variable in different local contexts (Curtis et al. 2018; Jayathilake et al. 2021). However, one of the main drivers of deforestation in many parts of the world, in particular in forests with high biodiversity value in the Global South, is agricultural expansion (Kissinger et al. 2012; Jayathilake et al. 2021). In the context of agricultural expansion, commercial agriculture stands out as the main driver of deforestation in the Americas, while both subsistence and commercial agriculture are the main drivers of deforestation in Africa and tropical Asia (Kissinger et al. 2012; Jayathilake et al. 2021).

Similar to other tropical countries, deforestation in Myanmar has been driven by agricultural expansion due to commercial commodity production (e.g., rubber and oil palm), as well as subsistence agriculture (i.e., shifting cultivation and small-scale agricultural encroachment by farmers) (Lim et al. 2017; Oo et al. 2020; Naing Tun et al. 2021). According to the existing Myanmar Forest Law (2018), forests may only be used for non-timber collection, and the establishment of new settlements and farming is strictly prohibited in state forests (MONREC 2018). The Forest Department (FD) is responsible for enforcing and monitoring this law (MONREC 2018), but poor governance, an unstable political situation, corruption, poverty, and population growth have limited the effectiveness of this law, leading to continued high levels of deforestation due to agriculture, even in state-managed forests (Lim et al. 2017; Oo et al. 2020). Furthermore, conflicting interests between the Ministry of Agriculture, Livestock and Irrigation (MoALI), which supports an increase in arable land, and the Ministry of Natural Resources and Environmental Conservation (MONREC), which aims to reduce deforestation and expand forest lands, undermine coherent intervention efforts. Once a forest land title is converted into an agricultural land title and subsequently managed under the MoALI, the land title change becomes practically irreversible, and the FD loses the right to intervene, e.g., through reforestation. Therefore, agricultural expansion in state forests has been a serious threat to the forests of Myanmar, causing permanent deforestation.

While the Myanmar FD is dedicating intensive efforts to expand state forests to meet the target of 30% of the country's area as mentioned in the nationally determined contributions submitted to the UNFCCC, many conflicts between the land use rights of farmers and the interests of forest conservation have become apparent, leading to intensive debates in parliament between 2010 and 2013 (Ananda 2012). To resolve this conflict, the government issued a policy intervention in 2013 that included instructions to survey encroached areas in state forests, degazette established paddy fields from forest to agriculture, and reforest rainfed agricultural areas through agroforestry community forests (President's Office 2013).

Despite the promotion of agroforestry community forests for reforestation on agricultural land, these efforts have fallen short of expectations, as highlighted by San et al. (2023b), who conducted the only study reported to date on the effectiveness of the policy on agricultural encroachment of forests in Myanmar. The importance of monitoring and evaluating policy implementation for effective forest management has been highlighted in many previous studies (Ghate and Nagendra 2005; Blackman 2013). However, given the limited availability of financial and human resources, monitoring agricultural encroachment in forests and evaluating the effect of forest policies pose significant challenges (Zeng et al. 2018; Pham et al. 2019; Trends 2021). To overcome the challenges associated with the need for substantial investment of manpower and money for effective monitoring, remote sensing has been proposed as a cost- and time-effective tool for sustainable forest management (Nandasena et al. 2022). Blackman (2013) also suggested remote sensing as a low-cost method to conduct ex post analysis of forest policies (Blackman 2013).

However, its limitations lie in its ability to capture context-specific explanations and social issues crucial for refining policies and their implications (Walker and Peters 2007). To address this shortcoming, Ishtiaque et al. (2020) suggested the integration of remote sensing techniques with social science methodologies as a promising approach to deal with social challenges in forest management (Ishtiaque et al. 2020). In order to evaluate the effectiveness of the policy intervention in changing the behavior of farmers, social data, including the reasons for increasing or decreasing encroachment activities and farmers' perceptions, are necessary to provide a deeper comprehension. The usefulness of the integrated approach in forestry research has also been demonstrated in previous studies (Kimutai and Watanabe 2016; Tripathi et al. 2020).

Hence, in this study, we intend to analyze land cover change and agricultural encroachment dynamics before and after the policy intervention to evaluate its effectiveness at the landscape level. The study provides a holistic and thorough evaluation of the policy related to agricultural encroachment in the state forests of Myanmar at the landscape scale. We apply an integrated approach using a land cover change analysis based on remote sensing techniques together with social data analysis, including a survey of local farmers. The results of the study have the potential to contribute to the effective monitoring and management of agricultural encroachment in Myanmar, as well as other tropical countries facing similar challenges and constraints.

4.3 Materials and methods

4.3.1 Methodological approach

In evaluating the effects of the forest policies, Blackman (2013) reviewed different approaches applied in previous studies. A common approach is a "before-versus-after comparison" that compares the status of the forest in two cross-sectional periods before and after policy implementation. In this study, we applied this approach to assess the effect of the policy on agricultural expansion in the study area. Considering spillover is an important aspect in this approach, therefore, we selected a large extent of state forests as the study area to cover spillover or leakage effects. In comparing the two study periods, we employed an integrated approach including land cover change analysis using remote sensing techniques and social data analysis through a questionnaire survey with closed and open-ended questions covering both quantitative and qualitative aspects related to monitoring and management of agricultural encroachment in forests at the landscape level.

4.3.2 Land cover change analysis

Selected time frames

As the policy intervention was introduced at the national level in 2013 and the implementation in the study area started in the governmental fiscal year of 2014–2015, we selected the years 2010, 2015, and 2020 for the land cover change analysis. To evaluate the impact of the policy intervention, these years were divided into two periods. The first period of 2010 to 2015 shows the general encroachment dynamics before the policy intervention showed any impacts. It therefore functions as a baseline for comparison. The period from 2015 to 2020 shows the general encroachment dynamics after the policy intervention was established to analyze the impact of the policy intervention on the land cover changes compared to the previous period.

Data acquisition

In the first step, the Landsat-7 Enhanced Thematic Mapper Plus (ETM+) images for 2010, Landsat-8 Operational Land Imager (OLI) images for 2015 and 2020 with 30 m resolutions, and the digital elevation model for the study area were downloaded for free from the website of US Earth Explorer (US) (Step. 1, Figure 4.1; Appendix 1). We selected images with a cloud cover percentage of less than 10% in November and December, when deciduous trees have full canopies. It is also the harvesting time for most farmers and provides clearer differentiation between agriculture and forested land. The steps of land cover classification and land cover change analysis are illustrated in Figure 4.1.

Preprocessing

Downloaded satellite images were preprocessed using ENVI 5.1. software (Step 2, Figure 4.1). Image preprocessing included atmospheric correction, radiometric calibration, dark subtraction, mosaicking of the images using the nearest neighbor algorithm, and subtraction of the study area from the mosaicked image.

Land cover classification and indices for land cover classification

We employed supervised classification using the semi-automatic plug-in with QGIS 3.28.6. software. The semi-automatic plug-in is an open-source tool that is widely used for land cover classification, as well as land use planning and monitoring (Congedo 2021). It enables users to achieve reliable image processing and land cover classification by creating regions of interest (ROIs) with their spectral signatures as training samples and applying a relevant algorithm with the collected samples containing the respective spectral signatures (Tempa and Aryal 2022).

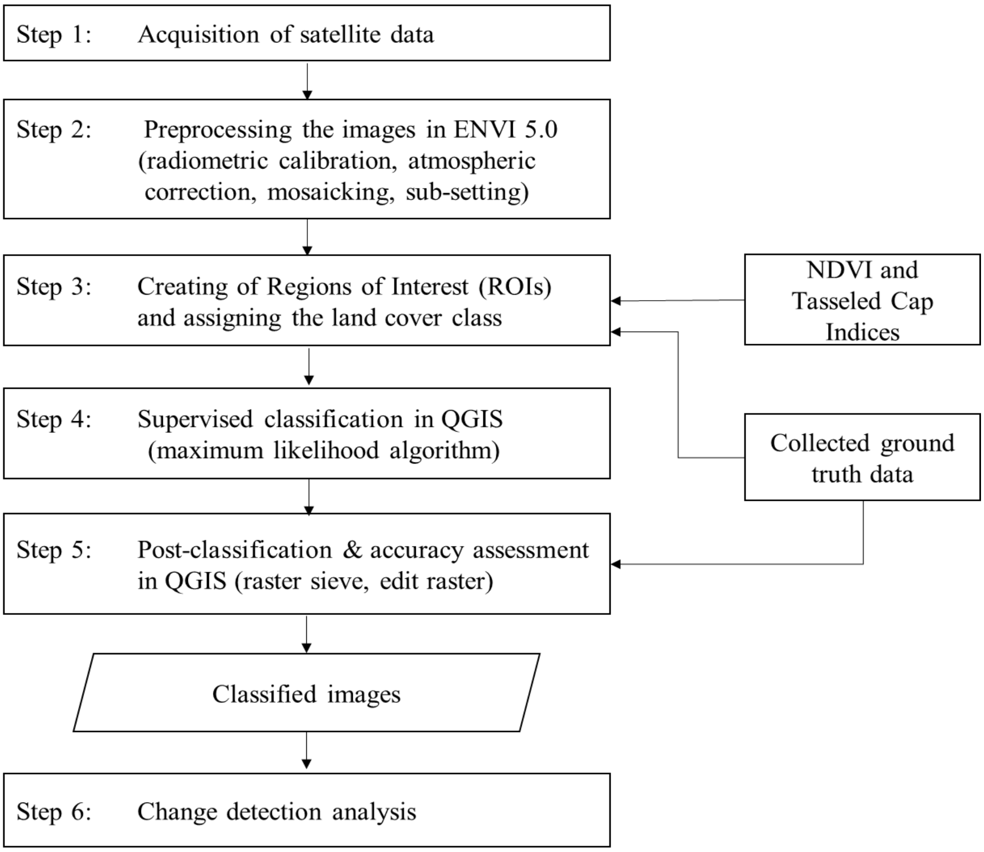

Figure 4.1: Processing steps of land cover classification and land cover change analysis in ENVI 5.0 and QGIS 3.28.6.

As the analysis was mainly focused on agricultural encroachment dynamics and forest cover status, five land cover classes were categorized: ‘forest’, ‘other wooded lands’, ‘agriculture’, ‘water bodies’, and ‘other’. Given the objective of the study, categorization was achieved during the field survey using field observations with reference to forest land categorization from FAO (2014). We categorized forest plantations depending on their canopy coverage and height. Forest plantations in Myanmar are established through the Taung-ya practice, in which agricultural crops are planted between newly planted trees by farmers during the first 2–3 years of plantation establishment. Therefore, young forest plantations were categorized through remote sensing as agriculture, as they are dominated by crops. After cropping stopped in the tree plantations, forest plantations were categorized as ‘other wooded lands’ until the trees were mature enough to meet the definition of the ‘forest’ category. A detailed description of each land cover class is provided in Table 4.1.

Table 4.1: Categories and definitions of land cover classes (adapted from FAO (2014))

Land Cover Class	Definition
Forest:	Forest land including mature forest plantations spanning more than 0.5 hectares, with trees higher than 5 m and a canopy cover of more than 10 percent or trees able to reach these thresholds in situ.
Other wooded lands:	Land not classified as "forest" spanning more than 0.5 hectares, with trees higher than 5 m and a canopy cover of 5–10 percent or trees able to reach these thresholds; or with a combined cover of shrubs, bushes, and trees above 10 percent. This category also includes immature forest plantations after Taung-ya cropping has stopped, but before they meet the criteria for "forest".
Agriculture:	Cropping areas, grazing land, and agricultural fallow land which are predominantly occupied by grasses or shrubs. This category also includes the first 2–3 years of Taungya forest plantations, during which crops are planted between trees until the trees' canopies are closed.
Water bodies:	Inland water bodies generally include major rivers, lakes, and water reservoirs.
Other:	All land that is not classified as any of the above categories. It mainly includes built-up areas, such as villages, buildings, and paved roads, and barren lands, such as sand and current and abandoned stone extraction areas, without any vegetation.

We employed stratified sampling based on the land cover types and collected respective land cover information from 458 ground control points covering all land cover classes (see Figure 3.1), including forests (50), other wooded lands (207), agriculture (172), water bodies (14), and other land (15). Although around 75–100 ground-truthing sites per class were suggested, the number and location of ground control points vary depending on the homogeneity, total extent of coverage, and accessibility of each land cover class to fulfil the objective of the study (Wohlfart et al. 2016). Therefore, we collected more ground-truthing sites in other wooded lands and agricultural areas, where heterogeneity is high, and fewer sites in forests, water bodies, and other areas. Collected field data were split into training (80%) and validation (20%) sets for accuracy assessment.

Before performing supervised land cover classification, a training dataset with land cover information was built by creating the ROIs (Step 3, Figure 4.1). In addition to ground truth data, values of other indices (normalized difference vegetation index (NDVI) and Tasseled cap indices or Tasseled cap transformations) were also applied.

The NDVI is an index indicating vegetation greenness, which correlates with vegetation density and distribution and is widely used in forest-related studies (Tucker and Sellers 1986; Pettorelli et al. 2005; Huang et al. 2021). NDVI can be calculated using the following formula in equation (4.1):

$$NDVI = (NIR - RED)/(NIR + RED) \quad (4.1),$$

where NDVI is the normalized difference vegetation index, NIR is the spectral reflectance of the near-infrared band, and RED is the spectral reflectance of the red band of the image. The NDVI value can range between −1 and 1; higher NDVI values correspond to healthier vegetation. The value of the NDVI for each pixel was calculated using QGIS software 3.28.6. and can directly be applied during the process of determining the respective land cover of each training ROI.

Tasseled cap indices or Tasseled cap transformations were additionally employed during land classification to identify bare soil and wet paddy fields in the study area. Among the indices, the brightness index (BI) and wetness index (WI) were used due to their effectiveness in indicating the biophysical characteristics of land (Kumar et al. 2017). Different maps for each tasseled cap index were separately produced and overlaid on the original satellite images. The respective value and visualization of each pixel from the produced maps helped in determining different land cover classes.

Overall, to determine the land cover class of each ROI, land cover information from ground truth data, reference data from Google Earth, visual interpretation of different band combinations, and values of the NDVI index and tasseled cap indices were cross-checked and validated. After creating the training input dataset, we applied supervised classification with a maximum likelihood algorithm that is widely used in land cover classification and considered one of the most reliable approaches, producing high levels of accuracy relative to other supervised land classification techniques (Patil et al. 2012; Madhura and Venkatachala 2015) (Step 4, Figure 4.1).

Post classification and accuracy assessment

After classification, we used the classification sieve and edit raster tools of the SCP plug-in to eliminate isolated pixels and misclassified areas (Step 5, Figure 4.1). Consequently, an accuracy assessment for each land classification was carried out, as this is an important step in land cover classification that reveals the usefulness of the classified map (Kamusoko 2022). We determined the required sample size for validation using the following equation (Equation 4.2) proposed by Olofsson et al. (2014):

$$N = (\frac{\sum_{i=1} \quad (W_i S_i)}{S_o})^2 \qquad (4.2),$$

where N is the desired number of samples for accuracy assessment, while W_i is the mapped proportion of the area of class '*i*', S_i is the standard deviation of stratum '*i*', and S_o is the expected standard deviation of overall accuracy. The accuracy values explain the reliability of classification. In previous literature, an accuracy value greater than 70% was considered acceptable by Congalton (1988), while Anderson (1976) mentioned accuracy values between 85% and 90% as satisfactory. The acceptable accuracy level can be varied depending on the users, nature of applications, land cover types, and the classification scheme (Geremew 2013; Horning et al. 2016).

After land cover classification, we calculated the annual rate of change for each land class using the following equation (Equation 4.3) proposed by Puyravaud (2003), which has been widely used for land cover change studies:

$$r = \left(\frac{1}{t_2 - t_1} ln \, ln \, \frac{A_2}{A_1}\right) 100, \qquad (4.3),$$

where r is the standardized annual rate of land cover change in percentage, and A_1 and A_2 are the areas of land cover at times t_1 and t_2, respectively, in years. We obtained the values of A_1 and A_2 from the land cover classification analysis conducted using QGIS software 3.28.6. for different study periods.

Change detection analysis

As the final step, we compared and analyzed the outputs of classification from different studied years using a change detection tool of the SCP plug-in (Step 6, Figure 4.1). It generates the land cover conversion matrices among land cover classes, the extent of the unchanged and changed areas among different land cover classes, and a map showing the locations where changes occur among different years studied. The land cover conversion matrices help users to understand which land cover classes have shifted to which other land cover classes and the extent of the shifted area for each class.

4.3.3 Questionnaire survey

Data collection

We carried out a questionnaire survey to understand the household and socioeconomic situation of encroaching farmers, as well as the impact of policy intervention on their encroachment behavior related to the policy intervention. We collected data from a total of 291 sample households. These were selected out of a total of 2409 households registered by the FD using a stratified random sampling method covering different locations (see also in San et al. (2023)). Of the interviewed participants, 75% were male, and 25% were female. Although we aimed to interview the same proportion of male and female participants, the gender of the interviewees varied depending on their availability and willingness to participate. In the field survey, we collected quantitative data related to the socioeconomic characteristics of the households, such as household size, income, and farm size, as well as qualitative data, using open-ended questions to explore the influence of the policy intervention, as well as other factors affecting their encroachment behavior (see questionnaires in Appendix 4).

Data analysis

We employed descriptive statistical analysis to explain the household characteristics and livelihoods of farmers, the previous land cover of the encroached areas, and the extent of their farm size dynamics. We coded and analyzed the qualitative responses, which were the reasons affecting the dynamics of encroachment in the study area, using ATLAS. ti software version 23 and visualized the results using Sankey diagrams.

4.4 Results

4.4.1 Land cover classification and accuracy assessment

The land cover classification results for 2010, 2015, and 2020 can be seen in Table 4.2 and Appendices 2 and 3. The accuracy assessment of classified land cover reveals high overall accuracy values of 95.0, 95.5, and 93.4 for 2010, 2015, and 2020, respectively. The average producer and user accuracy for each land cover class for each year and their standard error can be seen in Table 4.2.

Table 4.2: Detailed accuracy assessment results of land cover classification.

	Forest	Other Wooded Lands	Agriculture	Water	Other
2010					
Area (km^2)	3509	1430	529	107	15
(% of the total area)	(62.8%)	(25.6%)	(9.5%)	(1.9%)	(0.3%)
Standard Error	0.007	0.0078	0.0047	0.0026	0.0002
Producer Accuracy (%)	97.294	93.888	86.476	85.367	100
User Accuracy (%)	97.403	88.333	98.361	92.857	91.304
2015					
Area (km^2)	3254	1308	812	201	20
(% of the total area)	(58.2%)	(23.4%)	(14.5%)	(3.6%)	(0.3%)
Standard Error	0.0066	0.0075	0.005	0.0036	0
Producer Accuracy (%)	100	89.185	92.679	84.325	100
User Accuracy (%)	95.069	95.946	96.591	95.652	100
2020					
Area (km^2)	2903	1406	1037	224	23
(% of the total area)	(51.9%)	(25.1%)	(18.5%)	(4.0%)	(0.4%)
Standard Error	0.0075	0.0081	0.0059	0.0031	0.0007
Producer Accuracy (%)	94.093	92.128	92.824	94.438	100
User Accuracy (%)	98.101	86.441	92.667	81.250	83.333

According to the land cover classification results, most of the study area was covered by forests, other wooded lands, and agricultural lands, while water bodies and other land cover occupied only a small proportion of the study area. The area of water bodies slightly increased between 2010 and 2015 due to the construction of a new dam (see Appendix 3). Apart from that, water bodies did not show significant changes between 2015 and 2020. Other land cover classes, including settlements, roads, and bare land, covered only a small area, ranging between 0.3% and 0.4% throughout the entire ten-year (2010–2020) study period. Therefore, only land cover changes among forests, other wooded lands, and agriculture are highlighted in the following section 4.4.2.

4.4.2 Comparison of land cover changes before and after the policy intervention

The total forest area in 2010 was 62.8%, and it declined continuously throughout the whole study period: down to 58.2% and 51.9% in 2015 and 2020, respectively (Figure 4.2).

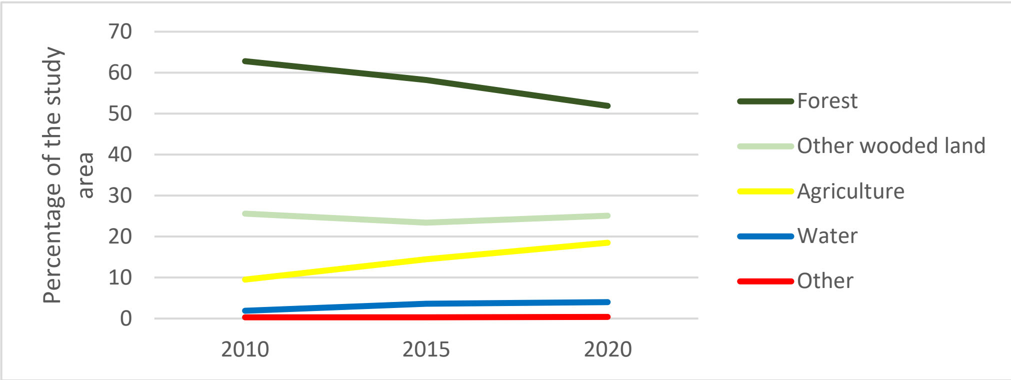

Figure 4.2: The extent of different land covers in 2010, 2015, and 2020.

Before the policy intervention, the annual rate of forest loss was −1.5% and, afterwards, increased to −2.28% per year. If we analyze the net forest loss by different land covers before the policy intervention, the major net forest loss was caused by a shift to agriculture rather than a shift to the other wooded lands. Contrarily, after the policy intervention, the amount of forest loss to other wooded lands was considerably higher than forest loss to agriculture (Figure 4.3).

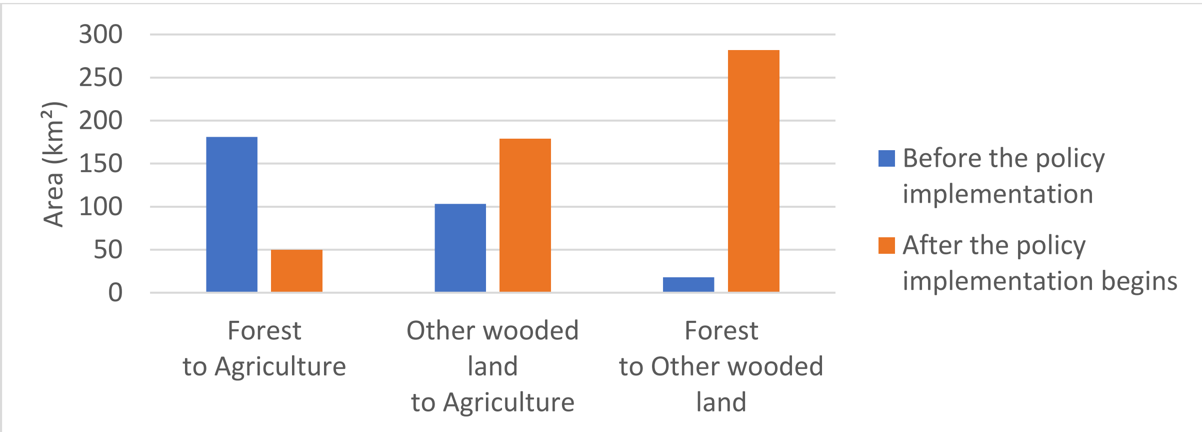

Figure 4.3: Net land cover changes among forests, agriculture (Agri), and other wooded lands (OWL) during the period of 2010–2020.

The other wooded lands decreased from 25.6% to 23.4% of the study area, with an annual rate of decrease of −1.78% before the policy. In contrast, after the policy intervention, other wooded lands increased considerably to 25.1% of the study area, with an annual increase rate of 1.46%. As previously mentioned, the major increase in other wooded land areas was due to a large area of forest land cover loss to other wooded lands.

In 2010, the total agricultural area covered 9.5% of the study area and increased in 2015 and 2020 to 14.5% and 18.5%, respectively. During the first five years (2010 to 2015), the annual rate of agricultural expansion was 8.58%. After the implementation of the policy in 2015, this expansion continued but at a lower annual rate of 4.9% until 2020.

Overall, we found that the net forest loss to agriculture reduced after the introduction of the policy compared to the period before the policy (Figure 4.3). However, we also observed that a large area of other wooded lands was converted to agricultural land, resulting in a high net loss of other wooded lands to agriculture after the policy implementation. We found a comparable increase in agricultural land between the two study periods, but with different dynamic land use change patterns. The net conversion of forest to other wooded land, which includes heavily degraded forest, immature forest plantations, and fallow forests, increased up to 282 km^2 after the policy implementation and was significantly higher than before (Figure 4.3). An overview of the detailed land use changes between categories over the two time periods can also be seen in Figure 4.2.

Change detection analysis revealed that areas of forest and other wooded lands gained from agriculture were partly from the areas cleared for Taung-ya forest plantation establishment, where farmers grow crops between newly planted trees for the first 2–3 years. Furthermore, the analysis detected areas of small-sized agricultural land that were reforested during both study periods.

Throughout the study periods, we found other wooded lands in buffer areas between forests and agricultural areas, and agricultural expansion occurred mainly in those areas, according to change detection analysis. It seems that after establishing agricultural fields, encroaching farmers degraded the surrounding forests over time and changed the forests to other wooded lands. In both study periods, the expanded agricultural areas were mostly clustered in small, sparse patches (less than 15 ha) that are likely to be expanded by small-scale encroaching farmers. We also observed a large clearance (greater than 60 ha) of forests and other wooded lands for forest plantation establishment.

4.4.3 Questionnaire survey responses

Household characteristics, livelihoods, and farming practices

The average age of the interviewed farmers was 50 years, and the average agricultural area per household was 4.5 ha, indicating small-scale and subsistence farming. On average, a household consisted of five persons, out of which three were family workers. The average annual income was USD 2465. The main crops grown in the study area were sesame, rice, and groundnuts in the rainfed upland areas and rice in the valley areas, which are often near streams among the hills. Out of the surveyed households, around 92% had been farmers since their first settlement in the forest. The occupations of the other 8% of respondents included government plantation workers, government staff, daily workers, and bamboo harvesters, who later changed their occupation to farmers.

During the field survey, it was found that 95.2% of total households (n = 291) practiced permanent agriculture, including bush fallow systems in their claimed farmland, while 3.1% practiced both permanent and shifting cultivation. No households were found to practice only shifting cultivation. The remaining 2% of households were no longer farmers and relied on off-farm income sources. Among the households practicing permanent agriculture during the field survey, 14% were originally shifting cultivators, and 2% were Taungya plantation farmers who switched to permanent agriculture and settled in villages within state forests between 2005 and 2020, while the rest practiced permanent agriculture since their first settlement. Shifting cultivators changed their practices for various reasons, such as a lack of areas for shifting cultivation because of occupation by private companies to establish plantations (32%) or due to population growth (16%); decisions to settle in a village instead of moving around for personal reasons such as marriage, getting old or limited labor capacity (29%); instruction from the FD's to stop cutting down the forests (18%); and an informal demarcation of farmland in the surrounding areas (5%).

Previous land cover and origin of encroached farms

The majority of farmers (45%) reported that they cleared already degraded forests to establish their agricultural fields. According to their general shared perception, a degraded forest is a forest that has been used for harvesting multiple times and consists of few and low-value tree species with a noticeably reduced density. Around 3% of farmers received land from the government as a special arrangement for old government plantation workers.

Around 52% of the farmers either inherited or bought land from other farmers. Regardless of the illegal status of the encroached farms, the existence of an informal market for the transfer of land was observed. Around 25% of farmers expanded their agricultural land by cutting down the forest around their farms after buying or receiving the land as an inheritance.

Farm size dynamics and the effect of the policy intervention

Among all households, for the majority of farmers (54%, n = 158), the farm size had not changed since their initial settlement. However, 40% (n = 116) of households expanded their agricultural area after settlement, while the other 6% (n = 17) had reduced their farm size in 2020 compared to their initial farm size.

Among the 40% of households that increased their farm size, 17% expanded their farms annually, while 23% expanded their farms only once in specific years (Figure 4.4-a). Most farmers responded that expansion occurred between 2005 and 2020. Some farmers (n = 18) responded that they expanded a long time ago (before 2005) and could not remember the specific year. Therefore, they were categorized together as having expanded before 2005. The most frequent expansion years after 2005 were 2010 and 2015 (Figure 4.4-b).

Most farmers (91%, n = 265) responded that the policy intervention in 2013 did not affect their farm expansion behavior or farm size changes. A few farmers (5%, n = 14) said that they expanded their encroached agricultural land by clearing the nearby degraded forest to claim more areas as their land because of the policy intervention. The remaining 4% (n = 12) mentioned that they started demarcating already encroached areas as their property after the policy intervention was initiated.

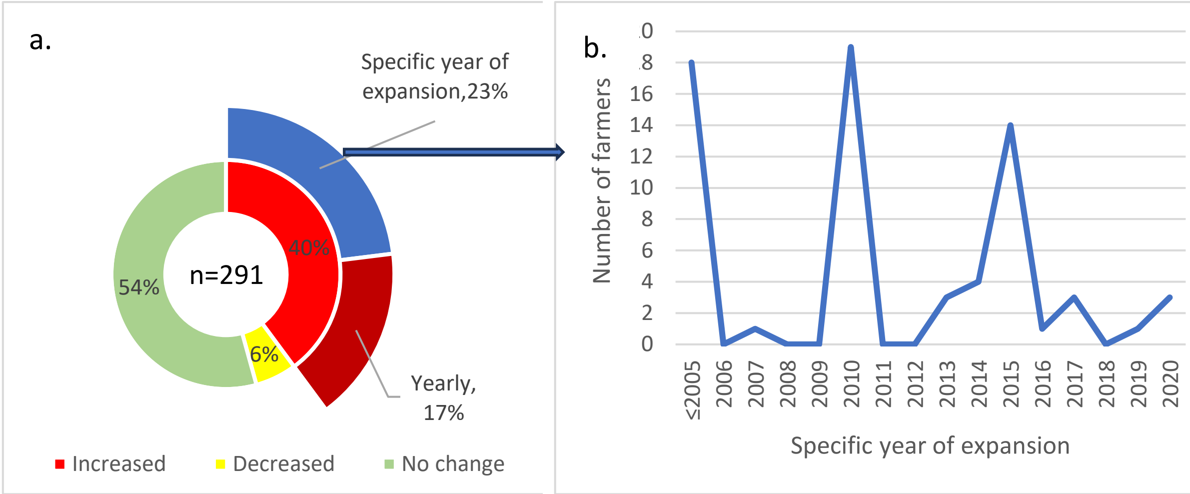

Figure 4.4: a. Percentage of farmers showing different farm size dynamics (*n* = 291); b. number of farmers who expanded their farms in specific years.

Factors affecting settlements and agricultural encroachment

We collected information related to the perception of interviewees on settlements and land use dynamics due to farmland encroachment in their surrounding areas between 2010 and 2020. As two farmers refused to respond, we were able to gather information about the perceptions of 289 farmers.

First, we asked farmers whether the policy intervention had the intended effect of decreasing the number of settlers and the encroachment area or if the policy intervention was instead working as an incentive for encroachment behavior and settlement. The majority (97%, *n* = 281) of farmers perceived that the policy did not reduce the amount of agricultural encroachment or the number of settlers in the study area. Only 3% (*n* = 8) indicated that some farmers had stopped farming in their surrounding areas as a result of the policy intervention. The majority (93%, *n* = 270) of farmers said that the policy intervention, particularly the establishment of agroforestry community forests, did not incentivize or attract other farmers to move into the forests and did not cause more encroachment. The rest (around 7%, *n* = 19) of the interviewed farmers perceived a minor increase in new farmers in the area, who immigrated due to the policy intervention. In conclusion, the intervention was not seen as directly affecting encroachment.

Secondly, we asked the interviewees which other factors, apart from the policy intervention, might be affecting settlement and agricultural encroachment, starting with factors that increased the number of settlers and encroachment, followed by other factors that decreased settlement and encroachment. Among the total respondents, the majority (87%, *n* = 253) responded that they were not aware of other factors, while 12% (*n* = 36) named different factors causing increases in agricultural encroachment and the number of settlers between 2010 and 2020. These mainly included socioeconomic factors, like livelihood needs and poverty, the availability of marketable non-timber forest products and job opportunities; social factors entailing immigration due to marriage; and an increase due to improved accessibility because of road construction (Figure 4.5).

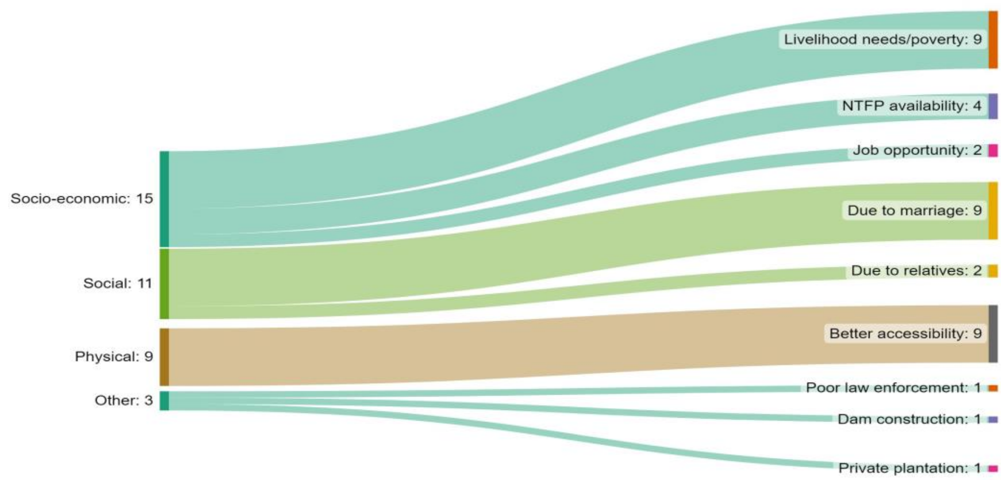

Figure 4.5: Reasons for increasing numbers of encroaching settlers in the surrounding area between 2010 and 2020 in relation to frequencies mentioned by the respondents (*n* = 36) (NTFP = non-timber forest products).

On the question of which other factors might have led to a decrease in encroachment and settlers, 82% (*n* = 236) of farmers replied that they were not aware of any, whereas 18% (*n* = 53) named other reasons besides the policy intervention. These included the establishment of commercial forest plantations by private, governmental, or unspecified actors. They explained that the establishment of these plantations often led to a situation where farmers had fewer opportunities to encroach on surrounding areas or even became landless. This practice of land grabbing led to farmers' outmigration or changes in livelihoods (Figure 4.6).

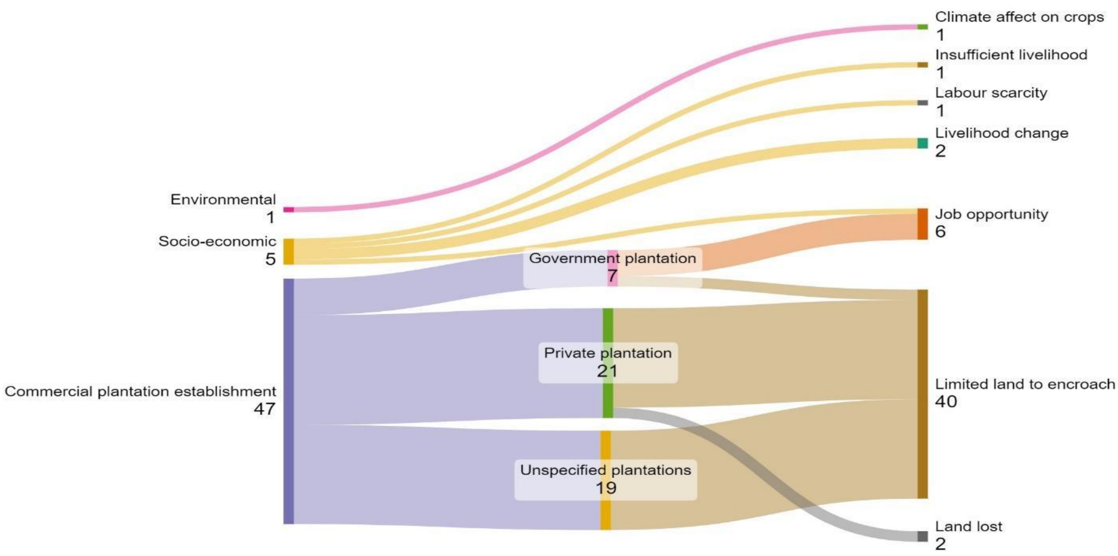

Figure 4.6: Reasons for decreasing numbers of encroaching settlers in the surrounding area between 2010 and 2020 in relation to the frequencies mentioned by the respondents (*n* = 53).

FD's monitoring and law enforcement of agricultural encroachment

We also found that the majority of farmers were not aware of any FD's law enforcement related to agricultural encroachment. The majority (around 90%) of interviewees responded that the FD did not monitor their agricultural encroachment status according to the policy. Only 10% (*n* = 30) mentioned that the FD followed up with them and reminded them not to increase the farmland area by encroaching on the forested land. However, even if they did, none of them experienced any legal action taken by the FD.

4.5 Discussion

4.5.1 Land cover dynamics between forests and agricultural land before and after the policy

According to the remote sensing results, the majority of land cover changes from forest to agriculture were mainly a result of the expansion of small-scale agriculture by local farmers along an encroachment frontier. In addition to the widespread clearance of small patches for agriculture by local farmers, we also observed deforestation due to land clearance for commercial forest plantations through Taung-ya agroforestry systems (Mon 2016). This system, which is commonly practiced in Myanmar, includes slash-and-burn practice (FD 2016) and the simultaneous growing of crops and trees at an early stage when the trees are still young. This practice has been criticized for its negative impacts on biodiversity conservation and ecological perspectives (Keenan and (Hamish) Kimmins 1993). For verification of our findings, we triangulated the results from the remote sensing analysis with the secondary data from the FD and results from the social data analysis resulting from the survey. The remote sensing results aligned with the information sourced from the FD regarding the establishment of monocultural or economically driven tree plantations, characterized by limited species diversity (FD 2015). The results are also reinforced by insights gathered from the survey data collected from local communities. In addition to state forest plantations, the establishment of commercial, private tree plantations has been promoted in degraded forests in the study area since 2006 (Chan Ko Ko et al. 2017).

Furthermore, the analysis detected that some areas of small-sized agricultural land were reforested during both study periods, before and after the policy. The farmers' explanation revealed during the survey was that parts of their agricultural land were taken over by private companies to establish tree plantations. From a reforestation perspective, this could be considered a positive land cover change from agriculture to forest plantations. However, farmers' perceptions indicated substantial conflicts between private companies and local farmers, with overall negative impacts in terms of sustainability outcomes (Gerber 2011). This can create spillover effects, causing deforestation in additional encroached areas.

4.5.2 Land cover dynamics between agriculture and other wooded lands before and after the policy

The change detection analysis indicated that agricultural areas were mainly cleared from other wooded lands, especially during the second period. Additionally, some areas initially classified as agricultural areas shifted back to other wooded lands. According to the interviews, part of these land cover changes was due to the practice of leaving fallows in agricultural systems and shifting cultivation. Although farmers who practiced conventional shifting cultivation were rarely encountered during the survey, the remote sensing results pointed to the possibility of a higher relevance of shifting cultivation in more remote areas of the study area. This dynamic was also pointed out in another study conducted by Chan et al. (2022), who mapped the shifting cultivation agriculture area throughout Myanmar (Chan et al. 2022). Results of our survey indicate that most farmers are smallholder farmers practicing farming on small land sizes, with an average of 4.5 ha. Generally, for smallholder farmers, other wooded lands are easier to change to agricultural areas than forests because of their lower tree density, demanding less labor and investment by farmers compared to clearing very dense forests. The land cover analysis also showed that other wooded lands were often located in buffer areas between forests and agricultural areas. Therefore, protecting those buffer areas with strict monitoring by the FD could be an option to stop further encroachment. Bhusal et al. (2018) showed successful cases of encroaching farmers protecting degraded forests around their farms in Nepal(Bhusal et al. 2018). The responsibility to protect the buffer area should be legally bound to individual farming rights, with clear rules and regulations for better accountability.

4.5.3 Land cover dynamics between forest and other wooded lands before and after the policy

Land cover changes from forests to other wooded lands increased more during the second period of the study than during the first period. As most agricultural areas were transformed from other wooded lands, effective forest conservation requires a deceleration of forest degradation in other wooded lands. Official selective logging by the state was practiced until 2015 in the study, after which point it was stopped with a plan of a 10-year logging ban in the Bago mountain range for forest rehabilitation purposes (World Bank 2019). Previous studies found that illegal logging activities in the study area frequently followed and used extraction roads developed for legal timber extraction (Win et al. 2018; Saung et al. 2021). The targeted illegally logged species included tree species not only for timber but also for charcoal production (Saung et al. 2021). Although logging was banned in the study area from 1 May 2016 onwards (Trends 2021), illegal logging continued (FD 2019; Trends 2021). Therefore, the protection of the forests from illegal cutting is also an urgent need to stop forest degradation and, consequently, agricultural expansion.

4.5.4 Effect of the policy intervention on farmers' agricultural encroachment

The remote sensing analysis revealed that the rate of forest loss was higher after the policy intervention than before. The main forest loss during the second period was due to the degradation of forest into other wooded lands, followed by agricultural expansion. Before the policy intervention, the main agricultural expansion was found in forested areas; however, it continued its expansion more into other wooded lands than forests after the policy intervention. Remote sensing analysis results showed that the agricultural expansion in the state forests did not significantly decrease after the policy intervention. This was validated by the survey results, indicating that the agricultural encroachment behavior of most interviewed farmers did not change due to the policy intervention. On the contrary, a few farmers (n = 26) mentioned that providing secure land use rights to their encroached areas through the establishment of agroforestry community forests through the policy intervention created incentives for them to encroach more areas or demarcate the encroached areas as their property. In the same study area, it was found that providing land use incentives could promote the participation of local people in forest conservation (Soe and Yeo-Chang 2019b). However, precautionary measures, such as setting clear boundaries between forests to be protected and allowing agriculture followed by strict monitoring, would have to be established to avoid a situation where land use rights for reforestation become an incentive to encroach more areas in forests, as indicated by our results.

Our results also indicated that other socioeconomic and physical factors may attract more settlers, increasing forest encroachment in the study area, including road construction, providing better accessibility, and livelihood opportunities. Many studies have already pointed out the negative consequences of roads, including deforestation worldwide (Ibisch et al. 2016; Shimizu et al. 2017b; Acheampong et al. 2018; Naing Tun et al. 2021). Therefore, we argue that strict monitoring and law enforcement are crucial after new road construction to protect forests from encroachments, and reducing the construction of roads in ecologically sensitive areas is recommended. Furthermore, the establishment of forest plantations was identified as a factor limiting the availability of encroachment areas.

4.5.5 Weak monitoring and law enforcement

The crucial importance of law enforcement in the context of deforestation associated with agricultural expansion has been pointed out by other studies, including that conducted by Nascimento et al. (2020).

Although agricultural encroachment and related encroacher land use rights were discussed and a policy intervention to solve the issue was implemented by governmental institutions in 2013 at the national level, the analysis reveals that encroachment problems remain. One of the major reasons based on the social survey results was the weakly implemented monitoring and law enforcement activities related to agricultural encroachment, as the majority (90%) reported that the FD did not continuously monitor their encroachment status. The insufficient number and limited capacity of field-level staff have been pointed out as major constraints in forest management in Myanmar (Myint Aung 2007; Cho et al. 2017). In this study, we have demonstrated the effectiveness of remote sensing analysis in detecting agricultural encroachment in forests, providing a potential solution for these constraints. Applying remote sensing techniques can increase time, as well as human and financial resource efficiency. Therefore, providing capacity building on remote sensing and GIS techniques to responsible staff and applying techniques to monitor the development of agricultural expansion can be an effective way to monitor agricultural encroachment in forests. Nowadays, remote sensing satellite images and analysis software can be freely and easily downloaded from open sources. Lechner et al. (2020) also highlighted that applying remote sensing techniques for forest management is cheaper and easier than in the past due to the availability of open sources, which provide preprocessed images (Lechner et al. 2020).

In addition to monitoring forest cover using remote sensing, community-based monitoring and reporting systems for encroachment and agricultural expansion in forests, as suggested by Fry (2011), have been proven successful in Vietnam (Fry 2011; Tien et al. 2020). As community monitoring and reporting systems (CMRS) have been successfully implemented in Myanmar to control illegal logging and timber extraction activities (FD 2020c), incorporating the monitoring of agricultural encroachment into the established system would be an efficient strategy for implementation. However, careful and participatory planning before implementation is necessary to avoid potential conflicts and corruption (Fry 2011).

4.5.6 Benefits of the integrated approach

Throughout this study, we observed the benefits of combining remote sensing techniques and social data analysis.

The study highlighted the advantage of the remote sensing analysis covering a large extent of the area at the landscape scale and provided an overview of the agricultural encroachment dynamics and forest cover change over time. On the other hand, the social analysis explained the social and environmental contexts that cannot be covered by the remote sensing analysis. This was also pointed out as a limitation of studies that rely exclusively on remote sensing (Walker and Peters 2007). Based on our mixed-method approach, we were able to include detailed information about small-scale farm households and their perception of the policy effects. In addition, we discovered weak monitoring of encroachment behavior, factors affecting settler dynamics, and the effect of the policy on their agricultural encroachment behavior through social data analysis.

Therefore, through the combination of remote sensing and social analysis, we were able to gain insights into the dynamics of forest cover and agricultural encroachment before and after the policy intervention. Similar to previous studies that applied an integrated approach to different research topics (Kimutai and Watanabe 2016; Da Ponte et al. 2017; Tripathi et al. 2020), we found it to be a useful tool for forestry research, especially within complex and challenging social contexts.

4.5.7 Limitations and challenges

As sample households were selected for this study based on data collected by the FD in 2013, the study results do not represent perceptions of unregistered households that settled in these areas after 2013 or in inaccessible areas, even if they were subsequently responsible for forest encroachment. Hence, we recommend a systematic and thorough survey and registration of encroaching farmers, including inaccessible and isolated farmers, to improve data availability and the monitoring process in the future. During ground truth data collection for the remote sensing analysis, we could not access all parts of the study area due to political instability, difficult terrain, weather conditions, and COVID-19 restrictions. As a substitute, we derived this information from inaccessible areas via high-resolution Google Earth and Sentinel images. Furthermore, since February 2021, the political situation in Myanmar has worsened due to the military coup, preventing us from carrying out another field survey to gather updated information after 2020.

The policy intervention (2013) facilitated the acquisition of land titles by some farmers for their irrigated paddy fields situated within state forest areas administered by the Agriculture Department. Consequently, these are no longer considered encroachments but are recognized as permanent agricultural areas. However, since the updated map showing the areas that were transferred to the authority of the Agriculture Department was not available, in this study, we defined all agricultural activities inside the borders of the state forest as encroachments, despite the possibility that some fields have been legally recognized as agricultural land. This lack of coordination regarding land titles, conflicting agendas, and competing targets among ministries has been a general obstacle contributing to deforestation in Myanmar (Prescott et al. 2017; World Bank 2019). In addition to developing a map with clearly demarcated agricultural and conservation zones, the strict implementation and enforcement of these zones is urgently needed for better forest management. To this end, coordination between responsible departments, mainly the FD and the Agriculture Department, needs to be strengthened (RECOFTC 2018).

Finally, the lack of a usable district land use map from the FD that delineates the location and boundaries of state and private forest plantations, and agroforestry community forest establishments in the study area (see (FD 2015)) has made it challenging to correlate forest gains with agroforestry community reforestations or larger private and state plantations. The development of a clear map showing different forest management areas is recommended for better management in the future. To compensate for this information gap, we used social survey data.

4.6 Conclusion

In this study, we demonstrated the benefits of integrating remote sensing techniques and questionnaire surveys in monitoring agricultural encroachment in forests and assessing the outcome of the applied policy. Based on the remote sensing analysis, we were able to reveal the dynamics of land cover and land use change, especially in the context of agricultural encroachment. Using the interview results, we were able to explain the driving factors behind these dynamics and the outcomes of the policy intervention. We showed that using remote sensing data to monitor the status of agricultural expansion in forests is an effective strategy for Myanmar and other countries with limited human and financial resources, while a social survey provides policymakers with information crucial for policy modification. Furthermore, we provided an overview of the outcomes of the forest policy intervention covering a large area of forest landscape. We concluded that the policy intervention (2013), established and designed by the FD to reduce agricultural encroachment, did not lead to a decrease in deforestation nor a decrease in encroachment. In order to decelerate smallholder agricultural encroachments in forests in Myanmar and other countries with similar issues, we suggest prioritizing the protection of degraded forests in the buffer areas between agricultural areas and forests to stop agricultural expansion. Farming rights should be strictly linked with the responsibility to protect nearby forests to prevent further encroachment. During the social survey, we observed forest plantation establishment as a factor limiting available encroachment areas in the study area. However, it should be noted that this is also likely to lead to land use conflicts with local communities or cause the migration of farmers into other areas, which might also be forests with an even higher ecological value. An explicit land use map that distinguishes between areas managed by the FD and other governing bodies is highly advised. The implementation of a combination of remote sensing and community-based monitoring, coupled with meticulous participatory planning, could be a promising system to surmount the resource constraints in monitoring agricultural expansion within forested regions.

5 AGROFORESTRY-BASED COMMUNITY FORESTRY AS A LARGE-SCALE STRATEGY TO REFOREST AGRICULTURAL ENCROACHMENT AREAS IN MYANMAR: AMBITION VS. LOCAL REALITY

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5.1 Abstract

The high rate of deforestation in Myanmar is mainly due to agricultural expansion. One task of the Forest Department (FD) is to increase tree cover in the agricultural encroachment areas by establishing large-scale agroforestry-based community forests (ACFs). The objectives of this study were to analyze the adoption and performance of the ACFs in the agricultural encroachment areas in the Bago-Yoma region, Myanmar, and to provide recommendations to enhance the adoption of ACFs by farmers. We inventoried 42 sample plots and surveyed 291 farmers. Survey responses were analyzed by binary logistic regression, one-way ANOVA, and non-parametric correlation tests to evaluate factors influencing the adoption of ACFs. Stand characteristics were calculated from the inventory data to evaluate the performance of ACFs. Our results show that farmer participation in ACFs was lower than stated in the registry of the FD. Farmers practiced four different agroforestry designs in ACFs with different outcomes. The FD strongly determined tree species and planting designs, farmers' perception, and participation in ACFs. Farmland size, unclear and insufficient information on ACFs, and a negative perception of raising trees in crop fields were the major factors limiting the adoption rates of ACFs. We recommend capacity building for farmers and FD staff and raising awareness about the benefits of planting designs and trees on farmland. A stronger consideration of farmers' preferences for design and species selection could increase their motivation to adopt ACFs and improve the long-term sustainability of ACFs.

Keywords: Agricultural encroachment, agroforestry, forest governance, perception, deforestation, degraded forest

5.2 Introduction

Deforestation is a major issue worldwide, as it contributes to climate change and land degradation (FAO 2020). Its impact has been severe between 2010 and 2020 (FAO 2020; Hoang and Kanemoto 2021; Vancutsem et al. 2021), when the world lost a net total of 4.7 million ha of forests annually, predominantly in the tropical regions (Keenan et al. 2015; FAO 2020). Deforestation in tropical countries was driven mainly by the conversion of forests to agricultural land, including commercial and subsistence farms (Keenan et al. 2015; Curtis et al. 2018). Many governments, especially in Southeast Asia, have been looking for sustainable solutions to manage and reforest agricultural encroachment areas and settlements in state forests (Iftekhar and Hoque 2005; Bhusal et al. 2018; Yurike et al. 2021).

Myanmar's forests cover 42.9% of the country's total area, and between 2010 and 2020, it was ranked seventh among the top ten countries with high rates of deforestation in the world (−2900 km^2 per year) (Reddy et al. 2019; FAO 2020). Agricultural expansion has been the main cause of deforestation in Myanmar, where 74% of the areas that were deforested from 1988 to 2017 became agricultural land (Lim et al. 2017; Yang et al. 2019; Naing Tun et al. 2021). Aside from the agricultural expansion of mostly small-scale farms, other underlying reasons for Myanmar's failure to protect forests from deforestation and degradation include large-scale logging, agricultural concessions, illegal timber extraction, corruption, inadequate staffing at the Forest Department (FD), and poor law enforcement by the FD (Erni 2018).

Fifty-nine percent of Myanmar's total forested area is state forests, which cover 25.5% of the country's total area (FD 2020a). The FD headquarters is in charge of monitoring and administration on the national level, while regional FD offices are in charge of implementing the forest management plans (FD 2020a). Agricultural expansion in state forests has been illegal and strictly prohibited since the adoption of the Forest Law in 1992; however, forest encroachment by settlements and agriculture amounted to 740,100 ha (i.e., 5% of the total state forest areas) by the year 2013 (FD 2013a). Since 2013, the FD has increased its efforts to reduce agricultural expansion in state forests and reforest deforested areas (FD 2013a; President's Office 2013).

Different strategies and goals have been implemented in various countries to reforest farmland (Harper et al. 2017; Yue et al. 2020). Among these, agroforestry has been promoted as a sustainable land use approach that addresses the reforestation of agricultural land as well as a climate change adaptation and mitigation strategy that can fulfil both the ecological and socio-economic needs of farmers (Nair 2013; Bezerra et al. 2019; Nyong and Martin 2019; Tubenchlak et al. 2021; Abbas et al. 2021). Although definitions may differ in many aspects, the concept of agroforestry generally involves the introduction and management of trees in different spatial or temporal arrangements on farmland (Atangana et al. 2014a).

To achieve the government's official goal of sustainable land use by increasing tree cover while ensuring the livelihood of local people, the Myanmar FD opted to let farmers plant a minimum of 150 trees per acre (375 trees per ha) in encroached forest land, rather than taking legal actions against them (FD 2013a). This decision took into consideration that many farmers had been farming these areas for generations (FD 2013a). The framework of the program is based on the national "community forestry instructions," and a community forest land title is given to farmers who have established agroforestry areas in the encroached farmlands (FD 2013a, 2018). In regular community forests (CFs), trees are planted on communal land and involve collective action and benefit-sharing. In contrast, in the agroforestry approach, farmers are required to plant trees on land that is perceived to be their property, and all decisions are made individually by each farmer (FD 2018). Here, we take into account the officially set national name of "community forestry" while highlighting the actual agroforestry nature of the reforestation approach, and thus, the term "agroforestry-based community forests" (ACFs) will be used to differentiate it from regular CFs.

Farmers who have received their community forest certificates can obtain an official, 30-year land lease with associated land use rights, including access, withdrawal, management, and exclusion rights except alienation rights for the area designated as ACFs (FD 2018). The FD is responsible for monitoring and following up on the status of those ACFs areas and can revoke the certificates of ACFs that are not working well (FD 2018). Previous studies have shown that the participation of farmers in reforestation programs can be increased if land use rights are secured and provided as an incentive (Soe and Yeo-Chang 2019b). However, ACFs have only been implemented by the FD in Myanmar on a large scale and in a top-down manner since 2013, mainly as a tool to increase tree cover in agriculturally encroached areas of state forests. Therefore, the efficiency of the program, as well as the levels of participation, motivation, and implementation by the farmers, remain unclear. Even though the long-term success of this approach is unclear, the current ACFs have been implemented on a nationwide scale (FD 2013a, 2020b). Therefore, in this study, we aimed to assess the levels of farmers' participation in, and performance of, the ACFs. Specifically, we aimed to understand the factors that drive the participation of farmers in ACFs; identify the ACFs designs that are practiced, as well as the factors that influence ACF design and species selection; and investigate tree survival and stand characteristics of different ACF designs.

This study provides insights that can be applied to other encroachment areas throughout Myanmar as well as other countries (e.g., Indonesia, Nepal, Ghana) facing similar challenges associated with the encroachment of agricultural areas into state forests (Bhusal et al. 2018; Yurike et al. 2021; Acheampong et al. 2021).

5.3 Materials and methods

5.3.1 Data collection

The mixed-method approach we employed in this study included a forest inventory and a survey, followed by open questions and semi-structured interviews. Information related to the ACF establishment was first collected from the FD. The methodological flow diagram is presented in Figure 5.1.

Questionnaires, surveys, and interviews

Sampled households were selected from among those registered as ACF members using a disproportional stratified random sampling method applied to different townships and ACF establishment years (2014–2018). The required sample size was calculated according to Desu and Raghavarao (1990) and Hahn and Meeker (1991) using NCSS software (Desu and Raghavarao 1990; Hahn and Meeker 1991; NCSS 2020). Out of a total population of 2409 households that are registered at FD as ACF members, a sample size of 291 households was selected, producing a 90% confidence interval with a margin of error of ±0.027 for an estimated proportion of 0.10. Household heads or other adults living in the same household were selected as interviewees, depending on their availability. Around 25% of the interviewees were female, and 75% were male. The survey was conducted in July and August 2020. In addition to survey questionnaires, we asked all sampled households open-ended questions (e.g., reasons of participation) during the survey to gather additional qualitative data and contextual information.

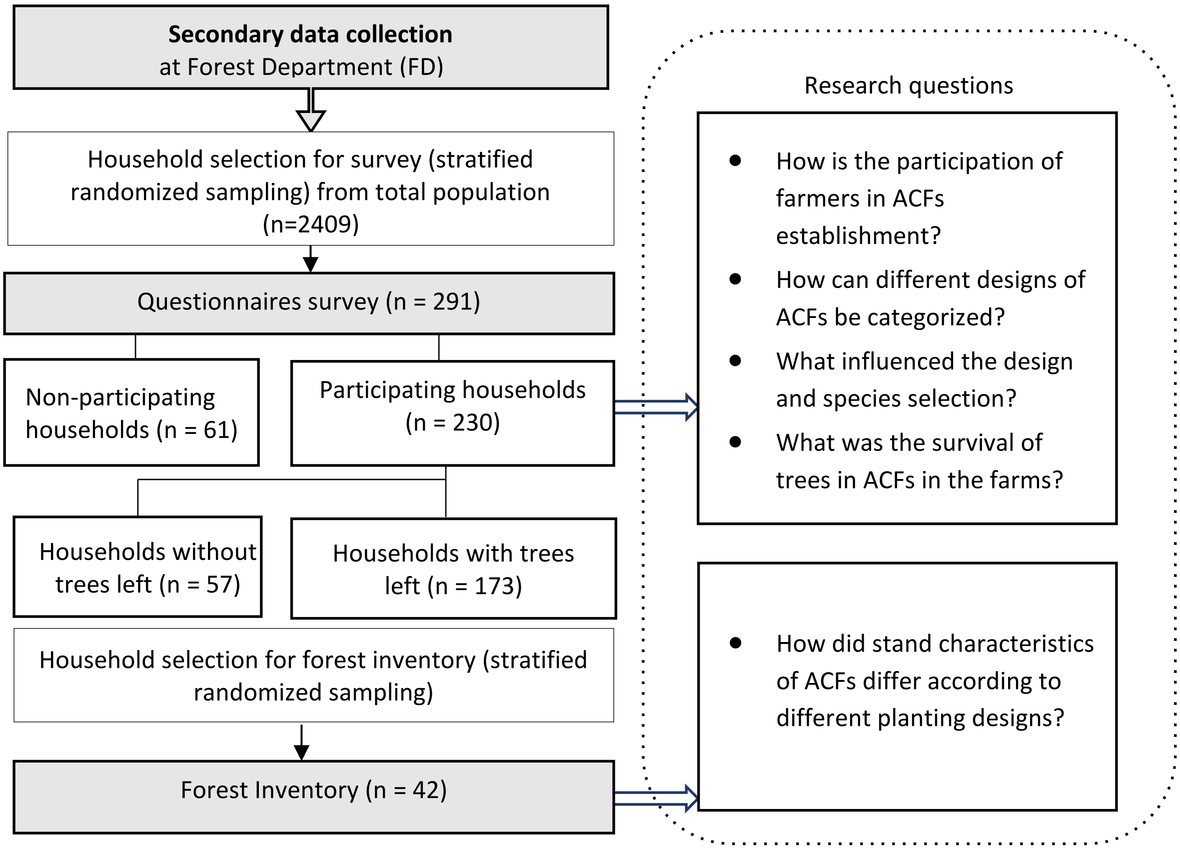

Figure 5.1: Methodological flow of the study

Forest inventory

Households without ACFs were excluded from the forest inventory sampling. To assess the forest conditions of established ACFs, we performed a forest inventory. First, we selected at least 24% of households with ACFs, using a stratified randomized sampling method. Then, a total of 42 plots measuring 20 × 20 m from different ACF designs were assessed during the forest inventory. The size of the sample plots was commonly used in previous forestry research in Myanmar (Aye et al. 2011; Oo and Lee 2012; Lwin and Aung 2015). For all the trees measuring ≥5 cm diameter at breast height (DBH) within the sample plots, we identified their species and recorded their DBH.

5.3.2 Statistical analysis

We applied descriptive statistics to summarize the survey results. To assess the influence of factors on participation in ACFs, we employed binary logistic regression analysis. This analysis evaluates the association between the dependent and independent variables when the dependent variable is binary (Harrell 2015). We considered participation as a binary and dependent variable, and therefore, the analysis was carried out to reveal whether the independent variables (i.e., household characteristics and knowledge level about ACFs) influenced participation in ACFs.

We used one-way ANOVA to compare the household characteristics among ACFs of different designs. This analysis evaluates the differences among three or more groups. ANOVA was followed by post-hoc tests to determine which groups differed significantly from the others.

We evaluated the association between the “designs instructed by the local FD” and the “designs that households practiced” through a Pearson chi-square test. This test is commonly used to check if non-parametric categorical data are statistically related or independent when the dependent variable is nominal (Nihan 2020). All descriptive statistics and statistical analysis of survey responses were performed using Stata/IC 16 software (StataCorp. 2019). The detailed dataset and the commands used in the analysis can be found on the Zenodo platform (San et al. 2023a).

For the data analysis of the forest inventory, we first calculated the average number and basal areas of trees per hectare for ACF forested plots without including cropping areas using Microsoft Excel. During interviews, farmers usually claimed that their farmland is divided into cropping areas, forested areas, and fallows. As the original goal of the FD was to let farmers plant a minimum of 375 per ha of their agricultural encroachment areas, we need to consider trees per total farmland areas by including all cropping areas, fallows, and reforested areas. Hence, to compare the inventory results with the FD’s goal, we additionally calculated ‘trees and basal area per ha of total farmland’ by including all types of farmers’ land that are perceived as their property. Since the total sampled area was less than 1 ha, the results expressed per hectare should be interpreted with caution, as they are based on the assumption of a uniform distribution.

5.3.3 Classification approach

Agroforestry systems need to be classified to evaluate the performance of different designs (Nair 1987). Several methods and approaches have been discussed and applied throughout the past decades (Sinclair 1999; Torquebiau 2000; Atangana et al. 2014b). Sinclair (1999), for example, proposed a classification approach based on the agroforestry practices and the predominant usage of the land (e.g., livestock and trees, trees in farmland, or multipurpose woodlot) as well as the spatial arrangement (e.g., lines or groups), density (number of trees per hectare), and diversity of tree components (e.g., monoculture or mixed species) (Sinclair 1999). This approach enables the detailed and specific classification of agroforestry practices, focusing on the functional and structural arrangements of trees.

Therefore, we adopted the classification approach of Sinclair (1999) in this study, although we adapted the approach based on field observations of the different agroforestry practices in the study area. Because of the lack of diversity of planted tree species and similar usage, which are mostly teak and eucalyptus (*Eucalyptus camaldulensis* D.), we categorized ACF practices based on the types of vegetation within two categories, namely "Tree planting without natural forest remnants" and "Natural Forest remnant-based practices." Under the first practice, we differentiated two design categories based on tree structural arrangements, namely A) boundary planting and B) woodlot planting (i.e., in plots). Under the "natural forest-based practices" category, we designated C) planting trees in degraded forest remnants and D) protection of degraded forest remnants as different design categories.

We define "boundary planting" (Category A) as planting trees at the border of the farmland in one or two rows of trees. Because the farms in the study site were often irregularly shaped, the trees under this category are in irregular lines along the farm border.

We define "woodlot planting" (Category B) as planting trees in plantation plots without mixing with existing natural vegetation or crops. The establishment procedures for these two categories included clearing the land by cutting all existing vegetation.

We define "planting trees in degraded forest remnants" (Category C) as planting trees in degraded natural forest patches situated near cropping areas. Households under this category have non-agricultural areas such as fallow forests or secondary forests on the hills next to their farms. These forest remnants are legally owned by the state; however, farmers with forest remnants around their farms have informally acquired these remnants as their property, with neighbors usually recognizing the informal land tenure.

Finally, we define "the protection of degraded forest remnants" (Category D) as the protection of a degraded forest and registering it as an ACFs without planting new trees. Similar to farmers in Category C, those under Category D have degraded forest remnants around their farms, which are recognized locally as their property, despite their original legal status as state forests. In comparison to category C, farmers in category D didn't plant any trees in the remnants and only reported protecting them as ACFs.

5.4 Results

5.4.1 General characteristics of the households

On average, farm households have a household head aged 50 years, with a household size of five persons, of which three are working on 4.5 ha of land, generating an annual income of 2465 USD. Sesame, groundnuts, and rice are the main crops grown in the study area. The majority (79%) of households rely purely on agriculture, while 19% have other income sources. The remaining 2% depend exclusively on off-farm income. The majority of household heads (92%) have only been educated up to the primary school level or via monastery education (i.e., monks teach farmers how to read and write).

5.4.2 Participation in ACFs

All interviewed households (n = 291) were registered as ACFs. According to the FD, all registered farmers participated in ACF implementation; however, our results showed that only 79% implemented ACFs in their farms. Among participating households, the majority (57%) of participants stated that the only reason they established ACFs on their farm was to follow the local FD's instructions. Forty-three percent of participants were driven by their inherent motivation. Among these, 36% cited the main reason for participation was to gain timber, bamboo, and firewood; 3% participated to secure land rights; around 2% expected to receive monetary income; 2% participated due to the influence of neighbors; and the remaining 1% stated other reasons such as a desire for shade during summer or to engage in ACFs as a hobby.

Among 21% of total households that did not participate in ACF establishment on their farmland, we asked their reasons for not participating. The majority of farmers (20%) provided no specific reasons and only stated that they were unwilling to plant trees on their farms. Because this topic is sensitive and sometimes complicated for some farmers, we did not ask for further elaboration. Another 20% of farmers stated their main reason for non-participation was a lack of information about ACFs. This group of farmers included those who did not know that they were listed as an ACF member, those who did not know that they had to plant trees, and those who did not know how to plant trees. Other stated reasons were insufficient land to plant trees (16%), insufficient labor and capital (13%), interference of trees with crops (10%), dispute with the FD (10%), insufficient seedling supply (5%), and others (7%).

"I do not know that I was registered as an ACFs user group member. I remember that FD gathered villagers to attend a seminar once, and I was there just to listen to their talk. I do not even have any farmland here in this village." (ID 247/ACF member/village head, household survey, August 19, 2020, translated from Myanmar)

"I do not understand why my name is registered as the ACF user group chairman. I am a machine repairing expert and work at a workshop. I am not a farmer or do not have farmland." (ID 14/ACF member/village head, household survey, July 30, 2020, translated from Myanmar)

Binary logistic regression between participation and explanatory household variables, including demographic and socio-economic factors, and knowledge about ACFs, was carried out to evaluate the relationship between the reported reasons and participation and non-participation in ACFs. The regression model was statistically significant ($\chi 2 = 117.29$, $p < 0.01$). Among demographic factors, annual income, number of workers per household, household size, age, and education of household heads did not significantly influence farmers' participation. This finding contradicts the farmers' statements that insufficient labor was the reason for not participating. The only variables with a significantly positive impact on the adoption of agroforestry were the total land size of farms ($\beta = 0.14$, $p < 0.05$, Table 5.1) and the information provided to the farmer about ACFs ($\beta = 2.89$, $p < 0.01$, Table 5.1), indicating that sufficient land size and knowledge about ACFs positively impact farmers' willingness to participate in ACFs.

In summary, the adoption of ACFs by most farmers was driven mainly by pressure from the FD on the farmers. Among non-participants, most reported not liking planting trees, lack of information, and insufficient land as the main reasons. The latter two points, the lack of information transfer from the FD and total land size, were statistically supported by binary logistic regression as influencing factors to participation.

Table 5.1: Results of the binary logistic regression analysis (* = P ≤ 0.05, significant ** = P ≤ 0.01, strongly significant)

Variable	Unit	Mean of non-participating households (n=61)	Mean of participating households (n=230)	β	P-value	Std. error
Total land size	ha	3.5	4.7	0.139	0.025*	0.062
Annual income	USD	2262	2519	0.000	0.503	0.000
No. family worker	Persons	3	3	- 0.141	0.514	0.216
Age	Years	47	51	0.004	0.802	0.017
Household size	Persons	5.2	4.8	- 0.192	0.198	0.149
Education	Level	1.1	1.1	- 0.654	0.187	0.496
Knowledge on ACF	Level	2.06	2.96	2.897	0.000**	0.362

Note: Education: level 1=primary, 2= secondary, 3= high school, and 4= higher education, Knowledge on ACFs (Agroforestry Community forests): level 1 = No knowledge, 2= little knowledge, 3= moderate knowledge, 4= good knowledge

5.4.3 Implementation and motivation for the specific agroforestry practice

The survey reveals that most participating households planted only eucalyptus and teak trees in their ACFs. Households that planted only eucalyptus were around 36% of the participating households, while only teak was planted by 29%. Around 10% of households planted both eucalyptus and teak, while the rest 25% planted two or three species in different mixtures. Although Community Forestry Instructions give farmers the right to develop their management plan for ACFs as well as to select their preferred species and designs, it was found that FD selected and distributed specific tree species without considering farmers' preferences.

Among the ACFs designs, the majority, 37% of participating farmers, adopted Category B, "planting trees as woodlots," followed by Category A, "Boundary planting" by 33% and Categories C and D, i.e., "planting in degraded forest remnants" and "protection of degraded forest remnants" by 11% and 10%, respectively. The remaining 9% of participating farmers adopted a mixture of two or more categories, and we excluded them from the subsequent characterization of each design category. Only households belonging to a single ACF design category were compared.

The analysis of the reasons for adopting the different agroforestry design categories is shown in Figure 5.2. The majority (39% and 43%, respectively) of farmers who adopted categories A and B stated their main reasons for selecting the specific designs were to follow the FD's instructions. Another main reason for adopting these two design categories was to avoid trees shading their crops, which they perceived as a disturbance to crop production. The availability of unused land or non-arable land on the farm was a major reason cited by 26%, 32%, and 38% of farmers for adopting ACF design categories B, C, and D, respectively, where woodlots are outside the cropping area. The abovementioned reasons reflect the desire of farmers to avoid growing trees in their cropping area, but rather establish ACFs outside the cropping areas.

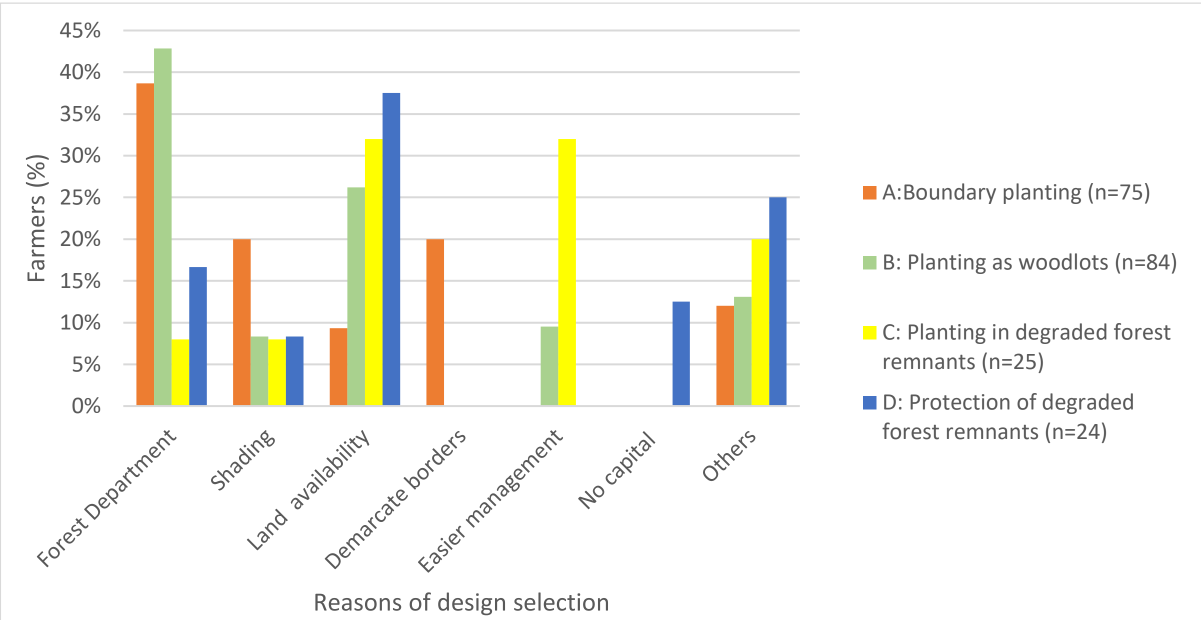

Figure 5.2: Farmers' reasons for the selection of different designs in Agroforestry Community Forests (ACFs)

Apart from the shared reasons mentioned above, farmers reported specific reasons for each design category. Specifically, farmers (20%) from Category A adopted the respective design to demarcate the borders of their farmland (Figure 5.2); farmers (10%) from Category B selected the design as a strategy to more easily manage weeds and fire protection; farmers (32%) from Category C adopted the design to combine newly planted trees with degraded forest remnants for easier management; and 13% of farmers from Category D chose the design due to limited availability of labor and funds for planting new trees.

"I found that the forested areas near my farms have Pyinkado trees (Xylia xylocarpa), which are one of the valuable timber-producing trees, so I decided to plant more teak trees in the area". (ID 96/ACF member, Household survey, August 8, 2020, translated from Myanmar)

"FD forced to plant trees in our farms. So, we chose to plant trees where we do not grow crops". (ID 208/ACF member, Household survey, August 8, 2020, translated from Myanmar)

Finally, although the FD's directive was to reforest agricultural areas, 21% of participating farmers planted trees or maintained natural forest remnants outside the cropping area, specifically in categories C and D.

5.4.4 Difficulties during the implementation of ACFs

The majority of farmers (55%) did not face any difficulties implementing ACFs, while 34% and 11% (keep order) of farmers reported having few or major difficulties, respectively. This was the case for all design categories. The number of farmers who faced a few manageable difficulties is the highest in Category B (38%), while 25% of farmers who adopted Category D faced more major difficulties than those who adopted the other categories (Figure 5.3).

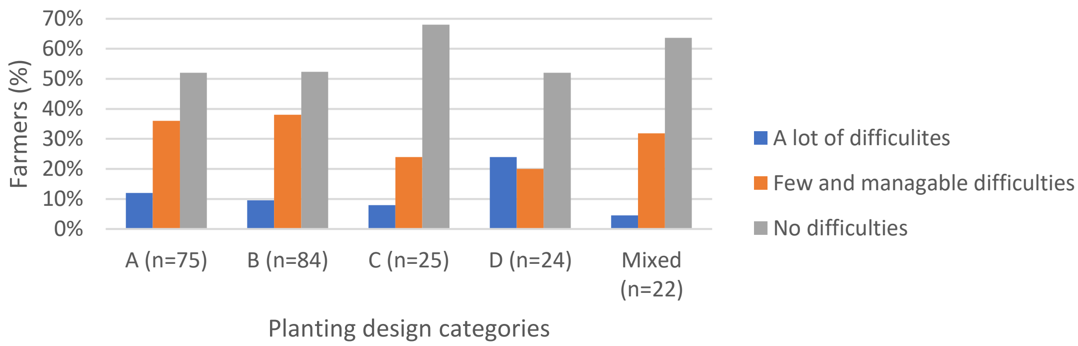

Figure 5.3: Percentage of farmers (n = 230) with the perceived level of difficulties in different design categories (A: boundary planting; B: planting as woodlots; C: planting in degraded natural forest remnants; D: protection of degraded forest remnants)

Farmers most frequently mentioned external disturbance factors (44%), such as fire, animals, insects, humans, and land grabbing, as difficulties, while 31% mentioned asset-related factors such as capital, labor, soil, and land availability as difficulties (Figure 5.4). Seedling-related difficulties, such as insufficient seedlings for planting and patching, seedling transport, and late seedling supply, were also considered difficulties but were less frequently mentioned (8%). Other less-mentioned difficulties were low survival of trees (9%), interference of trees with crops (5%), and the need for technical support from FD (3%).

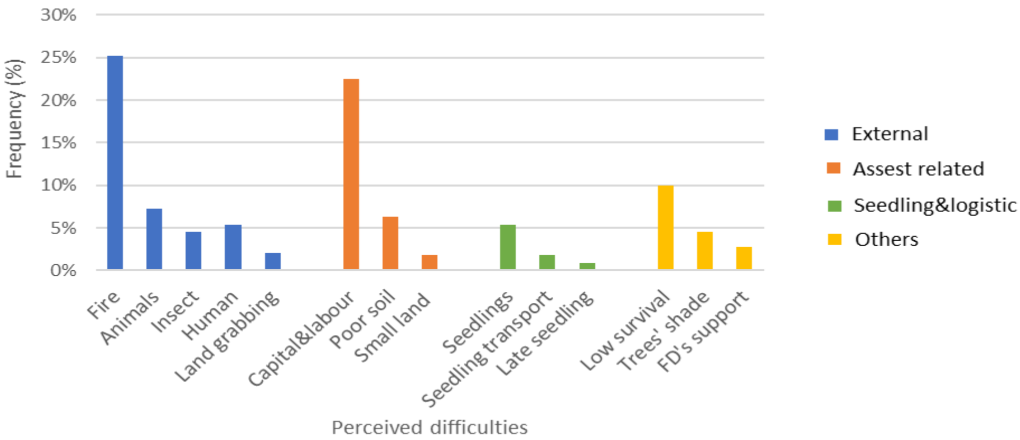

Figure 5.4: Frequency of difficulties mentioned by farmers (n = 103) during the implementation of Agroforestry Community Forests

In all design categories, interviewed households faced difficulties related to tree destruction by fire and animals such as cows and buffalo. Fire disturbance was mentioned as the main challenge for the growth of trees in Categories A and C, while limited availability of family labor was the main constraint for the maintenance and establishment of ACFs in Category B. In Category D, the illegal cutting of forest remnants was the major challenge for the farmers.

5.4.5 Influence of FD in the design selection process

FD provided information to farmers about three planting designs, namely, boundary planting, woodlot planting, and alley cropping. However, only a few households (n = 25, 9% of total households) were informed about alley cropping, and none of the farmers adopted this design on their farms. Therefore, alley cropping was omitted as a practice category.

Twenty-four percent of the interviewees were not informed by the FD about any planting design. A total of 60% were informed of only one planting design, 13% of interviewees received information about two designs, and 3% of interviewees received information about three designs. Thus, only this last group received the complete information for design selection.

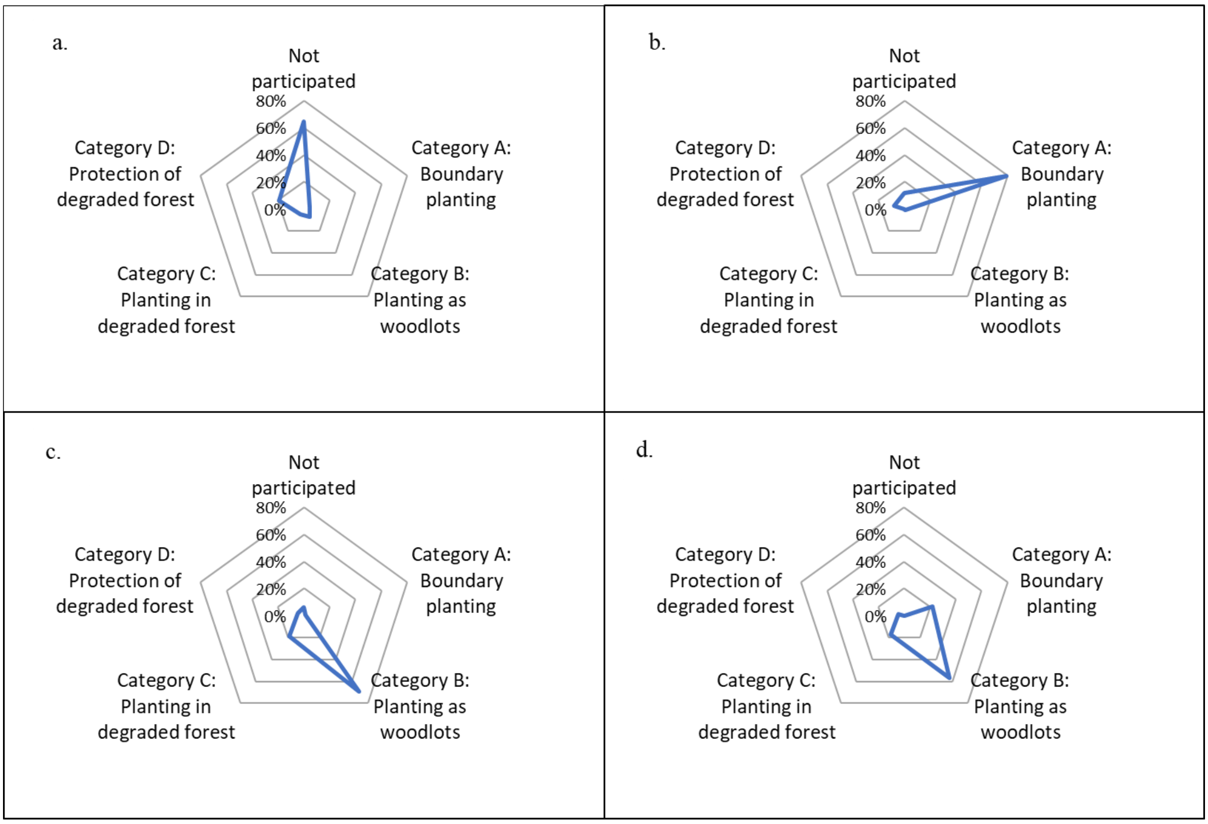

Figure 5.5: Percentage of households practicing different ACF planting design categories with a. Households receiving no information on planting designs (n = 68). b. Households who received information about planting trees within farm boundaries (n = 78). c. Households who received information about planting as woodlots (n = 81), and d. households who received information about boundary and woodlot planting (n = 23)

Households that were not informed about planting designs were unlikely to participate in tree planting. Only 17% of such households planted trees as ACFs (Figure 5.5-a). The majority (64%) of them did not adopt ACFs and did not plant any trees, while the remaining 19% also did not plant any new trees; however, they claimed that they protected their degraded forests as ACFs instead (Category D).

Households that were informed of only one planting design were likely to implement this specific design. Seventy-eight percent of households that were informed about boundary planting implemented this design (Category A) (Figure 5.5-b). Similarly, 63% of households that were informed about woodlot planting implemented this design (Category B) (Figure 5.5-c). Households that were informed about "Category A: boundary planting" and "Category B: planting as woodlots" tended to choose Category B (Figure 5.5-d).

We found a significant association between the information provided by the local FD and the designs implemented by the households, as indicated by a Pearson chi-square test of association ($\chi2$ (28) = 300; $p<0.01$). Therefore, farmers were significantly more likely to practice a design that had been provided by the FD.

5.4.6 Influence of household characteristics on design selection

The one-way ANOVA showed that the total annual income of the households, household size, number of family workers, and education did not differ significantly between the different design categories (Table 5.2).

Table 5.2: Household characteristics of different designs and ANOVA results

	Unit	A: Boundary planting	B: Planting trees as woodlots	C: Planting trees in degraded forest remnants	D: Protection of degraded forest remnants	*p*-value (ANOVA)
Mean annual income per household	USD	2468	2120	3243	2133	0.111
Household size	Person	4.8	4.6	5.2	4.7	0.507
No. family labour	Person	2.9	3	3.2	2.8	0.673
Education	Level	1.1	1.1	1.2	1.0	0.425
Total land size	Ha	3.9^{a}	$4.6^{a,b}$	6.2^{b}	$4.6^{a,b}$	0.046*
Age	Year	51^{a}	54^{a}	$48^{a,b}$	43^{b}	0.001**

*Note: (*p ≤ 0.05, significant **p ≤ 0.01, strongly significant. a,b,c Within a row, values not sharing a common superscript differ significantly (p < 0.05))*

Only "age" and "total land size" differed significantly between categories, and a pairwise comparison indicated that farmers practicing Category D are significantly younger than those practicing design categories A and B. The total land size of farmers implementing Category A was significantly smaller than that of farmers implementing Category C.

5.4.7 Evaluation of different design categories

A total of 25% of participating households reported that all trees planted as part of the ACFs had been lost by the time of the study. For the farms with surviving ACF trees, we evaluated the stand characteristics of different ACF designs and those in the forest inventory results (Table 5.3). ACFs with the Category A design had, on average, the lowest density of trees, with 129 ± 75 trees/ha and a mean basal area of 2.53 m^2/ha compared to other categories.

To compare the inventory results with the FD's goal of planting a minimum of 375 trees per ha of farmland, the average number of trees per ha of the total farmland for all categories was lower than 375 trees for all design categories. In calculating the average trees per ha of total farmland for categories C and D, we also considered the degraded forest remnants as part of the farmers' property based on their perception. The highest average number of trees was therefore 282 trees per ha of farmland in Category C (Table 5.3) through keeping forest remnant.

Table 5.3. Stand characteristics comparison among different designs

Category	*no. plot*	*Average species number*	*Mean number of trees in forested areas (trees/ ha)*±MOE	*Average forest plot-to-farm ratio*	*Mean number of trees per farm (trees/ ha)*	*FD's target (trees / ha)*	*Mean basal area (m^2/ ha) ±MOE*
A: Boundary planting	12	2	129±75	Around the farm	129	375	2.53± 1.6
B: Planting trees as woodlots	15	4	767±282	0.24	184	375	3.98± 1.6
C: Planting trees in degraded forest remnants	9	10	1175±464	0.24	282[a]	375	9.31± 5.1
D: Protection of degraded forest remnants	6	6	438±180	0.31	136[a]	375	7.79± 7.2

Note: ([a] =considering the degraded forest remnants as farmers' farmland, MOE=Margin of errors; FD = Forest Department)

Categories C and D had larger basal areas than categories A and B, which was mainly due to the previously existing vegetation and trees within Categories C and D. Category B had an overall smaller basal area, although it had more trees per ha than Category D. This was because plantations in Category B were relatively younger (3–6 years), thus most of the trees had a small DBH.

Overall, Category A performed the poorest among the implemented designs, as it had the lowest number of trees and the smallest tree basal areas. According to interviews, Category A trees that were planted at farm boundaries were more vulnerable to disturbance by animals, humans, and fire, compared to trees in the other categories. Furthermore, if the planted tree species provided no economic benefit to the farmer, then the farmer tended to provide less care and protection to the trees. During field visits, surviving trees in Category A tended to be mainly found between the cropping area and non-arable areas (e.g., stony hills, fallow areas, or streams).

5.5 Discussion

The results of this study highlight the level of participation of households in ACFs, the agroforestry designs implemented, and the condition of trees in ACFs differed from the initial FD recommendations and expectations.

The results show overall poor participation of farmers in ACFs, which has been a major challenge in the success of community forestry projects. Twenty-one percent of all households in the study did not actively participate in reforesting the agricultural encroachment areas, although they were listed as ACF members by the FD. The major variables affecting participation were the total land size of households and information provided by the FD about ACFs. The other household characteristics of farmers, such as age, education, labor, and income, did not affect participation in ACFs. The majority of households reporting a lack of information about ACFs as a major reason for not participating also tended to have insufficient land and were generally reluctant to grow trees on their farms. These results agree with those of previous studies conducted in South East Asia and Africa, where the unfavorable attitude of farmers toward tree planting and the lack of knowledge of tree planting were the major factors influencing the decisions of households to plant trees or adopt agroforestry practices (Meijer et al. 2015; Le et al. 2021).

The FD is the main source for information transfer related to ACFs, including the different possible designs. However, we found that the FD provided insufficient and inconsistent information on ACFs to the farmers. Farmers were likely not to participate in tree planting if they had limited knowledge about ACF designs and practices. Results from similar studies also highlight that a lack of awareness and poor knowledge can hinder the adoption of agroforestry by farmers (Pathania et al. 2020; Bettles et al. 2021). We also found that if farmers were given only one option of planting design, they tended to implement this specific design regardless of their perception. To ensure their long-term participation, consideration of farmers' preferences on designs and provision of sufficient information about different design options are essential to the success of large-scale ACF programs. This recommendation is in line with the findings of other studies that have pointed out the importance of information transfer, access to information, and the effects of information asymmetry in the implementation of agroforestry practices (Bettles et al. 2021; Ullah et al. 2022). Hence, improving information transfer and increasing the level of consideration and inclusion of farmers' perceptions on ACF design selection are necessary steps to ensure the success of future ACF programs.

In addition to providing information on ACFs and their planting designs, the FD also decides which species to distribute, which is done without considering the farmers' preferences. Previous studies have pointed out the importance of participation in the tree species selection process in the adoption and long-term maintenance of agroforestry practices, including ACFs (Weber et al. 2001; Kasolo and Temu 2008; He et al. 2015; Leakey 2017). Including farmers' interests and preferences for the selection of tree species, such as multipurpose tree species, would increase the motivation to grow trees on farms. Alternative income-generating activities apart from agriculture may help to incentivize farmers to protect and use trees, resulting in a shift from short-term financial interest to the long-term benefits of managing trees (Poscher and San 2022). In addition, given the poor education level of farmers, capacity-building programs for farmers are necessary to enable them to develop an ACF management plan that includes provisions for the selection of their preferred species and designs for ACFs. Previous studies on CF implementation in Myanmar have also highlighted the need for capacity building and technical support for farmers (Tint et al. 2011; Yamauchi and Inoue 2012; Poscher 2017).

A previous study by Soe and Yeo-Chang (2019) identified land tenure insecurity as an important factor affecting participation in forest conservation (Soe and Yeo-Chang 2019b). In our study, land use rights or land tenure security were mentioned by only a few (3%) farmers as a motivation for adopting ACF, although one of the major benefits of establishing ACFs is secure land use rights according to the Community Forestry Instructions of 1995 and 2018. As farmers have settled on the state forest land for multiple generations, it is possible that farmers already have an informal sense of land use security concerning state land on which farm settlements have encroached. Further investigation into the informal sense of land use security of the encroaching farmers is recommended.

According to our results, the majority of farmers (56%) were pressured by the FD to grow trees, while 44% were motivated by the benefits of ACFs. Other studies have shown that the motivation and interest of farmers were fundamental factors in agroforestry and CFs establishment (Baynes et al. 2015; Gebreegziabher et al. 2021). Therefore, future implementation of ACFs should be based on farmers' motivation and willingness rather than on pressure from the FD.

We found a strong negative perception among farmers regarding growing trees near crops. This perception hindered active participation in ACFs if it involved planting trees near the crops. Even though the FD expects farmers to practice alley cropping as one of the design practices in agricultural encroachment areas, the practice was not widely adopted, and those who were informed did not adopt it because they did not want the trees to disturb crop production in the middle of their fields. Our analysis of tree conditions under the different designs shows that trees in the “boundary planting” design had poor long-term survival, as farmers were worried about crop disturbance from the growing trees, resulting in a low number of trees per hectare. Only the practices that completely separated trees from the cropping areas had higher rates of tree survival. Whenever farmers assumed that planting trees meant sacrificing part of their agricultural income, they tended to lose their motivation to maintain trees on their farms. A study in Indonesia and Bangladesh pointed out that farmers’ resistance to changing their agricultural practices to tree-based agroforestry is likely related to the farmers’ inability to cope with the expected short-term loss in income from crop production before reaping the economic benefits of trees (Rahman et al. 2016). Further research into the underlying reasons behind farmers’ reluctance to grow trees on their farms and ways to change this attitude is necessary. If the FD, non-government organizations

(NGOs), and other bodies supporting reforestation through agroforestry intend to maintain long-term participation of farmers, it is important to create an inherent interest in farmers in growing trees by first educating them about the benefits of agroforestry and the interactions between trees and crops in agroforestry systems.

To help farmers understand the benefits of ACFs, we recommend establishing farmer field schools that can show successful cases of agroforestry practices and ACFs in a similar agroecological zone. Farmers-to-farmers training and knowledge sharing have proven to be successful for the adoption of sustainable land use practices, including agroforestry (Böhringer 2001; Kansanga et al. 2021). Furthermore, many studies in Myanmar and other countries have shown the potential benefit of agroforestry in comparison to conventional agriculture, with the former generating more environmental stability and economic profits (Córdova et al. 2018; Thinn et al. 2020; Duffy et al. 2021). Hence, to ensure the long-term participation of farmers, they should have a full understanding of the benefits of ACFs, and such knowledge should be transferred through well-established extension services or capacity-building training. Securing more resources, especially adequate staffing and financial support, is also needed for both farmers and the FD (Tint et al. 2011).

Participating farmers also reported that external disturbances caused by fire, livestock, and humans, as well as financial and labor constraints, were the main difficulties during ACF implementation and management. Providing technical and financial support for farmers by the government or other agencies, such as NGOs, as well as building a platform or network to provide support for farmers, can be a useful tool to handle the difficulties faced during ACF establishment. Establishing revolving funds among members may also be a way to overcome the problem of limited financial resources (Khaing et al. 2019).

Degraded natural forest-based designs performed well as ACFs, and all farmers who implemented these categories successfully maintained forested land at the time of the study. Clearing degraded forests or natural forest remnants to grow monocultural plantations has been criticized as “agrodeforestry” (Ollinaho and Kröger 2021) and should be avoided. Hence, whenever non-arable or unused land is available, farmers should be encouraged to plant additional indigenous trees in the degraded natural forest remnants, rather than clearing the natural vegetation to establish tree plantations. In this way, the existing conditions of forest remnants in or around the farms can be improved as well as protected from further encroachment while providing the benefits of ACFs to the farmers. The success of this approach was reported in Nepal, where CF was implemented by forest encroachers to conserve state forest remnants (Bhusal et al. 2018).

We found that the goal of the FD to transform the agricultural encroachment areas into agroforestry farms was not achieved in the study area. Although the applied CFs framework was originally developed as a bottom-up approach, the FD adopted a top-down approach in implementing ACFs. Many studies have pointed out the inefficiency of a top-down approach and the necessity for continuous governmental support of agroforestry-based reforestation programs, especially in the global south (Höhl et al. 2020; Bettles et al. 2021). To ensure the long-term participation of local farmers in community-based farmland reforestation activities and to increase the effectiveness of such activities, it is necessary to increase farmers' awareness of agroforestry systems and their benefits. Farmer acceptance of planting trees can be enhanced by considering their preferences, providing capacity-building training, developing incentives for long-term participation, and providing continuous technical support throughout the transition from agriculture to agroforestry. In addition, improved coordination and communication between the relevant ministries overseeing farmers, especially the ministries of agriculture and forestry, is recommended. These ministries should work to support clear tenure rights, enforce the law, and hamper illegal activities to prevent future agricultural expansion in forests.

Furthermore, the political situation under military rule in Myanmar is currently unstable and unfavorable for sustainable forest management (MONREC 2021). A stable and democratic political situation, a re-established rule of law with reduced corruption, openness to international financial and technical support, and well-functioned and coordinated government institutions are also important frame conditions that could support the long-term success of the ACF implementations.

5.6 Conclusion

The level of participation of households in ACF implementation was much lower than what the FD expected and claimed. The reasons for non-participation were related to insufficient land size, limited knowledge about ACFs, and the general reluctance of farmers to grow trees close to their crops. The majority of farmers adopted ACFs due to pressure from the FD, rather than inherent motivation. Participating farmers implemented four different ACF design categories, and FD greatly influenced farmers' decisions on design and species selection. However, because of the negative perception of growing trees near crops, farmers tended to plant trees in degraded forest remnants or outside the cropping areas.

To improve this situation, we suggest that the FD should consider farmers' perceptions and interests in ACF implementation, especially during the species and design selection process. A strategy to provide sufficient funds and qualified human resources that will invest time and effort in ACF establishment, as well as to provide incentives that will motivate farmer participation, should be developed by the FD or the implementing agencies. In addition, farmer field schools and well-functioning extension services should be established to increase farmers' interest in the socioeconomic and ecological benefits of agroforestry practices. A stable political situation, close coordination between ministries, reduced corruption, and better rule enforcement would be beneficial to increase the chances of successful ACF adoption and increased sustainability.

6 TOWARD SUCCESSFUL IMPLEMENTATION OF AGROFORESTRY-BASED COMMUNITY FORESTS IN MYANMAR: INCORPORATING FARMERS' PERCEPTIONS THROUGH AN ECOSYSTEM SERVICES APPROACH

This chapter has been submitted as San, S. M., Kumar, N., Biber-Freudenberger, L., & Schmitt, C. B. (2026). Toward Successful Implementation of Agroforestry-based Community Forests in Myanmar: Incorporating Farmers' Perceptions through an Ecosystem Services Approach. *Trees, forest, and people*, xx(x), xx.

6.1 Abstract

Agroforestry is a popular reforestation approach in agriculture-forest landscapes due to its focus on diverse ecosystem services. In Myanmar, agroforestry-based community forests (ACFs) have been implemented since 2013 to reforest agricultural encroachment areas in state forests. This study aimed to improve ACF implementation by analyzing farmers' perceptions of the contribution of ecosystem services, including provisioning, regulating, supporting, and cultural services, to their livelihoods. We surveyed 291 households by using a questionnaire including closed and open questions, and conducted forest inventories across 42 sample plots. The methods for analyzing social data included descriptive statistics, partial proportional odds model, and qualitative co-occurrence analysis. With regard to forest data, we analyzed species composition, above-ground biomass, and canopy cover. The results showed that farmers perceived provisioning services as the most desirable, followed by regulating services. The level of education of respondents influenced the perceived importance of local regulating ecosystem services and biodiversity conservation whereas household income affected perceptions of the importance of cultural services. The contribution of ACFs in terms of provisioning services and their economic potential was very low, highlighting an urgent need for enhancing these ecosystem services. We discuss options for improving provisioning services as well as other ecosystem services based on farmers' needs and values. Among these options is the incorporation of fast-growing native tree species that generate short- and long-term income by providing farmers with valuable timber and non-timber forest products. Overall, this study demonstrates that applying the ecosystem services framework to assess farmers' perceptions and the current contributions of ACFs provides insightful results highlighting the poor socio-economic contributions of ACFs to their livelihoods, and their ecological role in supporting environmental stability.

Keywords: reforestation; agriculture-forest landscape; forest policy; household characteristics; provisioning services; regulating services

6.2 Introduction

The concept of ecosystem services has been widely explored in scientific research (de Groot et al., 2010; Dehghani Pour et al., 2023; Xun et al., 2017). The concept acknowledges the crucial role of ecosystems and biodiversity for human wellbeing via the provision of different services integrating multiple aspects (social, economic, and ecological) (Alcamo et al. 2003; Millennium Ecosystem Assessment 2005). It provides policymakers with a holistic view from different perspectives, especially when assessing the effects of introduced policies on socio-ecological systems. Numerous studies have focused on and recommended the ecosystem services concept due to its usefulness in the development of environmental policies (de Groot et al., 2010; Dehghani Pour et al., 2023). This multidisciplinary approach also considers both the tangible and intangible benefits of ecosystems as well as their importance for decision-making (de Groot et al., 2010; Fontana et al., 2013; Raihan, 2023).

The Millennium Ecosystem Assessment (MEA) framework, developed in 2005, highlights the contributions of natural ecosystems to human well-being, categorizing them into four main types of services: "provisioning," "regulating," "supporting," and "cultural" (Millennium Ecosystem Assessment Program, 2005). The Economics of Ecosystems and Biodiversity Ecosystem services report also defined ecosystem services as "the direct and indirect contributions of ecosystems to human well-being" (TEEB, 2010). Among the variety of ecosystems worldwide, forests are particularly important as they provide a diverse range of services and benefits to human beings, both directly and indirectly (Jenkins and Schaap, 2018). In particular, tropical forests play a vital role by offering various products, mitigating climate change through carbon sequestration, conserving soil and water, cycling nutrients, and providing socio-cultural benefits (Brandon, 2014). During the past decades, deforestation has led to the loss of significant portions of tropical forests, compromising the vital ecosystem services they provide (Brandon, 2014; Hoang and Kanemoto, 2021; Jayathilake et al., 2021).

As agricultural expansion is one of the main drivers of tropical deforestation (Jayathilake et al., 2021; Kissinger et al., 2012), many reforestation efforts have focused on forest recovery at tropical agricultural frontiers (Harper et al., 2017; Paul et al., 2016; Yue et al., 2020). In particular, agroforestry is considered a potentially sustainable land use practice and has been applied as a reforestation strategy in agriculture-forest landscapes, especially in tropical regions with high deforestation rates. Previous studies have highlighted the important roles of various agroforestry practices and their contribution to human wellbeing via diverse ecosystem services (Dhyani and Handa, 2014; Duffy et al., 2021; Jose, 2009; Luedeling et al., 2016; Shennan-Farpón et al., 2022).

Like other tropical countries, Myanmar has a particularly high deforestation rate, mainly driven by agricultural expansion (Lim et al., 2017; Naing Tun et al., 2021). Since 2013, the Myanmar Forest Department (FD) has been implementing agroforestry-based community forests (ACFs) to reforest areas encroached upon by agriculture in state forests, fulfill farmers' needs and to secure forest land titles (FD, 2013; President's Office, 2013). The implementation approach is based on farmers' participation in tree planting and maintenance in the agricultural areas in state forests (FD, 2013). Originally, farming in the state forests was considered as illegal encroachment by the FD. Except for irrigated paddy fields, all land in the state forest area, including cultivated fields, has a state forest land title and falls under the management of the FD. Through ACFs, farmers are granted land-use and management rights to those areas as community forests, if they convert their fields to agroforestry and register the areas as ACFs. However, these rights cannot be sold or transferred, except by inheritance. Thus, participation in ACFs through agroforestry serves as a way for encroaching farmers to secure their land-use rights with the risk to incentive encroachment behavior.

Previous studies have however highlighted poor participation and performance of ACFs, resulting in low numbers of trees present on agricultural land and continued deforestation around the ACF areas (San et al., 2024, 2023). The failure of ACFs was mainly attributed to poor farmer participation and a lack of consideration of their perceptions during ACF establishment (San et al., 2023), which is key to the successful planning and implementation of ACFs (Pagdee et al., 2006; Sanou et al., 2019). Nevertheless, despite these poor outcomes, ACFs continue to be implemented nationwide (FD, 2020a).

Some studies in Myanmar suggested different ACF policy modifications focusing on their governance approaches, implementation, and outcomes at the landscape and field levels; however, understanding farmers' perceptions of benefits from ACFs remains insufficiently understood (Han et al., 2025; San et al., 2024, 2023). Therefore, this study aims to address this gap by examining farmers' perceptions and interests regarding ACF benefits in Myanmar through ecosystem services concept, an approach that has received limited attention in previous ACF studies in Myanmar, providing new insights for improving ACF planning and implementation. Based on the concept of ecosystem services, we assessed both the direct and indirect benefits that ACFs provide to farmers. To this end, we adopted the

MEA framework, as it offers a comprehensive approach that integrates social, economic, and ecological aspects. Specifically, this study addresses the following research questions: 1) Which ecosystem services do farmers expect from ACFs, how do they perceive their importance, and how are these expectations related to household characteristics? 2) To what extent do ACFs provide ecosystem services at the time of the study? To answer these research questions, we employed a mixed-methods approach combining a household survey and field measurements.

6.3 Materials and methods

6.3.1 Conceptual framework

In this study, we adopted the ecosystem service categories defined in the MEA framework, i.e., provisioning, regulating, cultural, and supporting services. According to MEA (2005), provision services are “products obtained from ecosystems”, regulating services are “benefits obtained from the regulation of ecosystem processes”, cultural services are “nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences” and supporting services are “services necessary for the production of all other ecosystem services”. As the ecosystem services provided by tropical forests vary widely depending on the scope of studies, it is challenging to comprehensively assess all the benefits, particularly when time and resources are limited. Another challenge is that people are often unaware of the benefits they receive from nature until these services are threatened or no longer available, as in the case of flood protection and groundwater recharge (Souza et al., 2024; TEEB, 2010).

Therefore, we selected the variables for assessment based on previous literature, measurability, and relevance for this study context (Baral et al., 2016; Jose, 2009). Specifically, we chose variables that reflect the ecosystem services most directly linked to agroforestry practices and farmers’ livelihoods, including forest product production and income generation, climate regulation, soil and water protection, biodiversity conservation, traditional uses and recreational benefits (Table 6.1). These variables are observable at the household level, relevant to local management practices, and meaningful for assessing farmer perceptions in the ACF context. The overall research design and methods of the study are also illustrated in Figure 6.1.

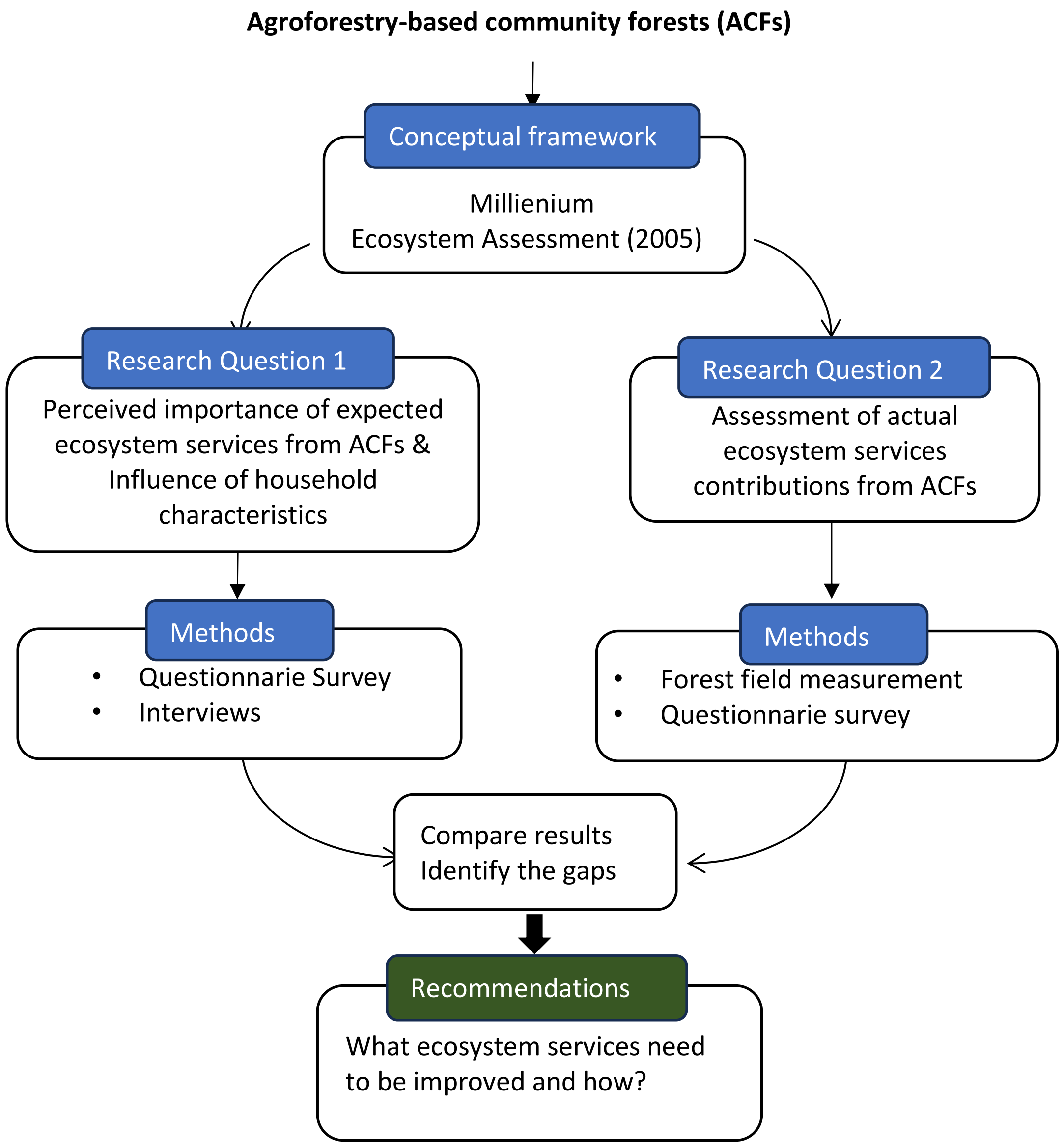

Figure 6.1: Research flow of the study

To assess provisioning services from ACFs, we collected data on all forest products harvested from ACFs for subsistence and income generation during the field survey. We also determined the commercial value of species detected in the forest inventory sample plots to evaluate their economic potential, which is described in detail in section 3.4. In our survey on the perceived importance of provisioning services, we explained this concept to farmers using the phrase "production of forest products (including own use and income)" (Table 6.1).

Table 6.1: Conceptual framework of our research based on the Millennium Ecosystem Assessment (2005) framework, including applied variables and corresponding data collection methods.

Ecosystem Service Type	Perception of farmers	Ecosystem Service Assessment
Provisioning Services	- Perceived importance of forest products (own use & income) (Survey, n = 291) - Interest in tree species and reasons for preference (Qualitative interview, n = 79)	- Harvested forest products (survey, n = 230) - Commercial species composition (forest inventory, n = 42)
Regulating Services	- Perceived importance of climate regulating (Survey, n = 291) - Perceived importance of soil & water protection (Survey, n = 291)	- Above-ground tree biomass (forest inventory, n = 42) - Vegetation cover measurement (forest inventory, n = 38)
Supporting Services	- Perceived importance of biodiversity conservation *(Survey, n = 291)*	- Tree species richness *(forest inventory, n = 42)*
Cultural Services	- Perceived importance of traditional value *(Survey, n = 291)* - Perceived importance of recreational value *(Survey, n = 291)*	- Contributed traditional and recreational value *(survey, n = 230)*

Under regulating services, forest ecosystem services can cover a wide range of services, including the regulation of climate, water, soil and air quality, erosion, and flood control. To assess global climate regulation, we measured the above-ground biomass of trees as it is directly linked to carbon sequestration and storage, soil protection, and nutrient cycling (Houghton et al., 2009; Thiffault et al., 2011). Additionally, we evaluated vegetation cover, an important indicator of soil and water protection (regulating services) (Ruiz-Colmenero et al., 2013; Zhou et al., 2008), by measuring canopy and ground cover percentages in the ACF sample plots. In the survey of farmers' perceptions with regard to the importance of regulating services, we referred to them using phrases such as "regulating climate" (meaning benefits of ACFs for local climate regulation) and "protection of soil and water."

The supporting services provided by forests are significantly affected by habitat quality, with the diversification and types of tree species determining the quality of habitats for biodiversity. (Nikula et al., 2004; Plath et al., 2012; Styring et al., 2011). Therefore, to assess supporting services, we determined tree species richness within ACFs (Table 6.1). In the survey of farmers' perceptions with regard to the importance of supporting services, we used the phrase "biodiversity conservation" to explain to farmers.

According to the MEA framework, cultural services are defined as "the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences" (Millennium system Assessment 2005). Another study simply refers to them as "cultural and amenity services" (de Groot et al., 2010). Therefore, we included traditional and recreational values under the cultural services category within the questionnaire-based survey. Traditional value refers to the knowledge and practices related to the use of forests that are passed down through generations, whereas recreational value is related to the spiritual well-being brought by ACFs (for example, by providing shade for rest during farming activities). To examine farmers' ecosystem service preferences related to ACFs and their actual contributions, the following data collection procedures were applied.

6.3.2 Questionnaire-based survey, qualitative Interviews, and data analysis

A questionnaire-based survey of 291 households was conducted in July and August 2020 to assess which ecosystem services provided by ACFs were desirable for farmers (see questionnaire in Appendix 4). Prior to data collection, ethical approval was granted by the Research Ethics Committee of the Center for Development Research (ZEF), University of Bonn, Germany. Sample households were selected from the ACF member household registry (n = 2,409) provided by the FD using a disproportional stratified random sampling method, stratified by township and ACF establishment year (2014–2018). The required sample size was calculated following the methods of Desu and Raghavarao (1990) and Hahn and Meeker (1991) using NCSS software (NCSS, 2020). A total 291 samples provided a 90% confidence interval with a margin of error of ±0.027 for an estimated proportion of 0.10. Household heads or other adult members present at the time of data collection were interviewed, depending on availability (see also San et al., 2023). Of all the consented respondents, only 25% were female and 75% were male depending willing to participate to answer the questions and their availably. Therefore, the predominance of male respondents (75%) may introduce gender-related bias in the results and should be considered when interpreting the findings. Additionally, as the sample was selected from the FD registry and accessible areas, it may not represent the perceptions of farmers who were not registered as participants in ACF implementation or those living in difficult-to-access areas.

For decisions with regard to desired ecosystem services and importance levels, we employed a participatory ranking method via the illustration of ecosystem services and point allocation. We first explained the meaning of each ecosystem service with the help of illustrations and captions. Then we conducted a point allocation exercise to help respondents decide the importance of each ecosystem service. To facilitate participation among respondents with varying literacy levels, each respondent received 10 candies as tangible importance points and was required to distribute all candies individually across the six ecosystem services, thereby indicating their relative importance. Respondents were allowed to allocate zero or multiple candies to any service. After the allocation, they confirmed and categorized the importance level of each ecosystem service based on the number of candies they had allocated. Importance levels were classified into four levels: very important, moderately important, slightly important, and not important. All allocations and corresponding importance levels were recorded for analysis.

To identify the determinants of farmers' perception, we used age, education level, gender, land size, and total household income as independent variables and the perceived importance of ecosystem services as dependent variables. Although dependent variables were ordinal in nature, the proportional odds assumption required for ordinal logistic regression was violated, as indicated by the Brant test (Brant, 1990). To address this issue, a partial proportional odds model was employed instead, as it allows certain predictors to vary across response categories, while other predictors adhere to the proportional odds assumption (Sasidharan and Menéndez, 2014).

Furthermore, as part of the questionnaire-based survey, we gathered data related to the provisioning and cultural services provided to the households of farmers implementing ACFs (n = 230). Non-implementing farmers (n = 61) were excluded from this part of the questionnaire. We also gathered qualitative information about the interest of farmers in particular species and the reasoning for desired ecosystem services using open-ended questions during the survey. This allowed us to better understand the farmers' preferences and possible ways for enhancing the ecosystem services they valued. Based on their availability, capacity, and willingness to provide detailed explanations, only 73 farmers responded to the questions. We applied an inductive approach and encoded the responses obtained based on species, respective reasoning, and perception of different ecosystem services, and conducted a co-occurrence analysis using ATLAS.ti 24 software (ATLAS.ti Scientific Software Development GmbH, 2024; Thomas, 2003).

6.3.3 Assessment of ecosystem services derived from ACFs

To assess the ecosystem services currently provided by ACFs, we established a total of 42 sample plots in the ACF areas of participating farmers. We conducted the field assessment during July and August 2020. When selecting the sample plots, we excluded failed ACFs that had no remaining trees at the time of the study (San et al. 2023b). We selected sample plots covering the following ACF categories: "boundary planting," "planting as woodlots," "planting in degraded forest remnants," and "protection of degraded forest remnants." (San et al. 2023b). The diameter at breast height (DBH), total height, and species names of all trees with a DBH ≥ 5 cm were measured in 400-m^2 sample plots following the procedures described in Ravindranath and Ostwald (2008) (Figure 6.2). Since the farming practices in the study area were typically small-scale agriculture, the 400-m^2 sample plot design was also suitable for the boundary planting category. The sample plots were carefully set up to represent the whole farm area, which aided in capturing any trees present inside the farms. Therefore, this sample plot design was maintained for all ACF designs. Additional information on the selection and setup of sample plots can be found in San et al. (2023b).

To evaluate the economic potential of ACFs in terms of provisioning services, the tree species identified in the sample plots were categorized into five groups based on the guidelines of the Myanma Timber Enterprise (1992), with Group 1 comprising trees producing timber of high commercial value, and Group 5 including those with the lowest commercial value. Teak (*Tectona grandis*), the most valuable native tree species in Myanmar, and Eucalyptus (*Eucalyptus camaldulensis*) and *Acacia mangium*, which are non-native species, were considered as a separate category due to their significance. Additionally, trees used for non-timber forest products (NTFPs), such as fruits, resins, or medicinal products, were also classified separately to highlight their distinct uses. The detailed classification of tree species is included in Appendix 8.

To evaluate regulating services, we estimated the above-ground biomass of trees in ACFs as an indicator of their contribution to global climate regulation using methods previously applied for tree species in the Bago Yoma mountain range (Oo and Lee 2012; Chan et al. 2013; Lwin and Aung 2015). In forest remnants-based ACFs, we used the methods developed for fallow forests in the Bago region described in Chan et al. (2013). In woodlot planting and boundary planting, AFCs with few planted species, we used species-specific equations to estimate above-ground biomass. In cases where such equations were not available for certain species in the study area or in Myanmar, e.g., for Eucalyptus plantations, we applied equations developed for those species in nearby countries with similar site conditions. The equations used for calculations are listed in Appendix 5. The above-ground tree biomass in the different ACF types, originally calculated in kilograms per plot, was converted to metric tons per hectare to enable comparison with other studies. Because the total plot area for each design was less than 1 ha, the extrapolated values should be interpreted with caution. Moreover, these estimates rely on the assumption that tree distribution across a full hectare is uniform and comparable to that observed within the sample plots.

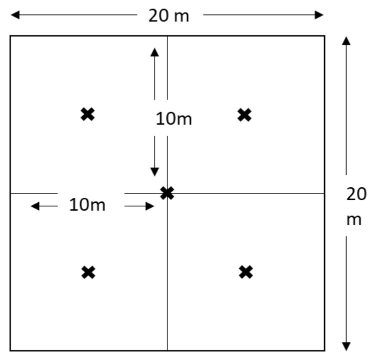

Figure 6.2: Sample plot design for the estimation of above-ground biomass of trees, vegetation cover, and tree species richness for all agroforestry-based community forest (ACF) categories (adapted from Ravindranath & Ostwald, 2008) (✖ = points in which photos of the vegetation cover were taken).

Canopy cover was estimated by taking hemispherical (zenith) photos using a smartphone camera with a fisheye lens, as this method is more reliable, simple, and time-efficient than taking hemispherical photos using a traditional camera or estimation via other visual techniques (Tichý 2016; Salas-Aguilar et al. 2017; Bianchi et al. 2017). Ground cover was assessed by taking pictures of it from above. Both the photos for assessing canopy cover and ground cover were taken from five sampling points in each sample plot (see Figure 6.2). We captured all hemispherical and downward photographs from a height of 1.3 m above the ground (Figure 6.2). Due to adverse weather conditions in July 2020, canopy and vegetation cover were successfully photographed in only 38 out of 42 sample plots. Consequently, the vegetation cover analysis, which evaluates ACF-derived regulating services, presented in Section 6.4.4, is based on data from these 38 plots. Photographs were analyzed using the GLAMA (Gap Light Analysis Mobile Application) and Canopeo applications to calculate the average canopy cover and ground cover percentages in each plot (Tichý 2016).

6.4 Results

6.4.1 Farm household characteristics

The age of household members who participated in the survey ranged from 26 to 83, with an average age of 50 years, and each household included five persons on average. In terms of gender, 75% of the respondents were male, and 25% were female. We intended to include more females (up to 50%), but they were less available and/or willing to take the survey. The average annual household income was around 2,465 USD per year, with the majority (57%) earning between 1,000 and 3,000 USD per year. The average land size per household was 4 ha, and agriculture represented the main source of income. Common crops cultivated in the area included sesame, groundnut, and rice. The majority of the respondents (45%) had a primary school education, whereas 43% had informal education, and the rest, 13% had higher education. The characteristics of farm households are detailed in Appendix 6.

6.4.2 Quantitative analysis of farmers' perceptions of the importance of ecosystem services derived from ACFs

Perceived importance of forest ecosystem services

Among all survey respondents (n = 291), 10 did not answer questions regarding their perception of the importance of different forest ecosystem services, stating that they were not willing to grow any trees except crops that provided income in the short term. Those 10 households were excluded from subsequent analyses, with the total number of households examined thus being reduced to 281.

As detailed in the ecosystem services framework, the farmers' perceptions of the importance of provisioning services were based on forest products and income obtained from ACFs. Among the 281 respondents, the majority (81.5%, n = 229) considered forest products and income as important benefits gained from ACFs, whereas the remaining 18.5% (n = 52) did not perceive these as important. Obtaining different forest products from ACFs (i.e., provisioning services) was considered the most important benefit by a significantly higher number of respondents compared to all the other ecosystem services (Figure 6.3).

Respondents considered regulating services, including the regulation of local climate, i.e., local precipitation, and temperature, as well as soil and water protection, as the second most important group of ecosystem services provided by ACFs (Figure 6.3). Supporting services (biodiversity conservation) were considered the third most important, whereas cultural services were perceived as the least important.

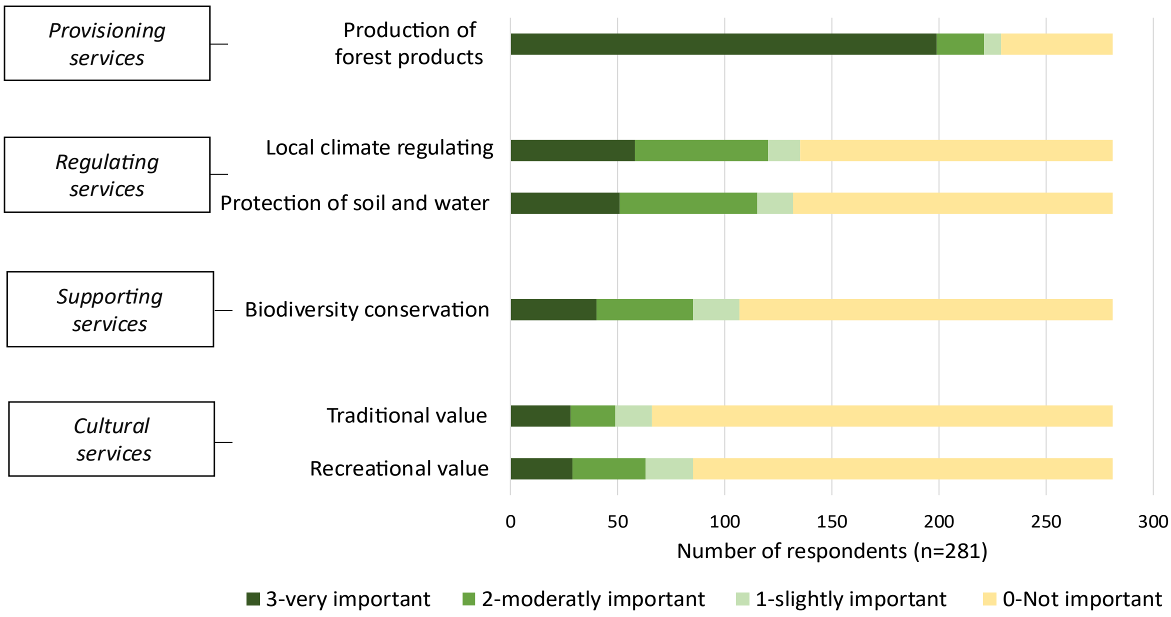

Figure 6.3: Perceived importance of different ecosystem services derived from agroforestry-based community forests (ACFs) in Taungoo District, Bago Region, Myanmar, for 281 farmers.

Influence of household characteristics on the perceived importance of the ecosystem services

To further explore how household characteristics influence farmers' perceptions, we analyzed the data using partial proportional odds regression models. In the following, only the results from the stable and significant models from the different ecosystem services were presented. Results from the logistic models for provisioning services and soil and water protection, which were unstable or not significant, were excluded. Additionally, for each significant model, only results from significant variables were presented below although education, age, household income, landholdings and genders were included as independent variables in all models.

Table 6.2: Results of the partial proportional odds models showing household characteristics that significantly influence the perceived importance of ecosystem services provided by agroforestry-based community forests (ACFs)

Ecosystem services	Variables	Adjusted Odds Ratio at different perceived importance level comparison			Parallel line assumption
		0 vs. 1,2,3	0,1 vs. 2,3	0,1,2 vs. 3	
Climate regulating	Primary education vs no education	1.53	2.21**	1.54	Violated
	Secondary & higher education vs no education	2.23*	2.23*	2.23*	Not violated
Biodiversity conservation	Primary education vs no education	1.07	1.09	0.30**	Violated
Traditional value	Household income	0.98	0.97*	0.93**	Violated
	Total land size	1.03	1.05	1.29**	Violated
Recreational value	Household income	1.00	0.98*	0.99	Violated

*Note: Farmers perceived the respective ecosystem services as 0 = not important, 1 = slightly important, 2 = moderately important, and 3= very important, *= significant ($p < 0.05$), ** = highly significant ($p < 0.01$)*

The partial proportional odds model for the perceived importance of local climate-regulating services from ACFs was statistically significant overall (LR $\chi^2(10) = 28.80$, $p = 0.001$; Pseudo $R^2 = 0.044$). The model indicated that education significantly influences the perceived importance of these services. Respondents with secondary or higher education showed a positive and statistically significant effect (Table 6.2). It indicated that they were more likely to perceive climate regulating services as important than those with no formal education. In case of respondents with primary education, a positive and statistically significant effect was only observed at the intermediate threshold. It explained that respondents with primary education were more likely to perceive climate regulating services as moderately important rather than "not important."

For the perceived importance of ACFs in biodiversity conservation, the partial proportional odds model was statistically significant overall (LR $\chi^2(12) = 23.69$, $p = 0.022$; Pseudo $R^2 = 0.040$). It showed that education had a significant negative effect at the highest threshold (Table 6.2). This indicates that farmers with primary or secondary and higher education were less likely than those with no formal education to perceive biodiversity benefits as very important.

The partial proportional odds model for the perceived traditional value of ACFs was statistically significant overall (LR $\chi^2(10) = 26.69$, $p = 0.003$; Pseudo $R^2 = 0.060$). It showed that total land size had a positive effect at the highest threshold (Table 6.2). It indicated that farmers with larger landholdings were more likely to perceive cultural benefits as highly important. In contrast, household income, showed a significant negative effect at both the intermediate and highest thresholds. It explained that higher-income farmers were less likely to perceive cultural benefits as moderately or very important.

For the perceived recreational value of ACFs, the partial proportional odds model was statistically significant overall (LR χ^2 (10) = 23.97, $p = 0.007$; Pseudo $R^2 = 0.045$). Only household income indicated a significant negative effect (Table 6.2). It explained that higher-income farmers were less likely to perceive recreational benefits as moderately or very important.

6.4.3 Qualitative analysis of farmers' perceptions of the importance of ecosystem services derived from ACFs

To complement the quantitative findings and gain deeper insights into farmers' perceptions, we conducted qualitative interviews with a subset of respondents. Out of 73 farmers, 56 highlighted the importance of receiving provisioning services from ACFs, especially the harvesting of different forest products, such as timber, housing materials, and food, for subsistence as well as for obtaining long and short-term income.

With regard to the tree species of interest, *Tectona grandis* (teak) (n = 42) was most frequently mentioned as one of the preferred trees. Co-occurrence analysis revealed a strong positive relationship between preferring teak and expecting a high income, with a high coefficient value of 0.76, whereas the correlation between the use of timber from this tree for subsistence purposes and income showed a lower coefficient of 0.16 (Appendix 7). One farmer explained the benefits of teak as follows: *"Teak is highly economically valuable and fast-growing. It also endures fire. It grows well even without doing weeding* (ID 46, household survey, translated from Burmese)". Similarly, farmers expressed their interest in other native species such as *Xylia xylocarpa* (Pyinkado) (n = 10) and *Pterocarpus macrocarpus* (Padauk) (n = 5). In addition to their value in terms of high-income potential and subsistence use, these tree species were preferred for improving soil conditions, for the benefit of future generations, and for traditional use.

Farmers also explained their preference for fast-growing timber-producing trees (n = 7) and trees generating short-term income, such as food-producing trees (n = 10). As the time required for generating income is a challenging factor for subsistence farmers, they perceive that planted species should not only provide high economic value but also generate income in the short term. One farmer pointed out the benefits of fast-growing species: "*If a tree species is fast-growing, has good market value, and is useful, then we are motivated to maintain it in the long term* (ID 22, household survey, translated from Burmese)". Other farmers also explained why they are interested in fruit-bearing trees: "*I am interested in planting mango trees in a home garden. I prefer trees which profit me in the short term*" (ID 185, household survey, translated from Burmese) and "*I don't like to grow teak trees because people can steal them or the government can harvest them. So, I want to grow tamarind and mango instead* (ID 240, household survey, translated from Burmese)".

Farmers also emphasized the importance of regulating services (n = 19), primarily in relation to maintaining agricultural productivity (n = 12). However, these services were generally seen as complementary to the more immediate benefits of provisioning services. As one farmer noted, "*With our (livelihood) situations, we cannot consider other aspects like soil and water protection unless they help us to receive benefits for our subsistence and income*" (ID 24, household survey, translated from Burmese). Another explained, "*The most important thing for me is good conditions for agriculture... As the rain is getting scarce, I want to do something to ensure the planting soil gets better*" (ID 5, household survey, translated from Burmese).

Farmers also mentioned the benefits derived from bamboo grown in ACFs (n = 4), highlighting the role of this tree in provisioning and cultural services. They explained that bamboo is widely used for subsistence, especially for house construction and agricultural tools, and also as a source of income. Furthermore, farmers mentioned their interest in cultural services provided by ACFs, such as obtaining traditional plowing tools and shade for resting during agricultural work, even though some of the benefits mentioned were primarily associated with provisioning services.

6.4.4 Assessment of ecosystem services provided by ACFs

Provisioning services

Beyond farmers' expectations, we also evaluated the actual ecosystem service contributions of ACFs. Based on the answers to the questionnaire about the benefits gained from ecosystem services provided by current ACFs, 90% of farmers participating in ACF implementation did not receive any benefits from ACFs for subsistence or income generation by the time of this study. Only about 10% (n = 22) of farmers who established ACFs have profited from harvesting various non-timber forest products, including fuelwood, poles, bamboo, charcoal, roofing materials, and fruits, since the ACF establishment period (2014-2017).

Among them, 12 households profited from naturally regenerated trees in the forest remnants, which they claimed as their ACFs, and not from the trees planted. The monetary value of harvested products used for subsistence was calculated based on the local market price of each item. The estimated financial benefits obtained from ACFs ranged from as low as 5,000 kyats (~4 USD) to a maximum of 1,500,000 kyats (~1,136 USD), averaging 239 USD. The total proportion and estimated monetary values of different forest products reported by farmers are illustrated in Figure 6.4-a. The highest benefits came from firewood harvesting, followed by bamboo harvesting, in this order (Figure 6.4-a). Overall, the benefits of provisioning services obtained from ACFs were very limited until the time of this study, as only very few farmers profited from ACFs, and the monetary benefits from different forest products were very low even for those farmers.

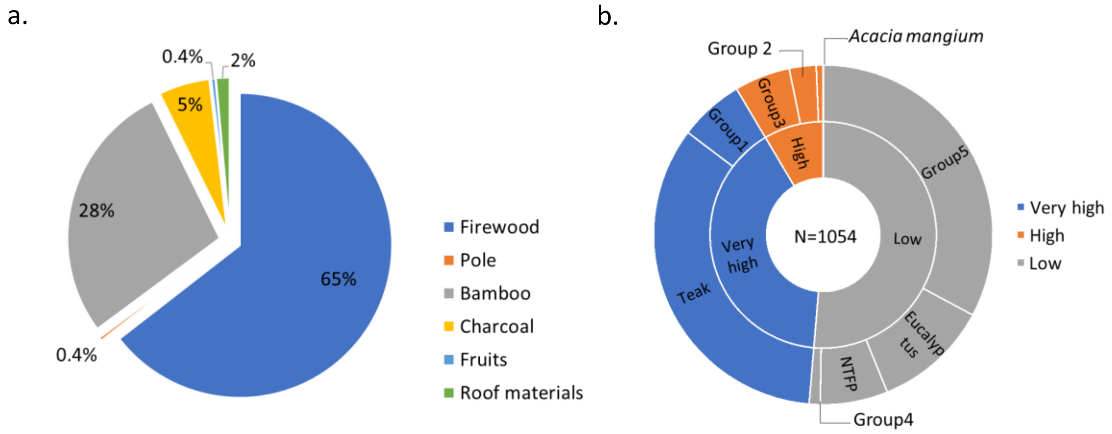

Figure 6.4: Assessment of provisioning services from agroforestry-based community forests (ACFs) in terms of monetary value. a. Percentage contribution of different forest products harvested from ACFs, with subsistence uses converted to monetary equivalents using local market prices. Data represent 22 beneficiary farmers. Total cumulative value over 5 years = 5248 USD (1 USD = 1320 Myanmar Kyats, 2020). b. Tree species composition in ACFs according to commercial value: very high (Teak, Group 1), high (Groups 2 and 3), and low (Groups 4 and 5). Groups were categorized based on the Myanmar Timber Enterprise guidelines. Eucalyptus, and Acacia mangium were categorized based on local price ranges, as they were not included in the guidelines. (NTFP = Non-timber Forest Products; N = tree counts.)

As the reported low profit from ACFs could be due to the young age of trees, we analyzed tree species composition in the forest inventory sample plots (n = 42) to evaluate the trees' economic potential in terms of commercial value and usage. Based on the categorization of tree species using the grouping system of the Myanma Timber Enterprise (1992) (see Appendix 8), trees with low commercial value, including Group 5 species along with Eucalyptus and NTFP species, were the most abundant and those with very high commercial value, including Group 1 species and teak, were the second most abundant (Figure 6.4-b).

Regulating services

Analysis of the forest inventory sample plots within ACFs showed an accumulation of 818 kg of above-ground tree biomass per plot (20 tons per ha) on average, with values being higher in forest remnants-based ACFs than in plantation-based ACFs (Table 6.3).

Table 6.3: Above-ground biomass of trees in different types of agroforestry-based community forests (ACFs).

Planting category	Number of plots	Average biomass ± MOE (metric ton/ha)
Boundary planting	12	6.9±4.6
Planting as woodlots	15	11.6±8.7
Planting in degraded forest remnants	9	39.1±21.0
Protection of degraded forest remnants	6	41.8±31.8

Note: (MOE - Margin of Error at 95% confidence level)

While tree age in the ACFs ranged between 3 and 5 years, previously existing degraded forest remnants had a large influence on above-ground biomass accumulation in forest remnants-based ACFs. The plantation-based ACFs categorized as "boundary planting" and "planting as woodlots" accumulated an average of around 7 tons per ha and 11.6 tons per ha, respectively. In comparison, forest remnants-based ACFs, which included "planting within degraded forest remnants" and "protection of degraded forest remnants," accumulated an average of around 39 tons per ha and 42 tons per ha, respectively. With regard to soil and water protection, which is another key regulating service provided by ACFs, vegetation cover analysis revealed average values of 55% and 48% for canopy and ground cover in the sample ACF plots, respectively, reflecting a good canopy coverage and moderate ground cover (Figure 6.5).

When considering each ACF category, degraded forest remnants-based ACFs demonstrated good canopy and ground cover. In the "planting in degraded forest remnants" ACFs, the values were 75% and 43% per plot, respectively, while in the "protection of degraded forest remnants" ACFs, they were 77% and 46% per plot, respectively. In contrast, plantation-based ACFs showed lower values for average canopy cover, with values of 21% and 58% in the "boundary planting" and "plantation as woodlots" categories, respectively (Figure 6.5). As ground vegetation depends on light availability under the tree canopies, canopy cover appeared to also affect ground cover in these ACFs.

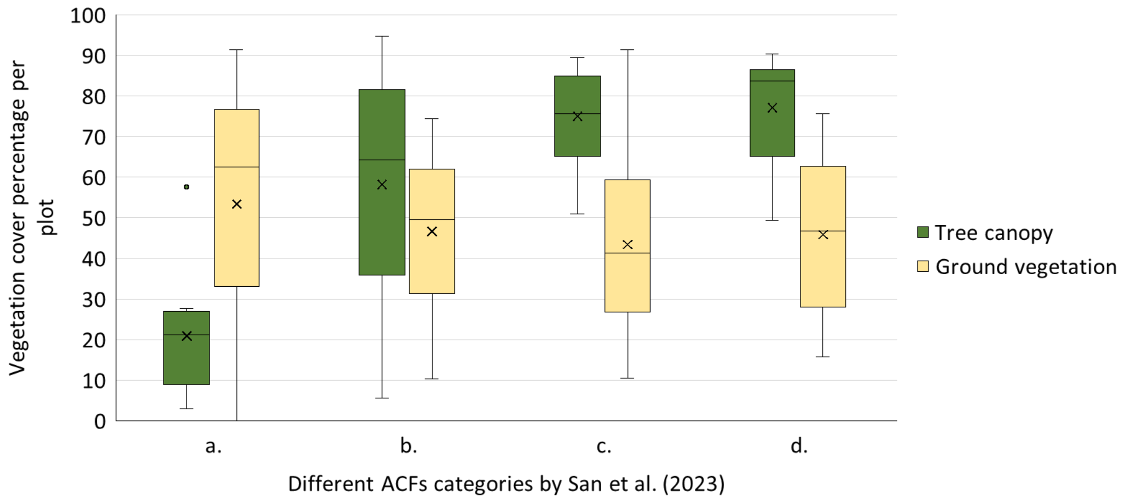

Figure 6.5: Canopy and ground cover percentages per ACF plot (n = 38): a. boundary planting (n = 10); b. planting as woodlots (n = 13); c. planting in degraded forest remnants (n = 9); d. protection of degraded forest remnants (n = 6). ×= Average value, ACFs= agroforestry-based community forests.

Supporting services (tree species richness)

The number of tree species recorded per ACF plot ranged from 1 to 21. Species richness was particularly low in the plantation-based categories, with an average of two species in "boundary planting" and four species in "planting as woodlots" (Figure 6.6).

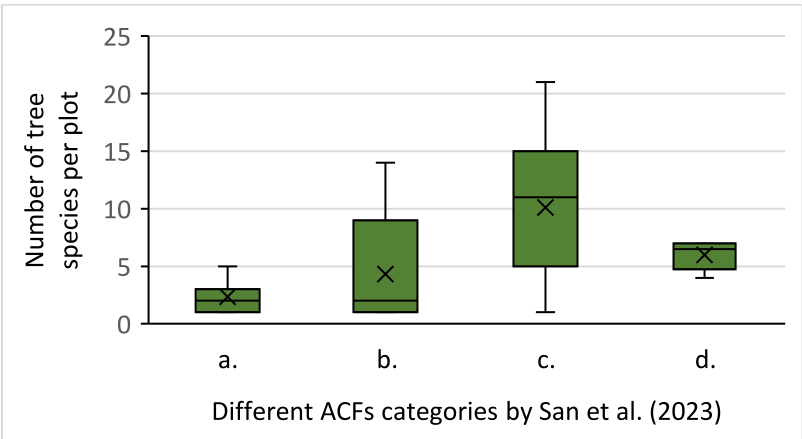

Figure 6.6: Tree species richness (diameter at breast height ≥ 5 cm) in agroforestry-based community forest (ACF) sample plots (n = 42): a. boundary planting (n = 12); b. planting as woodlots (n = 15); c. planting in degraded forest remnants (n = 9); d. protection of degraded forest remnants (n = 6).

Half of the plantation-based plots consisted of teak or non-native eucalyptus monocultures. Additional tree species recorded during the forest inventory were primarily naturally regenerated tree individuals. Species richness varied among plots and was lower in plots with more intensive weeding. The forest remnants-based ACF plots exhibited a higher number of species, with an average of 10 and 6 species per plot in the "planting in degraded forest remnants" and "protection of degraded forest remnants" ACFs, respectively.

Cultural services

During our survey, we asked the household members who participated in the establishment of ACFs (n = 230 out of 291) about the cultural benefits obtained and the inclusion of cultural perspectives in species and design selection during ACF establishment. The respondents (98.6% Burmese and 1.4% belonging to the Shan and Karen ethnic groups) did not attribute any special cultural value to the current ACFs (for example, in relation to community rituals or beliefs), except for one farmer who believed that growing trees near his farm is a good deed that will benefit his next life.

Only 5% (n = 12) of the participating household members stated that they considered the usefulness of trees from a traditional perspective during ACF establishment and that they were currently receiving benefits related to cultural services. Although these services primarily belong to the category of provisioning services, we considered them from the perspective of traditional knowledge and cultural benefits. The reported benefits included the tradition of growing teak using the Taungya system, providing materials for traditional house construction (especially from teak and bamboo) and for making agricultural tools, and use in traditional medicine [as in the case of moringa (*Moringa oleifera*) and neem (*Azadirachta indica*) leaves]. Apart from these reported benefits, most of the respondents, 94% (n = 215), answered that they did not consider the cultural value of trees during ACF establishment, while three farmers (1%) did not answer at all. Overall, cultural services from ACFs did not play an important role for most farmers.

6.5 Discussion

6.5.1 Provisioning services provided by ACFs

The evaluation of ecosystem services provided by ACFs revealed that provisioning services were not significant in terms of monetary value. Only 10% (n = 22) of all households surveyed in this study reported receiving financial benefits from ACFs. The reasons for the low number of benefiting households may be the high rate of failure in ACF implementation (San et al., 2023) and the immature age of planted trees, the oldest reaching 5 years of age. This is particularly relevant as a longer period of time is required to harvest the products of trees planted in ACFs (San et al., 2023). In addition to the negligible contribution of provisioning services to farmers' livelihoods, the income generation potential of most ACFs (except for teak plantations) was also low, as revealed by the analysis of the composition of commercial tree species within ACFs. This was because most ACF plots were dominated by tree species that could only provide firewood or less valuable timber, even under a successful growth scenario.

The actual contribution of provisioning services derived from ACFs is not in line with the expectations of farmers, as their responses in the questionnaire survey showed that receiving benefits from provisioning services in terms of different forest products and a good income was most important to them. Similar studies in other tropical countries have also shown that the actual income benefits derived from agroforestry systems often do not meet farmers' expectations of generating high income, frequently due to resource constraints such as limited land or capital resources and techniques (Dai et al., 2017; Waarts et al., 2021).

Furthermore, our qualitative analysis also showed that poor farmers who were struggling for subsistence were only interested in forest products and could not consider other ecosystem services derived from ACFs due to their socio-economic condition. Other studies have also shown that forest provisioning services are of vital importance to the subsistence, livelihood, and food security of poor farmers (Falconer and Arnold, 1989; Rasmussen et al., 2017; Shackleton et al., 2011; Tropical Forest Alliance, 2021; Vira et al., 2015). Ensuring provisioning services also incentivizes and motivates farmers to participate in forest-related projects and adopt sustainable practices (Dave et al., 2017; Tropical Forest Alliance, 2021). Suich, (2013) already highlighted that the application of appropriate incentives is key to engaging local communities in community-based forest management. Therefore, there is an urgent need to enhance provisioning services, production of forest products, from ACFs in Myanmar to ensure farmers' participation in tree planting, which is necessary for the long-term success of ACFs. In order to enhance provisioning services in ACFs, it requires careful selection of tree species that can meet farmers' livelihood needs while supporting sustainable forest management.

6.5.2 Selection of tree species with potential to enhance provisioning services

Qualitative analysis revealed that farmers were interested in timber-producing species of high economic value, such as teak (*Tectona grandis*) and Pyin-ka-do (*Xylia xylocarpa*), both are native species with good market value due to their high-quality timber. Additionally, *Acacia mangium,* another fast-growing and timber-producing tree species, has also been popular among farmers and widely planted in nearby areas (San and Hlaing, 2019), but this species is not native, and the negative consequences of its invasive nature should be carefully considered (Koutika and Richardson, 2019). Sudomo et al., (2023), a similar study in Indonesia, already highlighted negative impacts of commercial agroforestry on biodiversity and other related regulating ecosystem services. Considering a biodiversity conservation and ecological perspective, we therefore recommend promoting native fast-growing timber species such as teak and *Xylia xylocarpa,* while limiting the expansion of non-native species such as *A. mangium* and eucalyptus. Successful examples of intercropping teak or hardwood tree species with maize, banana or legume species have been demonstrated in South East Asia neighbouring countries (Mittelman, 2000; Najibunniam et al., 2025; Patil, 2010; Shenoy, 2019; Vanlalngurzauva et al., 2010).

Although farmers mentioned their interest in timber-producing species, one limitation of those trees, especially the native hardwood species, is the long waiting time until harvest. It often takes about 5 years to harvest small poles from thinning operations (FD, 2016) and 20–30 years to obtain high-quality timber with a good marketable price (ITTO et al., 2003; Ladrach, 2009). In the meantime, external threats, such as human-driven ecosystem destruction—identified as a key factor contributing to the failure of ACFs—can increase the risk of failure (San et al., 2023). However, farmers showed interest in long-rotation timber species during qualitative interviews. This preference may reflect socioeconomic differences among farmers. Households with higher income are often better positioned to tolerate long waiting periods before returns are produced, whereas poorer farmers often require short-term income generation. Alternatively, such preferences may also indicate limited awareness of or access to information about diversified agroforestry options that could provide earlier economic benefits. Therefore, planting tree species that generate income in a shorter time frame may represent a more suitable and attractive strategy, particularly to enhance farmers' engagement in ACF implementation, especially among those who have either not adopted or have struggled to sustain implementation of the practices.

Based on information from qualitative interviews, such species may include non-timber forest product–producing trees, particularly native fruit-bearing species, which can begin providing income within a few years and offer sustained yearly returns while supporting subsistence needs. Many studies in other tropical countries also pointed out the economic benefits of those short-term income generating species in different agroforestry systems (Roslinda et al., 2023; Tirkey et al., 2024). Therefore, we suggest that policymakers shift their focus from timber-oriented species, such as teak and eucalyptus, to multipurpose, fast-growing, short-term income-generating native species, such as mango and jackfruit, that incorporate farmers' preferences and support both ecological sustainability and livelihoods.

6.5.3 Benefits of other ecosystem services and their promotion among farmers

To minimize the decline in farm productivity and income, mixing tree species with crops is a good option rather than establishing separate wood plots in cropping areas. However, it was reported that many farmers were hesitant to plant trees in their productive fields within the study area (San et al. 2023b). Their reluctance was due to concerns about potential shading effects on main crops, including rice, sesame, and peanut (Rahman et al. 2016; San et al. 2023b). To address their concerns, the Myanmar FD, the organization responsible for ACF implementation, needs to propose successful combinations of crops and trees. For example, it can establish trial plots and showcase different intercropping techniques based on successful practices in nearby regions or in neighboring countries with similar growing conditions (Mittelman 2000; Vanlalngurzauva et al. 2010; Patil et al. 2012; Shenoy 2019). In the region, promotion of robusta coffee (*Coffea canephora*) for agroforestry practices was also observed. This may be an option to plant as an alternative crop in ACFs (MITV 2024; Department of Agriculture 2024). Coffee-based agroforestry practices have also been proven successful worldwide due to the ability of coffee plants to thrive in shaded environments (Meylan et al. 2017; Piato et al. 2020).

However, further research involving collaboration between agricultural and forestry experts is essential to explore potential combinations suitable for the growing conditions in this region, as knowledge of this topic is currently still very limited. One challenging aspect to consider when mixing different species is that their management becomes more complicated and requires greater knowledge and experience as well as better planning (Kelty 2006; Liu et al. 2018). Therefore, careful planning and research before promoting wide-scale planting is crucial to prevent negative ecological and economic consequences. Finally, it is necessary to effectively disseminate this important information to farmers using various extension tools to ensure the successful adoption of agroforestry practices in ACFs.

6.5.4 Research needs and limitations

Not only our study provides insights into farmers' preferences and ACF performance in terms of ecosystem services, but also reveals areas where additional research is needed to enhance ecosystem service contribution and farmer participation. Although mixing tree species with crops can increase provisioning services while minimizing declines in farm productivity and income, our study observed that farmers preferred establishing trees as separate wood plots rather than integrating them into cropping systems. Moreover, the species currently distributed to farmers are mainly teak and eucalyptus, which, according to our findings, did not contribute significantly to income generation, as around 90% of farmers had not yet received economic benefits from ACFs at the time of the study. Consequently, these species failed to attract farmer interest.

Many farmers were also hesitant to plant trees in their productive fields due to concerns about shading effects on major crops such as rice, sesame, and peanut (Rahman et al., 2016; San et al., 2023). To address their concerns, the FD, the organization responsible for ACF implementation, needs to propose successful combinations of crops and trees. For example, it can establish trial plots and showcase different intercropping techniques based on successful practices in nearby regions or in neighboring countries with similar growing conditions (Mittelman, 2000; Patil et al., 2012; Shenoy, 2019; Vanlalngurzauva et al., 2010). In the region, promotion of robusta coffee (*Coffea canephora*) for agroforestry practices was also observed. This may be an option to plant as an alternative crop in ACFs (Department of Agriculture, 2024; MITV, 2024). Coffee-based agroforestry practices have also been proven successful worldwide due to the ability of coffee plants to thrive in shaded environments (Meylan et al., 2017; Piato et al., 2020).

However, further research involving collaboration between agricultural and forestry experts is essential to explore potential combinations suitable for the growing conditions in this region, as knowledge of this topic is currently still very limited. One challenging aspect to consider when mixing different species is that their management becomes more complicated and requires greater knowledge and experience as well as better planning (Kelty, 2006; Liu et al., 2018). Therefore, careful planning and research before promoting wide-scale planting is crucial to prevent negative ecological and economic consequences. Finally, it is necessary to effectively disseminate this important information to farmers using various extension tools to ensure the successful adoption of agroforestry practices in ACFs (San et al., 2023).

Although other mechanisms, such as REDD+ and payments for ecosystem services, offer potential long-term financial and ecological benefits, they are not currently viable options for the ACFs in the study area due to low carbon storage levels and the complex technical, administrative, and organizational requirements involved (Agrawal and Angelsen, 2009; Cerbu et al., 2013; Kanninen et al., 2007). Additionally, the political instability in Myanmar following the 2021 military coup has made it increasingly difficult to explore and access alternative financial mechanisms within ACFs, such as ecotourism.

6.6 Conclusion

This study highlights the limited contribution of provisioning services provided by ACFs to farmer livelihoods and their lack of economic potential in the Taungoo district of Myanmar. At the same time, provisioning services were revealed as the most important ACF-derived ecosystem services desired by farmers. These findings emphasize the need to enhance the benefits of provisioning services to ensure farmers relying on ACFs can maintain their livelihoods in the long term. Based on the results of qualitative analysis, there are different ways to improve provisioning services from ACFs, for example, by including farmers' perceptions and their interest in tree species selection in ACF implementation. Although teak plantations within current ACFs may generate a good income in future successful growth scenarios, we recommend planting a diverse mixture of native fast-growing tree species as well as species generating income in the short term, either intercropped with cash crops or established as woodlots. This would lead to 1) increased species diversity and consequent enhancement of supporting ecosystem services, 2) maximization of other ecological and economic benefits, and 3) satisfaction of the farmers' need to wait less time until harvest. Our analysis revealed that the perceived importance of ecosystem services provided by ACFs was significantly influenced by specific characteristics of farm households. In particular, farmers' education influenced perceptions of regulating ecosystem services and biodiversity conservation, whereas household income affected perceptions of the importance of cultural services. Overall, this study showed that applying the ecosystem services concept through an interdisciplinary perspective, including social, socio-economic, and ecological aspects, is useful in identifying knowledge gaps and ways to improve ACFs in Myanmar. Finally, we recommend that future studies investigate the further development of ACFs, with particular emphasis on identifying successful tree–crop combinations across different agroecological regions, exploring approaches to raise farmers' awareness of different ecosystem services relevant to their practices and longitudinal research to assess long-term outcomes. Furthermore, beyond the national context, the findings and recommendations can be applied in other tropical countries facing similar socio-economic and environmental conditions, contributing to more effective and sustainable agroforestry implementation.

7 SYNTHESIS

The overall objective of this dissertation is to evaluate Myanmar's approach to managing agricultural encroachment in forests through the establishment of ACFs, using a multi-level analysis with integrated diverse disciplinary methods. The first analytical chapter (Chapter 4) analyzed the ACF approach at a district level. It provided an overview of the impact of ACF establishment on forest cover and the behaviors of encroaching settlers in the districts. The results contributed to the overall objective by highlighting the performance of the approach at a landscape scale. The second analytical chapter (Chapter 5) examined the participation of encroaching farmers in ACF implementation and the performance of ACFs based on different design categories. The results contributed to the overall objective by explaining the actual status of ACFs in the field and the reasoning behind the outcome. The final analytical chapter (Chapter 6) investigated farmers' perceptions of the ecosystem services they desired from the ACFs, as well as the ecosystem services currently provided by the ACFs. The results supported the main objective of the dissertation by providing a detailed understanding of how ACFs support farmers' ecosystem service needs and help to identify ways for improving the current contributions. This session will discuss how the three analytical chapters are interconnected, deliver the overall research objective in detail, and share common themes in different levels of analysis.

7.1 Methodological perspective

For achieving each objective, we employed a range of disciplinary techniques to analyze the management of agricultural encroachment in state forests. It showcased the benefits of an integrated approach, particularly employing remote sensing to gain an insight into policy impact on a landscape level, forest inventory for evaluating ACFs, and social surveys for analyzing people's perceptions and the significance of household attributes. Findings derived from various disciplinary methods synergized, effectively addressing the knowledge gap concerning the effect of the policy and the development of agroforestry-based community forests. Overall, the applied integrated approach provided clear evidence of the current policies' performance at the landscape level (Chapter 4), and in the establishment of ACFs (Chapter 5), the urgent need for improvement in terms of ecosystem services (Chapter 6).

Conducting integrated multidisciplinary research presented several challenges. Understanding and applying different disciplinary approaches was time-consuming and required expert support to ensure appropriate methods and accurate interpretation. Without sufficient investment in learning each methodology, there is a risk of superficial analysis and misinterpretation (Reinecke et al. 2024). Logistical complexity also posed difficulties in collecting different data types within the specified timeframe. Integrating diverse datasets to be compatible was also a challenging aspect, as discussed by Dalton et al. (2022). However, it was addressed through a clear methodological framework and well-structured data organization to achieve the desired research objectives.

7.2 Discrepancies between ACFs official data and actual practices

In all three levels of analysis, the data related to ACFs provided by the documentation from the responsible government organisation of Myanmar, the FD, differ greatly from the actual status —a problem that is also commonly observed in national and international forestry data (Pallante Giacomo 2013; Kallio and Solberg 2018; Pyzhev et al. 2020).

Firstly, the land cover change analysis revealed that the total area of agricultural encroachment was 812 km^2 in 2015, while it was stated as just 112 km^2 in the district management plan (Section 4.4.1; Table 4.2).

Furthermore, one of the intentions of the FD—to implement agroforestry-based practices, including intercropping trees and crops, in encroaching agricultural land—was not effectively adopted by farmers as they were not willing to mix trees with crops to avoid potential crop productivity reduction caused by shade (Section 5.4.3). Previous studies in other countries also pointed out that one reason leading to farmers' resistance to agroforestry is their prioritisation of short-term income (Achmad et al. 2022; Wienhold and Goulao 2023). Furthermore, the areas are registered as community forests and appear to be managed collectively; however, their actual management is based on household-based practices similar to smallholder farm forestry practices.

In addition, according to the FD's ACFs establishment data, around 2409 households were implementing agroforestry practices in their encroached agricultural areas of 44 km^2. However, our study pointed out that not all households registered at the FD participated, and only a proportion (60%) have trees as their ACFs (Section 5.4.7). The registered ACFs areas were around 44 km^2 in the whole study area; however, the areas of agricultural land shifted to other wooded land were found to be much smaller than that, according to the land cover change analysis, which was only 26 km^2, even after combining with other plantation types and fallows (Section 4.4.2; Appendix 2).

Although all the agricultural encroached areas seem to be reforested through ACFs at the registry, with a minimum of 150 trees per acre (375 trees per ha), only a portion of encroaching agricultural land has tree cover in 'boundary planting' and 'planting as woodlots'. Meanwhile, ACFs in other categories are located in natural forest remnants outside the encroached cropping areas (Section 5.4.3). The number of trees found in all planting categories is also often less than the targeted count (Section 5.4.7).

7.3 Performance of the ACF approach

Overall, ACFs' performance in the study area was found to be poor from both ecological and socio-economic aspects at all analytical levels. At the landscape scale, agricultural encroachment did not decrease after introducing the ACF policy compared to before. Instead, it expanded after 2015. Consequently, forest cover did not increase; in contrast, it shrank by up to 17% of the 2010 forest cover. Although 'other wooded land' from agriculture increased slightly compared to the 5 years before the ACF policy (Section 4.4.2). However, it was not solely from ACFs, as it also included other types of plantations and agricultural fallows that were validated by household surveys (Section 4.4.3).

The following community forest level analysis complemented the land cover change analysis results by demonstrating poor performance of ACFs. This was because not all registered households participated in ACFs implementation, and a large proportion of sample households (40%) did not have any trees under ACFs by the time of the study (Section 5.4.7). The evaluation of ecosystem services from ACFs (see section 6.4.2; Section 6.4.4) also backed up the results from the land cover change analysis and community forest level analysis by explaining the current contribution of ACFs. It highlighted the poor provisioning services of ACFs, particularly forest products and income, and their low economic potential, except for teak plantations, which may fail to sufficiently motivate farmers to maintain their interest in actively participating in ACF implementation in the long run. Previous studies have mentioned the importance of appropriate incentives and provisioning services to ensure participation in forestry activities (Suich 2013; Dave et al. 2017; Tropical Forest Alliance 2021). The regulating services of ACFs, particularly in terms of biomass accumulation, were not significant compared to natural forests, although the ACF areas, except boundary plantings, had a good percentage of vegetation cover. Furthermore, the biodiversity aspect, particularly in species composition in plantation-based practices, received minimal attention. Similarly, cultural perspective was also overlooked in most ACFs.

7.4 Factors affecting ACF performance

Regardless of the different research emphases of each chapter, it was found that the following factors greatly influence the performance of ACFs throughout the dissertation.

7.4.1 Household Characteristics

Despite different analytical chapters emphasising different levels of management and research focus, the influence of household characteristics features throughout the dissertation. Similar to the results of previous studies, one influential variable is the total land size of the households, which showed a positive influence on farmers' participation as mentioned in Section 5.4.2 (Mercer 2004; Gashu et al. 2025). The limited contribution of ACFs to provisioning services, as highlighted in Section 6.4.4, is likely to be a reason for failing to attract small landowners to participate in ACFs, as they have a greater tendency to rely on these services for subsistence. Furthermore, in addition to FD influence, total land size also affected decisions related to ACF design selection (Section 5.4.6). Farmers with small landholdings tend to choose boundary planting among the given planting design options by FD because it suits their cropping land availability limitation, allowing them to comply with FD's instructions without compromising their crop productivity (Section 5.4.6).

Another variable that influenced the planting design selection decision is the 'Age' of the households, as young households tend to choose the protection of forest remnants as ACFs (Section 5.4.6). Similar age-related effects on farmers' decision-making in agroforestry have also been reported in previous studies (Le et al. 2021; Bandi et al. 2022). Furthermore, 'Education' and 'Age' also played an important role in their perception of the importance of regulation services from ACFs; respondents with younger ages tend to perceive regulation services as important (Section 6.4.2). Meanwhile, gender and income affect the perceived importance of ACFs for biodiversity conservation, as females tend to perceive them as more important than males and respondents from richer households tend to place less importance on biodiversity than ones with less household income (Section 6.4.2).

7.4.2 Lack of inclusion of local farmers and a top-down approach

Although the concept of ACF, which is based on the CF framework, theoretically emphasizes community interest, motivation, and participation (FD 2018), the actual field implementation revealed low inclusiveness and limited consideration of farmers' perceptions throughout the study (Section 5.4.5). From the aspect of planting designs and species selection, FD greatly influenced farmers' decisions, as a result, farmers simply followed as they were instructed or did not participate at all in ACF implementation (Section 5.4.2). As a consequence of the top-down approach, ACFs' long-term tree survival and growth performance were found to be poor by the time of the study (Section 5.4.7; Table 5.3). Many studies have highlighted failed outcomes from top-down reforestation programs, especially in the global south (Höhl et al. 2020; Ullah et al. 2022). Since FD is the main decision maker of seedling selection and distribution, with little or no involvement of farmers (Section 5.4.3), ACFs' contributions did not align with farmers' interests. As a result, the ecosystem service evaluation of ACFs mentioned in Chapter 6 revealed that the provisioning services prioritized by the farmers were not delivered by most ACFs. Furthermore, the distributed species did not fit most farmers' preferences (Section 6.4.2).

7.4.3 Information dissemination

The need for better information transfer and awareness-raising was also found as a problem in field-level operations. Previous studies also highlighted the negative consequences of a lack of awareness and poor knowledge of farmers in the adoption of agroforestry by farmers (Pathania et al. 2020; Bettles et al. 2021). Information about being ACF members, the benefits and usage rights of the ACF establishment, possible designs, and responsibilities was poorly communicated, resulting in poor participation and low motivation in maintenance (Section 5.4.2). The significant influence of information on participation was proven statistically through binary logistic regression analysis (Table 5.1). The possible options of planting designs and species were also not well-informed.

7.4.4 Overall monitoring

At the landscape level, monitoring of agricultural encroachment in the forest was observed as weak, proven by household surveys (Section 4.4.3) and the land cover change analysis results showing extensive expansion of agricultural areas (Section 4.4.2). Previous studies also pointed out a weak forest monitoring system in Myanmar (World Bank 2019; Naing Tun et al. 2021).

According to existing community forest instructions, at the ACF level, the community forest management committee is organized by local community forest user groups and local FDs. In addition, FD is also responsible for following up and monitoring the status of the ACFs every three months (CF unit 2024). However, at the time of the study, the status of ACFs was not updated by the local FD, as many failed ACFs were still listed as current working ACFs at the FD. The underlying reason includes the limited human and financial resources availability (RECOFTC 2018; World Bank 2019).

7.4.5 Ineffective multi-level management

The approach to community forestry is based on decentralization and needs well-coordinated and effective multi-level management. Multi-level management is complex, as it involves different stakeholders and needs high transaction costs (Mwangi and Wardell 2012; Ciasullo et al. 2020). In Myanmar, CF units are organized to focus on CFs, including ACFs, at the different management levels of townships and districts, comprising staff from the FD. However, those staff are also responsible for other forestry operations, causing the staff to be unable to manage effectively in CF activities.

In addition, ACF implementation, which is based on rule compliance instead of self-motivation and interest (Section 5.3.2), makes multi-level management in ACFs more complicated than the original CFs, incurs more transaction costs to ensure farmers' participation, and demands continuous monitoring. Meanwhile, coordination and communication between local FD and ACFs members are often weak, with limited follow-up visits from FDs as well as a low level of trust in FD staff (Section 4.4.3; World Bank 2019), leading to ineffective management.

7.5 Positive aspects

Although ACFs showed overall poor performance through our analysis, well-performing ACFs with planting in degraded forest remnants showed good results in existing tree counts and stand basal areas (Section 5.4.7). Although practices based on forest remnants did not fit with the FD's purpose of reforesting the encroaching agricultural areas, establishing ACFs in forest remnants situated on the agricultural frontier could be a strategy to stop further encroachment into degraded forest remnants, which was a successful approach in Nepal (Bhusal et al. 2018). Good ACFs from those practices also showed the potential for good biomass accumulation and vegetation cover compared to fallow land (Section 6.4.4; Chan et al. 2013, 2016). With functioning governance and careful implementation, those ACFs that are planted in degraded forest remnants have the potential to bring satisfying ecological and socio-economic outcomes.

8 OUTLOOK

8.1 Methodological perspective

The integrated multidisciplinary approach in this dissertation has shown its benefits and potential for further application. The approach is especially relevant in complex socio-ecological contexts that involve different disciplinary elements, such as agricultural encroachment issues in forests. Therefore, the study suggests employing such integrated approaches in future forestry research and policy development.

However, as mentioned in the synthesis, this approach was found challenging as it needs a thorough understanding of different disciplinary knowledge. It requires researchers to invest sufficient time to scope all necessary methodologies or for a research team with various disciplinary experts to collaborate effectively, understand each other's expertise, and develop a shared framework (Frodeman et al. 2017; Repko and Szostak 2017). Furthermore, it is important to be mindful about other potential challenges and limitations of interdisciplinary and multidisciplinary research including disciplinary and methodological incompatibilities, having different norms and language (terminology), risk of losing focus and trade-off between broadening the research scope and depth in one disciplinary (Roy et al. 2013; Lach 2014; Nowell et al. 2022; Dalton et al. 2022; Reinecke et al. 2024). To overcome such challenges, developing and adopting a strong and clear pragmatic approach in advance that creates tolerance for ambiguity and facilitates productive collaboration among different disciplinary experts is essential to ensure the success of the research (Lach 2014; Nowell et al. 2022; Dalton et al. 2022). Lastly, the researcher or research team should remain open-minded, reflective, and adaptive throughout the research process. For example, it is essential to continuously evaluate whether the selected methods are time- and resource-efficient. If a method from another discipline proves to be more effective in achieving the research objectives, it should be adopted without hesitation.

8.2 Urgent need to address data discrepancies and reporting challenges

As it was pointed out under the synthesis, the impression given by data in the documents that decision makers consider for policy making and the real status of encroachment and ACF implementation differ greatly. Failing to update the current status could present a misleading overview at the national level, with potentially inflated numbers, and could hinder the achievement of sustainable forest management. Data discrepancies between forest data records and real-world forest status occur in many countries and represent an important issue to tackle (Pallante Giacomo 2013; Pyzhev et al. 2020). The study suggests that addressing the issue is urgent and crucial, particularly for policymakers, to reflect on the current policy implementation and to adopt relevant management decisions. The responsible government organisations, the FD in Myanmar's case, should pay attention to updating the current status and data reflecting the reality regularly. Further studies should investigate the challenges and underlying reasons for the ineffectiveness of the current forest management reporting system, particularly in ACFs, and identify its limitations.

8.3 Recommendations and research to improve the performance of the ACF approach

The analyses and synthesis of the dissertation highlighted the underperformance of the ACF approach at different management levels. The study also investigated perceived reasons for failures and difficulties of implementation. However, to prevent further ACF failures, a detailed ACF governance analysis that identifies constraints and challenges in implementation and assesses compliance with the existing community forestry framework to determine the need for modifications is necessary. Furthermore, the evidence of the study calls for further assessment and evaluation of ACFs’ performance in other areas of the country due to the high potential for failure.

Our results also highlighted the need for proper incentives that farmers are interested in, such as forest products for their use and income. However, information related to successful trees and crop combinations in different agroecological zones is still limited and should be further explored to attract farmers to participate in ACFs by showcasing them. Based on our results related to the factors influencing ACFs' performances, the following further investigations and suggestions should be taken into consideration towards successful implementation.

8.3.1 Consideration of household characteristics during implementation

As discussed in the synthesis chapter, certain household characteristics played important roles in overall implementation. Considering the influence of land size on participation and design selection, further research should focus on ACF implementation related to small-landholder farmers. For example, future studies should focus on (1) strategies to increase the participation of small-landholder farmers in meeting their subsistence needs, (2) planting designs and species choices that fit small landholdings, and (3) species and maintenance techniques suitable for boundary-planting by drawing on and adapting proven successful agroforestry models from other tropical countries (Córdova et al. 2018; Do et al. 2020; Achmad et al. 2022). Policymakers should also ensure the incentives are relevant to all types of landowners.

Furthermore, as the study highlighted, 'Age', 'Education', 'Gender', and 'Income' influenced their perceived importance of ecosystem services from ACFs, which is crucial for increasing farmers' participation. Therefore, policymakers should develop strategies on how to approach different types of household heads, such as prioritizing and explaining the provisioning services of ACFs to small landholders and regulation services to old and uneducated ones.

8.3.2 Better inclusion of farmers

Although farmers are supposed to follow the FD's instructions to avoid legal consequences, it is still important that the FD invests time and effort in persuading farmers and including their perception and interest in ACF establishment. As the study reveals the limited inclusion of farmers in implementation and its importance, it is essential to find out the underlying reasons and challenges of field staff from the FD for not including farmers in the implementation process. The study noticed possible constraints, such as limited FD staff, the pressure of meeting the target on time, and the limited knowledge and capacity of FD staff, as mentioned in previous studies (Tint et al. 2011; World Bank 2019). However, it is crucial to conduct a detailed analysis to examine the constraints and find possible solutions to address the underlying issue.

8.3.3 Information dissemination

This research also uncovered deficiencies in information dissemination and extension services to farmers regarding ACFs, resulting in a lack of motivation for farmers to participate in ACFs programs. The FD or other relevant ACF implementing agencies, such as NGOs, should conduct comprehensive extension and awareness raising before implementing ACFs. Further research should also focus on investigating the factors that limit the effectiveness of extension services, such as resource and capacity constraints of field-level FD staff, and exploring strategies to address and improve these limitations.

8.3.4 Effective monitoring

To solve the ineffective monitoring of agricultural encroachment and ACF progress in state forests in the study area, the study recommends utilizing remote sensing, a cost-effective and resource-efficient method, to continuously monitor agricultural expansion and forest cover status. This approach is particularly relevant in countries like Myanmar and Global South countries, where there is a shortage of staff and resources to monitor extensive forest areas. Other studies have also suggested using remote sensing for effective forest monitoring (Alzu'bi and Alsmadi 2022; Mujetahid et al. 2023; Win and Sasaki 2024). However, to apply remote sensing techniques effectively, clear land use maps are a fundamental need that the government agencies should address as a priority.

Although our study pointed out the weak monitoring status of the government agency, FD, the study failed to analyze the local community monitoring functions and collective actions of ACFs, as it was beyond the scope of the study. According to the community forestry framework, they are supposed to be formally monitored by the respective community forestry management committee. Therefore, further research should also investigate on functioning of the local monitoring systems of ACFs.

8.3.5 Better coordination

Poor resource governance of ACFs at multiple levels, including individual, community, and landscape level management by both farmers and FD staff, has been observed throughout the dissertation. As ACFs are based on nested management, ensuring no coordination gap between the community and the responsible organisation is crucial. World Bank (2019) also recommended strengthening dialogue and stakeholder interaction between FD staff and local communities to foster better relationships and improve management. Therefore, policymakers and further research should focus on examining the challenges and constraints in coordination and ACF governance at different management levels and developing simple and effective solutions with low transaction costs that overcome the weaknesses of multi-level governance.

8.4 Relevance for Broader Application

Lessons learnt from Myanmar through this study can be applied to other countries facing similar agricultural encroachment issues in forests, especially in Africa and Southeast Asia, such as in Bangladesh, Nepal, Ghana, Kenya, and Zambia (Iftekhar and Hoque 2005; Kissinger et al. 2012; Bhusal et al. 2018; Imai et al. 2018; Acheampong et al. 2019; Phiri et al. 2023). The study identified weaknesses in the management of agricultural encroachment in Myanmar, including inadequate monitoring, unclear land titles and management, insufficient information dissemination, and a lack of consideration for local people's perceptions. These issues need to be addressed and avoided to ensure effective agricultural encroachment management in forests through the implementation of ACFs. Strong coordination among related government authorities should also be ensured. Capacity building and raising awareness on the benefits of agroforestry practices, including showcasing successful agroforestry practices, and thorough planning and monitoring, are important aspects for ensuring the participation of farmers and the long-term success of agroforestry implementation. The study also highlighted the significance of not only reforesting expanded agricultural areas but also preventing further encroachment or agricultural expansion through effective monitoring.

8.5 Policy relevance

Through these findings, this doctoral thesis intends to fill the knowledge gap of managing agricultural encroachment areas in forests using ACFs and how to achieve successful ACFs implementation.

At the national level, including our research results in ACF implementation, contributes to achieving its Nationally Determined Contributions (NDC) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) according to the Paris Agreement. The findings highlighted important aspects not only for reforesting agricultural encroachment areas but also for preventing further encroachment and maintaining forest land titles as state forests. The findings are relevant for policymakers as Myanmar aimed to extend state forest areas up to 30% of the country in its NDC.

The results are expected to contribute not only to Myanmar ACF implementation but also to implementing successful implementation in agricultural expansion areas in other countries. By this means, our study has the potential to contribute to various Sustainable Development Goals (SDGs) from the global agenda. Firstly, the study’s results contribute to ‘Sustainable Development Goal 15 (SDG 15): Life on Land’ by supporting to mitigation of deforestation due to agricultural encroachment and promoting reforestation efforts and ecosystem services through ACFs. As the study focused on advocating successful reforestation in agricultural encroachment areas through ACFs, our study's policy implications are in line with SDG 15's overall objectives, which are conserving biodiversity and promoting the sustainable management of forests and other related terrestrial ecosystems.

Furthermore, our research findings also have the potential to contribute to SDG 13, which intends to limit and adapt to climate change. Transforming agricultural areas into agroforestry and protecting degraded forest remnants has been considered a climate change mitigation and adaptation measure worldwide (Jose 2009; Nair 2013; Paudel et al. 2022). Hence, our research findings, which aim to provide ways for successful ACF establishment, are relevant to SDG 13.

Additionally, the research findings indirectly support other SDGs such as 'SDG 1: no poverty' and 'SDG 2: zero hunger'. Through our research findings and suggestions, promoting ACFs by increasing their provisioning services can help subsistence farmers generate better income, reduce poverty, and increase food security. By this means, it can contribute to enhancing the productivity and resilience of agriculture-forest landscapes, while forest ecosystem services are well maintained. Many studies have also proven agroforestry as a poverty alleviation strategy for farmers as well as a climate change adaptation strategy (Nyong and Martin 2019; Desmiwati et al. 2021).

To summarize, our study's focus and the findings align and contribute to achieving SDGs 15 and 13, which are related to climate action, environmental and biodiversity conservation, and sustainable forest management. It also indirectly contributes to other SDGs related to poverty eradication and ensuring food security.

Lastly, the findings of this study offer relevant insights for policy and practice in developing ACFs in areas affected by agricultural encroachment. However, their uptake must be considered in the context of Myanmar's current political situation. Since the military coup in February 2021, the country has experienced ongoing instability, which has severely constrained the capacity of both government institutions and non-governmental organizations to engage with rural communities. Therefore, the practical application of these findings in policy or field-level implementation remains uncertain. A cautious approach is needed, recognizing that broader outreach to farmers and institutional uptake may not be feasible until political conditions stabilize.

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10 APPENDICES

Appendix 1. Satellite images used for the study and their information

No	Name of the satellite image	Type	Orbit	Captured date	Resolution
1	LE07_L1TP_132047_20101221 _20161211_01_T1	Landsat 7	132, 047	21.12.2010	30m×30m
2	LE07_L1TP_133047_20101126 _20161211_01_T1	Landsat 7	133, 047	26.11.2010	30m×30m
3	LC08_L2SP_132047_20151211 _20200908_02_T1	Landsat 8	132, 047	11.12.2015	30m×30m
4	LC08_L2SP_133047_20151218 _20200908_02_T1	Landsat 8	133, 047	18.12.2015	30m×30m
5	LC08_L2SP_132047_20201224 _20210310_02_T1	Landsat 8	132, 047	24.12.2020	30m×30m
6	LC08_L2SP_133047_20201215 _20210314_02_T1	Landsat 8	133, 047	15.12.2020	30m×30m

Appendix 2. Land cover dynamics among different land cover classes: a) between 2010 and 2015 (before the policy intervention), b) between 2015 and 2020 (after the policy intervention)

a)

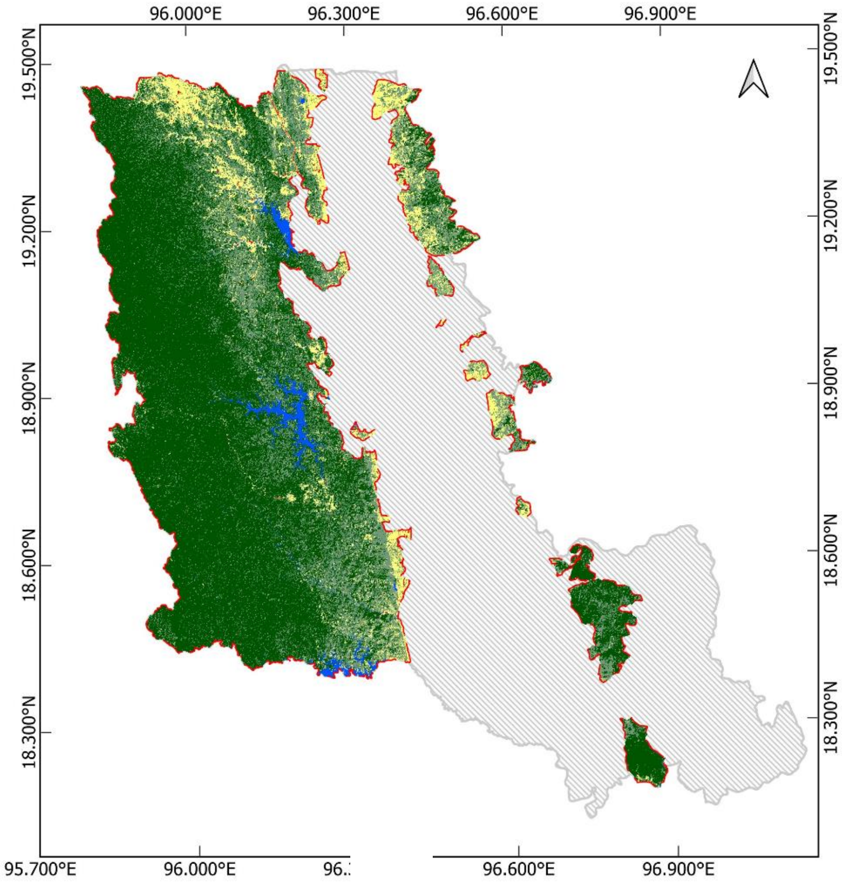
Area (km2)		Land cover in 2015 Forest	Other wooded land	Agriculture	Water	Other	Total
Land cover in 2010	Forest	2739	467	234	63	3	3508
	Other wooded land	449	659	278	39	2	1430
	Agriculture	53	175	278	12	9	528
	Water	7	2	10	86	1	107
	Other	1	2	7	1	4	15
	Total	3250	1304	808	201	19	5574

b)

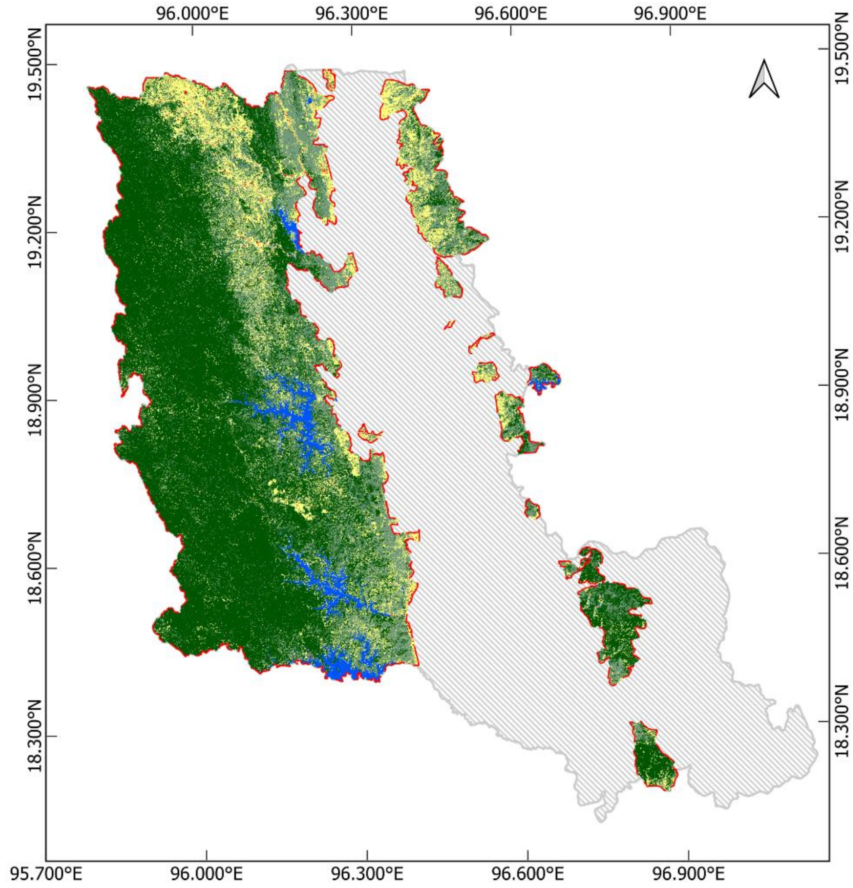
Area (km2)		Land cover in 2020 Forest	Other wooded land	Agriculture	Water	Other	Total
Land cover in 2015	Forest	2460	564	193	33	2	3254
	Other wooded land	282	635	380	7	2	1308
	Agriculture	143	201	432	22	11	811
	Water	14	5	20	161	1	201
	Other	1	1	10	1	7	19
	Total	2900	1404	1025	222	16	5575

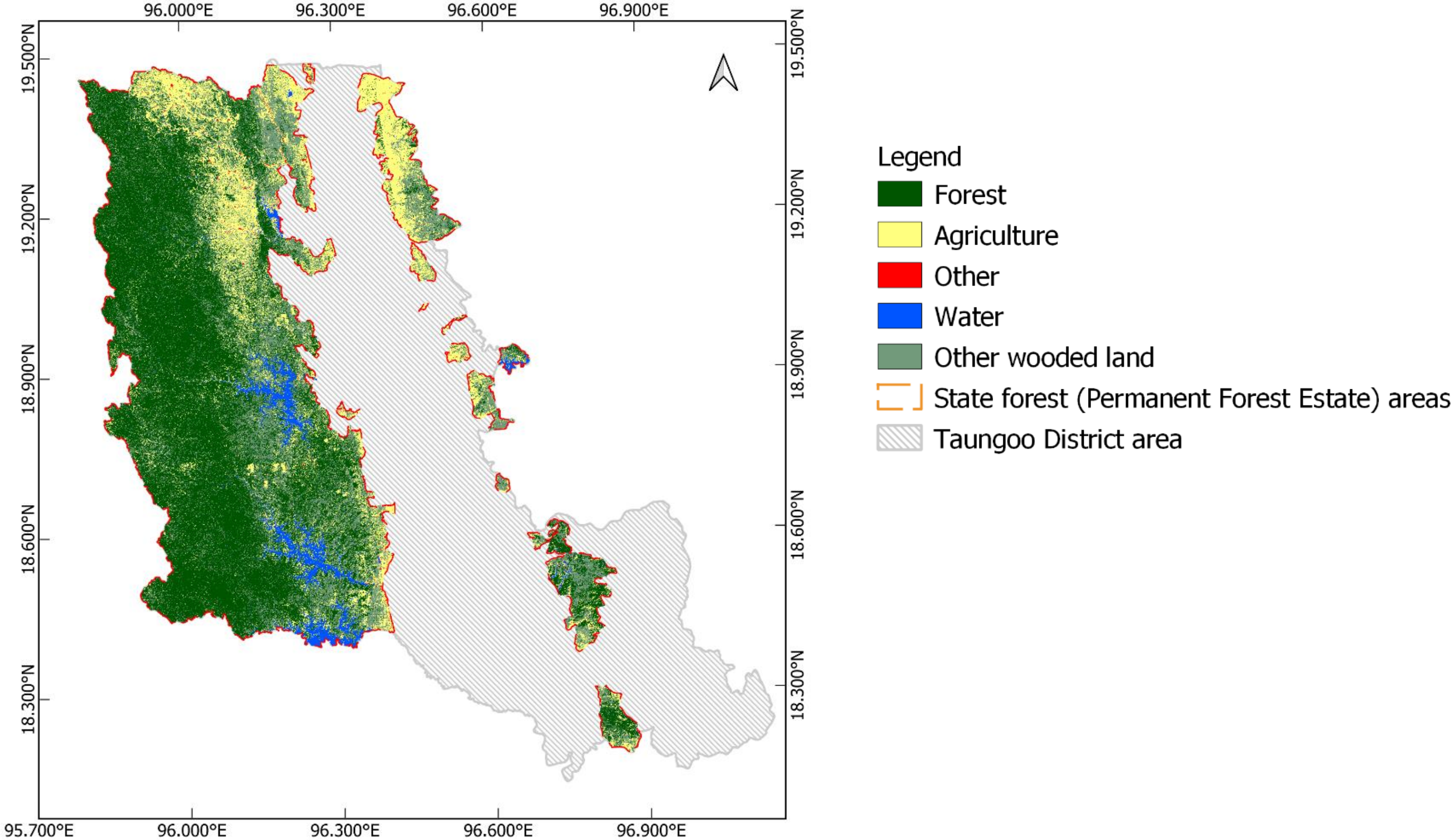
Appendix 3. Land cover classification map of the state forest areas in Taungoo District in different study years: a) 2010, b) 2015, and c) 2020

a)



b)




96.000°E
96.300°E
96.600°E
96.900°E
19.500°N
19.200°N
18.900°N
18.600°N
18.300°N
95.700°E
Legend
Forest
Agriculture
Other
Water
Other wooded land
State forest (Permanent Forest Estate) areas
Taungoo District area

c)

Appendix 4. Questionnaires used in the survey

Please let me introduce myself. My name is Su Mon San, a junior researcher from the University of Bonn. I am independent from any government department or NGO organization. I am doing research on managing agricultural farms in the Permanent Forest Estates in order to fulfill my PhD degree. My study is funded by the DAAD and Fiat Panis organizations. My study includes an analysis of how farming behavior in the forests changed in relation to the community forestry establishment in the farms (the resettlement plan 2013), how much vital forest ecosystem services are provided by the established community forests/agro-forests, and your perception of the importance of different ecosystem services provided by the community forest in the farms. The research intends to provide recommendations on how different ecosystem services should be considered in the establishment of community forests on the farms in order to ensure long-term sustainability. The interview might take around 25 minutes. Your answer will be kept confidential and will be as anonymous in the results. If you do not want to participate or do not have time, you can openly say "No" or arrange some other time. You can also withdraw your participation at any time after you answer the interview.

Would you agree to provide your consent for your participation in the survey and publication of the results?

☐ Yes, (by ticking the box, I agree to participate and also confirm that there is no pressure or threat to get my consent.)

Household characteristics

1. Interviewee' name……………………………., Date ....
2. Village……………community forest group name……………
3. Household size/how many persons live in this household?

No	Farmers	Non-farmers		Gender	Age	Nationality	Education
		Jobs	Income				
1							
2							
3							

4. Current land holdings

	Type of land use	Size	Estimated annual income from land
1	Community Forests		
2	Ya (dry farms)		
3	Lae (paddy fields)		
4.	….		

Questions for Chapter 4.

5. In which year did you start settling here?
6. What previous job/ livelihood did you have before?
7. How did you get the current farming land?

a. Self-clearance b. as heritage c. bought it

8. Do you practice shifting cultivation now?
9. If not in question 8, did you practice shifting cultivation before? If yes, why did you change the practice?
10. Farm size dynamics history

	Settlement year	2005	2010	2015	2020
Farm size					
Household population					
Reason for change					

11. Did the policy intervention affect your encroachment behaviour? Please choose or answer how it affects your behaviour.
    a. I expanded more farms due to the policy intervention.
    b. I reduced my farm size due to the policy intervention.
    c. I moved out or stopped farming due to the policy intervention.
    d. I started encroaching on farms due to the policy intervention.
    e. I started demarcating land as my farms due to the policy intervention.
    f. Other……………………………
12. Do you think encroaching farmers increased in this area due to the policy intervention?
13. Are there any other reasons that cause more settlers/farmers to move to this area apart from the policy? What are those?
14. Do you think encroaching settlers/farmers decreased in this area due to the policy intervention?
15. Are there any other reasons that caused more settlers/farmers to move out of this area apart from the policy? What are those?

16. After recording/ surveying the encroachment status in 2013, did the Forest Department control/ monitor the development or status of the encroachment in the follow-up years? If yes, when and how often?

Questions for Chapter 5

17. Do you know about ACFs? (Yes / No). Please explain what you know. (membership/ rights/ planting designs/ responsibilities)
18. What did FD inform about planting designs? Please tick them.
    a. Alley cropping
    b. Boundary planting
    c. Planting as woodlots
    d. Planted all areas
    e. others
19. Do you participate in ACF planting? (Yes/No) why? What is the motivation?
20. If not, why did you not participate?
21. If yes, what planting design did you choose, or how did you plant? Why did you choose/decide to plant that way?
22. How did you choose the designs? (decision making in design selection)
    a. Just follow what FD said
    b. Decide on my own
    c. Following neighbors
    d. Follow the village head/chairperson
23. What species did you plant?
24. How many trees did you plant?
25. How many trees survived/ are in the farm now?
26. During ACF implementation with this design, did you encounter any difficulties? How would you grade the difficulty level?
    a= major difficulties, b= few and manageable difficulties, c= no difficulties, (*.= not relavent)
27. What are the difficulties?

Questions for Chapter 6

28. Did you already benefit from ACFs in terms of forest products or money? What and how much?
29. Did you consider the cultural aspects/ spiritual aspects of ACFs during ACFs implementation? If yes, what are they?
30. Do current ACFs hold any cultural/ spiritual value for you?
    If yes, a. very important b. moderately important c. only a little important
31. Could you please decide which of the following ecosystem services from ACFs you wish to gain?
    a. Provision of forest products (own use or income)
    b. Good climate
    c. Soil and water protection
    d. Biodiversity conservation
    e. Traditional value
    f. Recreational/ spiritual value
32. Among the ecosystem services that you perceived as important, how important is each one compared to others?
    (using 4-level scale between 0 (not important) to 3 (very highly important)
    a. Provision of forest products (own use or income) ……………………………………
    b. Good climate ……………………………………
    c. Soil and water protection ……………………………………
    d. Biodiversity conservation ……………………………………
    e. Traditional value ……………………………………
    f. Recreational/ spiritual value ……………………………………

Questions for follow-up qualitative information.

1. You mentioned that (xxx) ecosystem services are important for you to get from the ACF. Why and how would you like to achieve this? Which kind of species would you like to plant in ACFs? Why?

Appendix 5. Equations used for above-ground biomass calculation and their sources

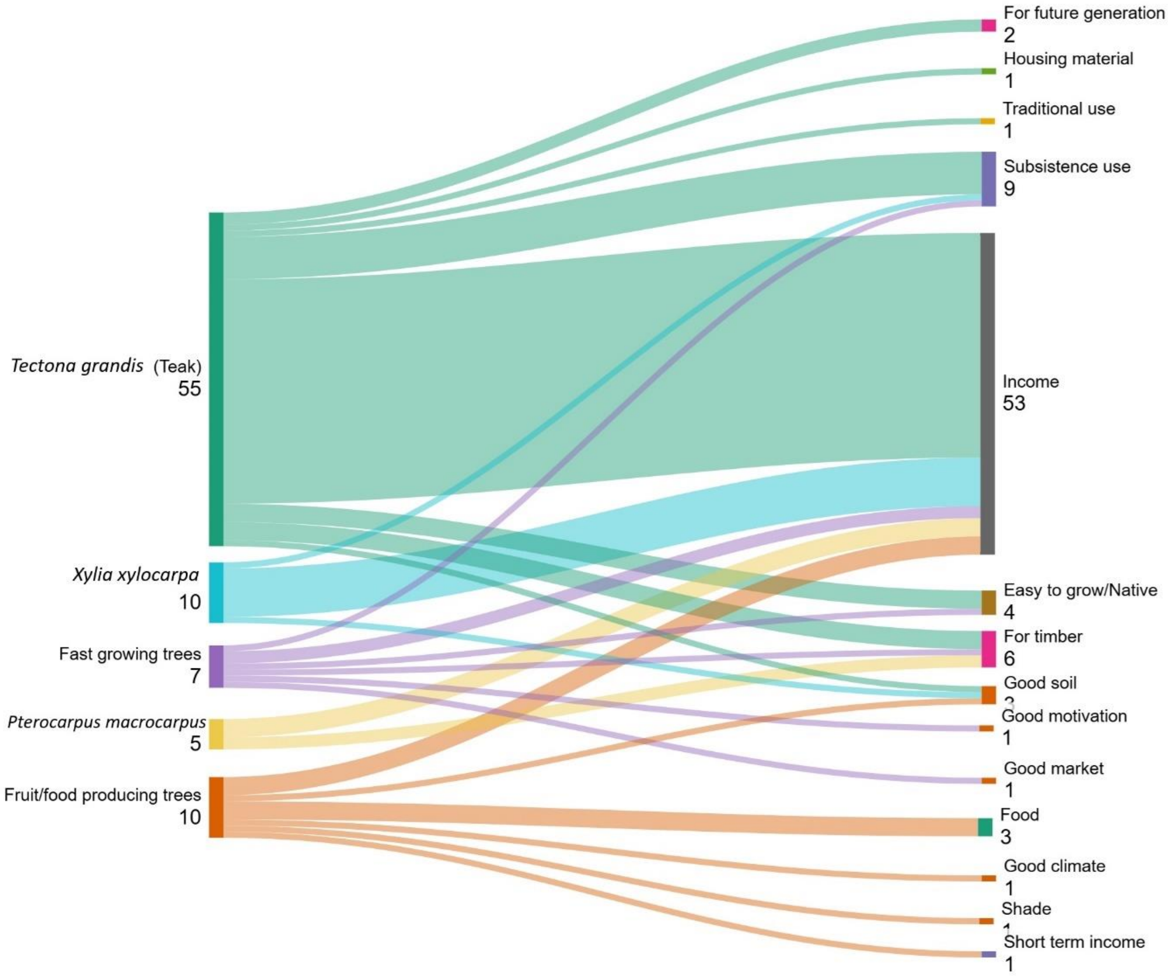
No	Species	Equation	Source
1.	Teak	0.045*(D^2*H)^0.921	Ounban et al. (2016)
2.	Eucalyptus	0.045*(D)^1.692*H^1.045	Wongchai et al. (2020)
3.	Rubber	0.136*D^2.437-(0.108*D^1.948)	Tang et al. (2009)
4.	Fallow forests in the study area	0.063*((D^2)*H)^0.862	Chan et al. (2013)

Note: D: Diameter at breast height (1.3m), H: total height of the tree

Appendix 6. Household characteristics of respondents during the household survey

Household characteristics	Unit	Mean	Different groups	Frequencies in different groups
Age	Year	50.5	26-30	8
			31-40	63
			41-50	76
			51-60	78
			>60	66
Household size	Person	4.9	1-5	199
			6-10	90
			>10	2
Gender			Female	74
			Male	217
Education	level		Informal	124
			Primary	131
			Higher	36
Household labor	Person	3	1 to 3	192
			4 to 6	97
			>6	2
Land size	Hectare	4	0	5
			0.1-5.0	217
			5.1-28	69
Income	USD per year	2465.6	<1000	59
			1001-3000	165
			3001-5000	44
			>5000	23
Agricultural income	USD per year	1308	<1000	142
			1001-2000	95
			>2000	54

Appendix 7. Co-occurrence analysis results on tree species and their benefits based on the perception of farmers (n =73): A Sankey diagram (species mentioned by less than 5 farmers is excluded from the diagram)



Appendix 8. Trees species found in sample plots and their respective groups according to their commercial value and uses referring to Myanma Timber Enterprise (1992) (0 =*Tectona grandis*; 1 = Group 1 (very high commercial value); 2 = Group 2 (high commercial value); 3 = Group 3 (high commercial value); 4 = Group 4 (low commercial value); 5 = Group 5 (low commercial value), respectively according to Myanma Timber Enterprise (1992), 6 = *Eucalyptus camaldulensis,* 7 = *Acacia mangium,* NTFP = Non-timber forest product)

No.	Species names	Scientific names	Group
1	Teak	*Tectona grandis*	0
2	Thitpadauk	*Pterocarpus macrocarpus*	1
3	Thit Yar	*Shorea oblongifolia*	1
4	Pyinkado	*Xylia xylocarpa*	1
5	Taungmagyi	*Albizia odoratissima*	2
6	Sit	*Albizzia procera*	2
7	Binga	*Mitragyna rotundifolia*	2
8	Inn	*Shoea siamensis*	2
9	Yone	*Anogeissus acuminata*	3
10	Aukchinsa	*Diospyros ehretioides*	3
11	Pyinma	*Lagerstroemia speciosa*	3
12	Thapyaynyo	*Linociera macrophylla*	3
13	Nyang	*Quercus serrata*	3
14	Htaukyan	*Terminalia crenulata*	3
15	Let pan	*Bombax ceiba*	4
16	Chinyok	Garuga pinnata	4
17	Nabae	*Lannea coromandelica*	4
18	Dedu	*Salmalia insignis*	4
19	Satechae	*Bridelia ovata*	5
20	Tha phan	*Ficus chartacea*	5
21	Kyalaesan	*other spp.*	5
22	Magyipauk	Sapindus saponaria	5
23	Thanthat	*Albizia lucidior*	5
24	Yemain	*Aporosa villosa*	5
25	Swetaw	*Bauhinia monandra*	5
26	Banbwe	*Careya arborea*	5
27	Ngu	*Cassia fistula*	5
28	Ngu war	*Cassia fistula*	5
29	Maezali	*Cassia siamea*	5
30	Baepya	*Cratoxylon neriifolium*	5
31	Yinsat	*Dalbergia fusca*	5
32	Madama	*Dalbergia ovata*	5
33	Seinpangyi	*Delonix regia*	5
34	Pothinmamyatkauk	*Derris robusta*	5
35	LinYaw	*Dillenia parviflora*	5
36	Kalarmae	*Ficus spp.*	5
37	Nyaung	*Ficus spp.*	5
38	Magyisupauk	*Gardenia sessiliflora*	5

No.	Species names	Scientific names	Group
39	Hman	*Gardenia turgida*	5
40	Htaminchauk	*Gomphostemma lucidum*	5
41	Phatthan	*Haplophragma adenophyllum*	5
42	Lethtote	*Holarrhena pubescens*	5
43	Lethtotepho	*Holarrhena pubescens*	5
44	Myaukchaw	*Homalium tomentosum*	5
45	Laeza	*Lagerstroemia tomentosa*	5
46	Zaungbalwe	*Lagerstroemia villosa*	5
47	ohnton	*Litsea glutinosa*	5
48	Phatwon	*Macaranga denticulata*	5
49	Mahlwa	*Markhamia stipulata. W*	5
50	Thabutkyi	*Miliusa velutina*	5
51	Thitpagan	*Millettia brandisiana*	5
52	Thithtein	*Mitragyna parvifolia*	5
53	Nepasae	*Morinda tinctoria*	5
54	Kyun salin	*Premna latifolia*	5
55	Nakyae	*Pterospermum semisagittatum*	5
56	Kati	*Samadera lucida*	5
57	Gyo	*Schleichera oleosa*	5
58	Gyo ma	*Schleichera trijuga*	5
59	Gwe	*Spondias pinnata*	5
60	Thanthae	*Stereospermum colais*	5
61	Khabaung	*Strychnos nux-blanda*	5
62	Lein	*Terminalia pyrifolia*	5
63	Kyatyo	*Vitex pubescens*	5
64	Gyo pho	*Walsura robusta*	5
65	Eucalyptus	*Eucalyptus camaldulensis*	6
66	Mangancia	*Acacia mangium*	7
67	Zephyu	*Emblica officinalis*	NTFP/Fruit
68	Jackfruit/Painnae	*Artocarpus heterophyllus*	NTFP/Fruit
69	Zeephyu	*Emblica officinalis*	NTFP/Fruit
70	Mango	*Mangifera indica*	NTFP/Fruit
71	Kyaungsha	*Oroxylum indicum*	NTFP/Fruit
72	Malarkar	*Psidium guajava*	NTFP/Fruit
73	Thayingyi	*Croton oblongifolius*	NTFP/Medicinal use
74	Thitsein	*Terminalia bellerica*	NTFP/Medicinal use
75	Rubber	*Hevea brasiliensis*	NTFP/Resin
76	Sterculia versicolor	*Sterculia versicolor*	NTFP/Resin