Evaluating forest utilization and conservation of local communities in the buffer zone of Inlay Lake Biosphere Reserve, Myanmar

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By

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Acronyms and Abbreviations

AIC	Akaike's Information Criterion
AICc	Corrected Akaike's Information Criterion
ATT	Average effect of the Treatment on the Treated
CF	Community Forestry
CFs	Community Forests
CFIs	Community Forestry Instructions
CFUG	Community Forestry User Group
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization
FRA	Forest Resource Assessment
GIS	Geographic Information System
GLMM	Generalized Linear Mixed Model
IRS-LISS III	Indian Remote Sensing-Linear Imaging Self-Scanning System III
MIMU	Myanmar Information Management Unit
NTFPs	Non-Timber Forest Products
PA	Protected Area
PAs	Protected Areas
PFE	Permanent Forest Estate
PPF	Protected Public Forest
PPFs	Protected Public Forests
RF	Reserved Forest
RFs	Reserved Forests
SRTM	Shuttle Radar Topographic Mission
UN	United Nations
USD	U.S. Dollar
USGS	United States Geographical Survey
ΔAICc	Delta AICc

Summary

Forests can be identified as a source of forest products and ecosystem services, a habitat of biological diversity, a home for indigenous people, and a place for carbon storage (Chazdon et al., 2016). There has been a long-lasting relationship between forests and humans over the previous 10,000 years of the Holocene epoch, initially through ecological cycles and hunting, and then agro-forestry practice and shifting cultivation (Dancer, 2021). In 2012, about 1.6 billion rural people lived within 5 km of forests around the world and relied on forest resources for both basic needs and income (Newton et al., 2020). Forest resources are facing pressure from human intervention, resulting in resource scarcity. On the other hand, rural communities have the potential to conserve forests sustainably due to the proximity to the forests. The success of community forest management is crucial in ecological and socio-economic sustainability. Thus this study aims to explore: (i) how forest degradation influences the utilization of forest resources, especially firewood resources; (ii) whether forest conservation program conducted by communities is effective; (iii) what deforestation drivers are. Chapter 1 described the background information and objectives of the study.

Chapter 2 evaluated the impact of forest degradation on firewood consumption patterns in a rural area of Myanmar. Household interviews were conducted for 143 households from 20 villages, and per capita consumption rates for each household were calculated. The per capita consumption rates of households that only used firewood for cooking were regressed against several potentially important factors, including an index of forest degradation. Approximately 85% of sample households used firewood for cooking. The average per capita annual firewood consumption rate for cooking was 530 kg for households that used firewood exclusively for cooking. The regression analysis clearly showed that the open forest area ratio, an indicator of forest degradation, had a negative effect on per capita annual firewood consumption rate. In addition to the open forest ratio, household size, elevation, and the consumption rate of firewood for drying cigar leaves were strongly related to per capita annual firewood consumption rate. However, the nearest distance to the forest had a weak relationship with per capita annual firewood consumption, although previous studies have suggested that the nearest distance to the forest negatively affects the firewood consumption rate. Combined with previous studies showing that firewood collection causes forest

degradation, it can be concluded that forest degradation and decreases in firewood consumption mutually affected each other.

Chapter 3 examined the effectiveness of community forests (CFs) on forest conservation compared to outside CFs between 2000 and 2019 in Inlay East Reserved Forest (RF) and Inlay West Protected Public Forest (PPF) in the buffer zone of Inlay Lake Biosphere Reserve. Based on a simple comparison, deforestation inside CFs was lower than those of outside CFs in two watershed conservation forests on average. However, there is a contrasting pattern of deforestation between inside and outside CFs in each watershed conservation forest. It was observed that deforestation inside CFs was higher than outside CFs in PPF despite lower deforestation inside CFs in RF. To prevent biased comparison, propensity score matching was employed for evaluating the effectiveness of CFs in two watershed conservation forests and specific analysis in each forest, respectively. Community forests showed no significant evidence of avoiding deforestation in general, but CFs in RF was greatly significant to deceleration in deforestation. This chapter suggests that the effectiveness of CFs on avoided deforestation may vary with anthropogenic pressure.

Chapter 4 evaluated the importance of geographical factors and community characteristics in the deforestation of CFs between 2000 and 2019 in two watershed conservation forests in the buffer zone of Inlay Lake Biosphere Reserve, using a mixed-effects logistic regression model. Distance to the nearest village, slope, and distance to the community forestry boundary were the most important variables explaining deforestation in CFs. Forests closer to human settlements and gentle slopes faced higher deforestation risks, presumably because such forests are more accessible. In addition, forests located far from the boundaries of CFs were more vulnerable to deforestation. Community characteristics were less important compared with geographical factors. Leadership was the most important variable among community characteristics, although not statistically significant. It should be worthily noted that deforestation depends more on forest accessibility. It indicates that the locations at which new community forests are established should receive increased consideration.

In summary, firewood is the major cooking energy for rural communities, mostly collected from forests. Forest degradation reduces the firewood consumption of local communities. Forest degradation and firewood consumption exist in a state of mutual effects. Forest conservation programs with the involvement of local

communities are not effective in general. Their effectiveness of avoided deforestation differs greatly in each watershed conservation forest. The mixed results of effectiveness may be due to the variation in human interventions. Geographical factors are mainly associated with the likelihood of deforestation in CFs, while community characteristics are poor indicators of deforestation. Deforestation more likely occurs in forest accessible areas, and therefore forest accessibility should be paid full attention to while establishing new CFs. Patrols are effective measures to disturb deforestation but need to be done in both areas that are accessible to and far from the community forestry boundary.

Chapter 1

General introduction

1.1. Background information

About one-third of the global land area is covered with forests (FAO, 2020a) which occupy supporting, regulation, cultural, and provisioning services (Bologna and Aquino, 2020; Brockerhoff et al., 2017; Himes-Cornell et al., 2018; Primmer et al., 2021; Roces-Díaz et al., 2021; Sotirov and Arts, 2018). Forests are the territories of terrestrial biodiversity which provide habitats for 80 percent of amphibian species, 75 percent of bird species, and 68 percent of mammal species (FAO and UNEP, 2020). Forests serve as a natural carbon sink (Lin and Ge, 2021) and sequester carbon in living biomass, soil organic matter, deadwood, and litter (FAO, 2020a). Also, they provide recreational facilities, presenting as cultural services (Alemu et al., 2021). They contribute to the livelihoods of about 20% of the global population (Cheng et al., 2019), generating income and meeting the basic needs of both rural and urban communities for food, fuel, fodder, medicine, and others (Angelsen et al., 2014; Byron and Arnold, 1999; Sunderlin et al., 2005).

People greatly benefit from the forests in terms of livelihood improvement and subsistence needs. There are two types of forest products; timber and non-timber forest products (NTFPs) (FAO and Non-Timber Forest Products-Exchange Programme, 2020). NTFPs include products other than wood from forests (Pohjanmies et al., 2021). NTFPs contribute 25 percent of the income of 1 billion people (Molnar et al., 2004). Over half of the wood harvesting is used as wood fuel globally (firewood and charcoal) (Bailis et al., 2015). According to the 2015 Global Forest Resource Assessment (FRA) published by the UN Food and Agriculture Organization (FAO), the total annual wood removals comprising woodfuel removals increased between 1990 and 2011 (Köhl et al., 2015). About 2.6 billion people use firewood, which represents 50-90% of household energy consumption, for cooking in developing countries (Singh et al., 2021). About 880 million people, mostly women, spend their time for collecting firewood or making charcoal (FAO and UNEP, 2020). While female-headed households were more likely to collect forest products other than wood, households with more adult male members tended to collect both wood and non-wood forest products (Ali and Rahut, 2018). Forest degradation is mainly related to firewood collection conducted by women, and deforestation is primarily linked with the extraction of household and farm materials executed by men (Htun et al., 2013).

Both forest degradation and deforestation are global climate change issues because these forest disturbances represent substantial carbon emissions to the atmosphere (Houghton, 2012; van der Werf et al., 2009). Like deforestation, forest degradation contributed to global carbon emissions, ranging from 40 to 212% of those for deforestation (Bullock et al., 2020). Although forest degradation is a matter of considerable concern for international organizations and conventions (Thompson et al., 2013), there is a lack of an internationally agreed definition of forest degradation (Gao et al., 2020a). According to FAO's definition, forest degradation is a change process that has a negative effect on the structure or function of the stand and site, causing the reduction in the capacity of forest ecosystem services (FAO, 2002). Forest degradation is related to forest disturbances that do not change the land cover (e.g. selective logging, firewood collection, and wildfire) (Bullock and Woodcock, 2021; GFOI, 2013; Hosonuma et al., 2012; Thompson et al., 2013). In terms of deforestation, it is mainly linked with the conversion of forest to non-forest land cover (Bullock and Woodcock, 2021). Agricultural expansion is the main driver of deforestation (Geist and Lambin, 2002; Houghton, 2012) with socioeconomic benefits (Santiago and Couto, 2020). The lower provision of forest resources caused by forest degradation may affect the livelihoods of local communities that depend on forests. Thus, the impact of forest degradation is of great significance to local communities in terms of the provision and utilization of forest resources.

Forests have a mutual relationship with people, implying that forests provide the livelihoods of people and likewise human interventions impact forest resources (Yinghe and Yeo-Chang, 2021). For example, forests produce firewood resources for cooking and income generation of people (Badola et al., 2021; Khadija et al., 2021; Rahman et al., 2021). In contrast, forest degradation, the decline in forest quality (Hosonuma et al., 2012; Htun et al., 2009), occurs when firewood harvesting is more than forest growth (Ghilardi et al., 2009; Negi et al., 2018; Pearson et al., 2017; Rajwar and Kumar, 2011; Singh et al., 2010). Many studies reported that firewood collection is the primary driver of forest degradation (Démurger and Fournier, 2011; Foley et al., 2005; Heltberg et al., 2000; Specht et al., 2015; Sulaiman et al., 2017). As a result, forest degradation may impact millions of people who depend on forests at a varying degree at a local scale and billions of people at a regional or global scale (FAO, 2011a). Because only limited studies examine the effects of forest degradation on firewood consumption (Jagger and Kittner, 2017; Jagger and Perez-Heydrich, 2016; Jagger and Shively, 2014), additional studies are required.

Deforestation is also a serious global environmental concern (Yanai et al., 2020; Zambrano-Monserrate et al., 2018) which threatens biodiversity (de Lima Filho et al., 2021), rural livelihoods (Duriaux-Chavarría et al., 2021) and releases carbon into the atmosphere (Achard et al., 2014; Baccini et al., 2012; Bala et al., 2007; Friedlingstein et al., 2019; Ramankutty et al., 2007). Human activities such as infrastructure development, logging, and agricultural expansion directly impact forests (Acheampong et al., 2019; Bebbington et al., 2018; Curtis et al., 2018; Geist and Lambin, 2002; Hosonuma et al., 2012; Kyere-Boateng and Marek, 2021; Oldekop et al., 2020; Plata-Rocha et al., 2021; Stibig et al., 2014), causing deforestation. The global agricultural land had an increase of 110% over the past 150 years (1850-2015) (Houghton and Nassikas, 2017), and about 80% of agricultural expansion occurred in tropical forests between 1980 and 2000 (Gibbs et al., 2010). Also, linear infrastructure such as roads, highways, power lines, and gas lines are increasingly developing in tropical regions (Laurance et al., 2009). As a result, annual deforestation rates increase over time in the tropics (Hansen et al., 2013; Houghton and Nassikas, 2017; Keenan et al., 2015).

To reduce deforestation and forest degradation, various forest conservation policies have been developing across the countries (Angelsen, 2010; Blackman, 2013; Börner et al., 2020; Jones et al., 2017; Min-Venditti et al., 2017). Of these conservation policies, community forestry (CF) is a crucially important measure with two main objectives of managing forest resources sustainably and improving the livelihoods of local communities (Molnar et al., 2004). CF, decentralized forest management, resulted from the poor outcomes of the state management (Agrawal and Gibson, 1999; Kellert et al., 2000). The main focus of the state management on forest resources was commercial timber production (Wiersum, 2004), resulting in the failure of socioeconomic development of local communities and the increase in deforestation and forest degradation (Gilmour, 2016). Considering the fulfilment of the basic needs of local communities and their participation in forest management activities, CF has been introduced as a forest conservation approach in tropical developing countries (Gilmour, 2016; Wiersum, 2004). CF means forest management and conservation activities conducted by local communities based on local norms and interests (Wiersum, 2004). Local communities are the key actors who both utilize and conserve forest resources. While millions of people depend on forest resources for their livelihoods (Nambiar, 2019) and conversely, about 10% of the global forest areas are under the management of local communities (Casse and Milhøj, 2011). Understanding the success or failure of CF is greatly important to ensure or redesign the processes for effectiveness. Impact evaluation, one of the research trends in the CF literature (Lund et al., 2018), is employed to produce such evidence using matching methods (Ho et al., 2011). Although some countries apply impact evaluations to examine forest conservation impacts, most countries have not yet started these evaluations (Miller et al., 2017).

The effectiveness of CF is associated with several factors such as biophysical, institutional, demographic, and socio-economic contexts (Agrawal and Chhatre, 2006; Pagdee et al., 2006). Most studies focused on the role of institutional arrangements on CF (Hajjar et al., 2016) and confirmed that institutional factors had a significant relationship with successful ecological outcomes (Chhatre and Agrawal, 2008; Coleman, 2009; Gibson et al., 2005; Oldekop et al., 2010). However, the interactions between biophysical and socioeconomic characteristics and CF are under study in the literature (Hajjar et al., 2016). Therefore, a rigorous evaluation of the influence of these characteristics on CF is of critical importance for CF effectiveness.

1.2. Forest management in Myanmar

Myanmar is a tropical developing country with diverse flora and fauna (Myers et al., 2000; Yang et al., 2020) and is represented as one of the most forested countries in the region (Bhagwat et al., 2017; Leimgruber et al., 2005). Myanmar forests perform valuable services such as the provision of forest products, erosion control, carbon sequestration, recreation facilities, and conservation of biological diversity (Estoque et al., 2018; Karki et al., 2018; Shrestha et al., 2021; Soe Zin et al., 2019; Tantipisanuh et al., 2016). In addition, they made a major contribution to the basic needs and livelihoods of millions of people. For example, about 81% of households in Myanmar depend on wood-related energy such as firewood or charcoal for cooking (Department of

Population, 2015a). Also, forests provide cash income ranged from 6% to 83% of total household income for local communities across the country (Aung et al., 2015; Aye et al., 2019; Feurer et al., 2018; Hlaing et al., 2017; Saung et al., 2020).

Myanmar suffered a forest loss of 2,897 thousand hectares over the past decade (2010-2020) and 28,544 thousand hectares of forest areas (42.19% of the total country area) remained in 2020 (FAO, 2020a). Myanmar forests have been experiencing severe deforestation over the years, and deforestation risks were different in different administrative units (Bhagwat et al., 2017; Biswas et al., 2021; Leimgruber et al., 2005; Reddy et al., 2019a; Yang et al., 2019). A review of Myanmar's forests reported being 40 forest conservation issues in Myanmar (e.g., land tenure insecurity, infrastructure development, internal conflicts, and poor governance capacity) (Prescott et al., 2017). Some studies observed that infrastructure development, timber extraction, and agricultural expansion were the leading causes of deforestation in Myanmar (Lim et al., 2017; Yang et al., 2019). Meanwhile, there have been spatial variations in drivers of deforestation. For example, oil palm or rubber plantations were the main reason for widespread deforestation in southern Myanmar (Donald et al., 2015; Nomura et al., 2019). Rice cultivation posed a serious threat to mangrove forests in the delta regions (Richards and Friess, 2016). Gold mining and agricultural concessions were associated with forest cover change in the northern part of Myanmar (Papworth et al., 2017). Urbanization and shrimp farmings were identified as drivers of local deforestation, and shifting cultivation was classified as regional level deforestation (Stibig et al., 2014).

In Myanmar, forest areas are listed in three classifications: reserved forest (RF), protected public forest (PPF), and protected area (PA) constituting permanent forest estate (PFE). Lands under the management of the government can be demarcated as RFs for environmental conservation and sustainable production of forest resources. Outside of RFs, PPFs can be declared for the conservation of water, soil, biodiversity, forests, and sustainable production. PAs can be designated for biodiversity and ecosystems conservation outside of forest areas (RFs and PPFs). However, coordination between governmental organizations is required if the land is under the management of other governmental organizations. The government set a target of ca. 20,297 thousand hectares of RFs and PPFs and ca. 6766 thousand hectares of PAs (30% and 10% of the total country area, respectively) by 2030 (Forest Department, 2001). According to

Forestry in Myanmar 2019-2020, 25.49% of the total country area has been established for RFs and PPFs and 5.85% for PAs (Forest Department, 2020).

RFs, PPFs, and PAs were established for sustainable forest management and environmental conservation. However, they could not avoid deforestation and forest degradation. Forest cover change occurred not only outside PFE but also inside PFE. Drivers of deforestation and forest degradation in PFE were examined by case studies (Mon et al., 2009, 2010, 2012). They found higher forest degradation in the central Bago Mountain area, and elevation and distance to the nearest town were the significant factors affecting both deforestation and forest degradation (Mon et al., 2012, 2010). Also, some studies evaluated the effectiveness of PAs on reducing deforestation and forest degradation and the determinants of forest cover change (Connette et al., 2017; Htun et al., 2009; Liu et al., 2016; Songer et al., 2009). Some previous studies observed that deforestation inside PAs was lower than outside areas (Htun et al., 2009; Songer et al., 2009), but forest degradation inside a protected area had a reversed effect (Htun et al., 2009). A recent country scale study revealed that RFs, PPFs, and PAs effectively reduced deforestation using a robust matching method (Lwin et al., 2020).

In Myanmar, the role of forest dwellers and forest-dependent people has been considered in forest management since the earliest stage. Dr. Dietrich Brandis, the German scientist who initiated scientific forestry in Myanmar, proposed three main objectives of forest management: (i) to protect, and improve the forests, to arrange the cuttings within the productive powers of the forests, and to ensure a permanent and sustained yield; (ii) to keep the role of forest dwellers and people in the surrounding areas; (iii) to produce an annual surplus revenue as soon as possible (Tint et al., 2011). In 1856, the formulation of working plans was started for sustainable forest management, and local supply working circles were included to meet the basic needs of people who live in or depend on forests. After the independence, the Myanmar Forest Policy was issued in 1995 with six imperatives (protection, sustainability, basic needs, efficiency, participation, and public awareness) to ensure the sustainable development of forest resources in environmental and economic terms. Three imperatives relate to local communities by providing basic needs, engaging people participation in forest conservation and utilization, and increasing public awareness of the importance of forests. Local communities mainly depend on forests for their basic needs and livelihoods, and conversely, the sustainability of forests also depends on local communities.

In 1995, people's participation in forest management was inaugurated by the Community Forestry Instructions (CFIs). People are allowed to take part in afforestation and reforestation for forest conservation and livelihood improvement. CFs are permitted in the following six areas: (i) degraded natural forests; (ii) areas where there is potential to meet subsistence need and livelihoods; (iii) village firewood plantations established by the Forest Department; (iv) areas where soil and water conservation is needed; (v) natural forests where local communities should manage for various reasons; (vi) traditionally community manage forests. The CFIs were subsequently amended in 2019. According to the 2019 CFIs, CF is defined as forest management and utilization activities on a sustainable basis with people's involvement. There are five objectives in CF: (i) provision of forest resources for basic needs, (ii) livelihood improvement, (iii) sustainability of forest cover increase and forest utilization, (iv) enhancement of participatory forest management, and (v) environmental services. The government's target is 9,186 km^2 of community forests (1.36% of the country area) by 2030. Until 2019, community forests were extensively established in Sagaing, Magway Divisions, Shan State, and Bago Division. It was estimated that CF could contribute 25% of firewood demand in the country.

Forests are essential for the people in Myanmar. About 70% of the total population lives in rural areas and heavily depends on forest resources for basic needs and income. Human activities such as overexploitation of forest resources have an impact on the provision services of forests. As a result, forest utilization patterns of local communities may need to adapt to fit these changes. Therefore, it is greatly important to understand the forest utilization and conservation of local communities to ensure sustainability.

1.3. Research objectives and dissertation structure

This study has three major objectives:

1. To evaluate the impact of forest degradation on firewood consumption patterns of local communities,
2. To examine the performance of community forests on reducing

deforestation,

3. To explore the influence of geographical and community factors on deforestation in two watershed conservation forests in Myanmar.

The dissertation is composed of five chapters, including a general introduction, discussion, and conclusion.

Chapter 1 introduced background information of the study, forest management in Myanmar, research objectives, and dissertation structure (Figure 1.1.).

Chapter 2 evaluated the impact of forest degradation on firewood consumption patterns in a rural area in Myanmar. A total of 143 households from 20 villages was interviewed for household surveys, including household characteristics and firewood consumption patterns. The influencing factors of per capita firewood consumption rates were determined by regression analysis.

Chapter 3 examined the effectiveness of CFs on avoided deforestation compared to outside CFs between 2000 and 2019 in Inlay East Reserved Forest and Inlay West Protected Public Forest in the buffer zone of Inlay Lake Biosphere Reserve. Propensity score matching was employed to prevent biased comparisons in measuring CF effectiveness in two watershed conservation forests, and specific analysis was done in each forest.

Chapter 4 assessed the importance of geographical factors and community characteristics in deforestation of CFs between 2000 and 2019 in two watershed conservation forests in the buffer zone of Inlay Lake Biosphere Reserve using a mixed-effects logistic regression model.

Chapter 5 involved a general discussion and conclusion based on research findings.

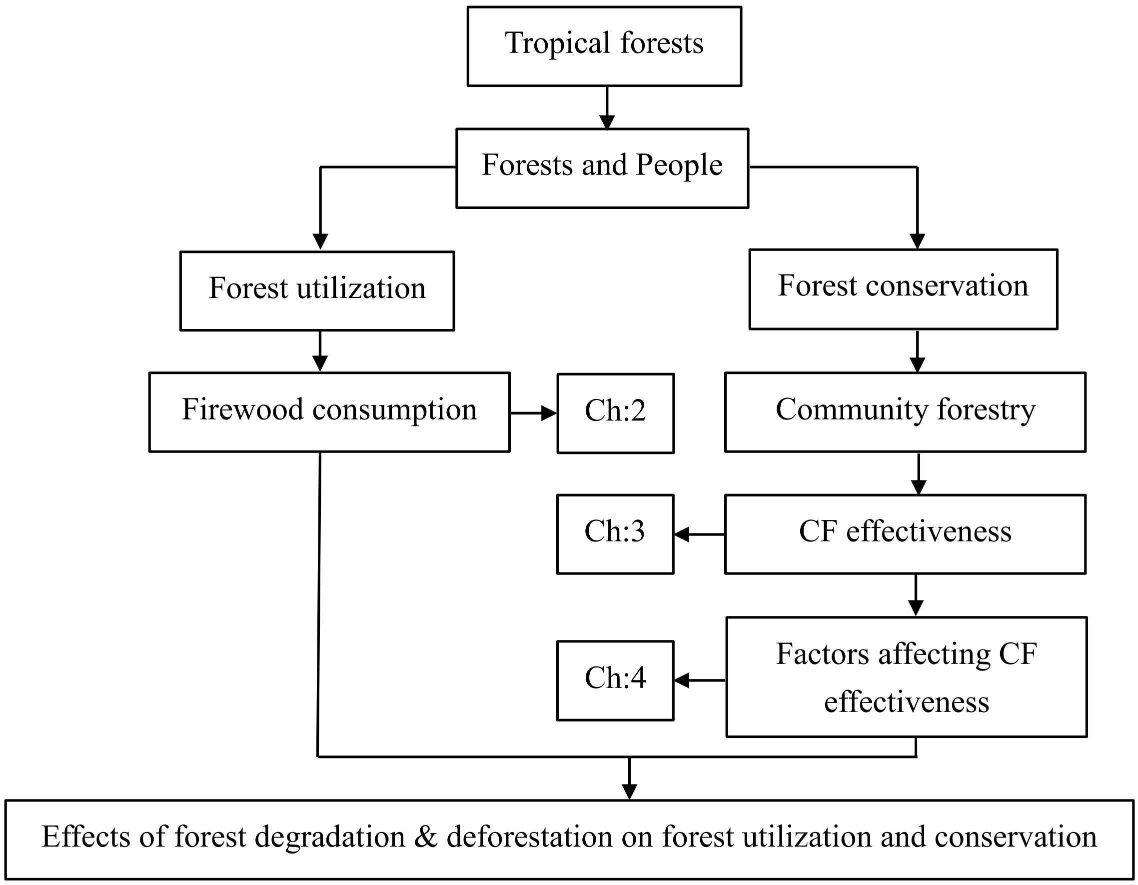

Figure 1.1. Research framework

Chapter 2

Forest degradation impacts firewood consumption patterns: A case study in the buffer zone of Inlay Lake Biosphere Reserve, Myanmar

2.1. Introduction

Firewood is an important energy source, especially in developing countries, because 2 billion people in developing countries depend on firewood for energy (FAO, 2010a). Woodfuel consumption was approximately 42 million m^3 in 2011 (FAO, 2014) and is expected to increase to 55 million m^3 by 2030 (UN-REDD, 2017). Thus, the sustainable production and utilization of firewood for satisfying future demand has received considerable attention. Understanding the factors affecting firewood consumption patterns is important for sustainable firewood utilization. Variation in firewood consumption patterns can depend on several factors, such as activities using firewood (San et al., 2012), firewood prices (Danlami, 2019), elevation (Khuman et al., 2011), and household size (Kituyi et al., 2001; Win et al., 2018a, 2018b). Therefore, evidence relating to the factors that affect the consumption rate of firewood is crucial for policymakers.

While firewood can be collected from various sources such as bushes, forests are one of the most important sources of firewood. Numerous studies have evaluated the relationship between firewood consumption, collection patterns, and the characteristics of surrounding forests (e.g., Jagger and Shively, 2014; Jumbe and Angelsen, 2011; Top et al., 2004). Those previous studies have focused on the distance to forests. For example, Top et al. (2004) evaluated the relationship between firewood consumption and the distance to forests in Cambodia and showed that the distance to forests negatively affected the per capita firewood consumption rate. Similarly, Jagger and Shively (2014) also found in Uganda that distance to the nearest forest negatively affected the volume of firewood harvested from forests. These studies have generally shown that long distances to forests may be a major barrier to collecting high quantities of firewood, implying that firewood collection and consumption patterns depend on the ease of firewood collection. Other factors relating to the ease of firewood collection other than the distance to forests may also affect firewood consumption patterns.

One possible factor related to the ease of firewood collection is forest degradation. Living trees are important woodfuel resources, especially when collected trees are converted to charcoal (Bensch and Peters, 2013; Nagothu, 2001; Top et al., 2004); deadwood is also often collected as firewood. Because forest degradation can decrease the number of both living and dead trees, it may decrease the amount of extractable firewood resources in forests and make the collection of firewood increasingly difficult. Thus, evaluation of the impact of forest degradation on firewood consumption patterns is critical.

Previous studies on the relationship between firewood collection and forest degradation have focused on the impacts of firewood on forest degradation and have shown that firewood collection is a major cause of forest degradation (Baland et al., 2010; Démurger and Fournier, 2011; Heltberg et al., 2000; Kirubi et al., 2000; Specht et al., 2015; Trossero, 2002). However, few studies have characterized the impacts of forest degradation on firewood consumption patterns. For example, studies in Uganda analyzing the effects of forest cover change on the firewood consumption rate (Jagger and Kittner, 2017; Jagger and Shively, 2014) were primarily focused on deforestation because deforestation was the major environmental problem in the study area. Jagger and Perez-Heydrich (2016) also found that forest degradation causes households to purchase firewood, but they did not evaluate the relationship between forest degradation and firewood consumption rate. Thus, the impacts of forest degradation on firewood consumption patterns have not been fully explored. Here, this study evaluated the impact of forest degradation on the firewood consumption rate.

Myanmar has one of the largest remaining forest areas in Southeast Asia (Kelso, 1992; Leimgruber et al., 2005). Forests are the primary energy resource for people in Myanmar. For example, approximately 81% of total households in Myanmar use wood-derived energy for cooking (Department of Population, 2015a). However, Myanmar has suffered from deforestation and forest degradation for decades (Kelso, 1992; Shimizu et al., 2017; Wang and Myint, 2016). Previous studies have shown that firewood collection is one of the most important drivers of forest degradation (Htun et al., 2013; Kelso, 1992; Mon et al., 2012, 2010; Myint, 2018; National Commission for Environmental Affairs, 1997; UN-REDD, 2017). Thus, firewood consumption rates in Myanmar may critically depend on forest degradation.

Here, this evaluated the impact of forest degradation on firewood consumption patterns in a rural area of Myanmar. Specifically, this study calculated the firewood consumption rates of households from a household survey. A regression analysis was used to characterize the effects of several factors, including forest degradation, on firewood consumption. Generally, the results of this study elucidated the effect of forest degradation on firewood consumption patterns.

2.2. Materials and methods

2.2.1. Study area

The study was conducted in the northern part of Nyaungshwe Township, Taunggyi District, the southern Shan State, Myanmar between 19° 58´ and 20° 45´ N and 96° 46´ and 97° 07´ E (Figure 2.1.). The area of Nyaungshwe Township is 1454.04 km^2. It has a population of 189,407 in the township, and roughly half of the total population are males (49.9%), and the others are females (50.1%) (Department of Population, 2015b). Approximately 27.8% of the total population is children (0-14 age group), 67.4% is economically productive (15-64 age group), and 4.8% is the elderly population (65+ age group). While 14.1% of the population aged 25 and over has never been to school, 51.5%,17.5%, 8.2%, and 8.7% of the population aged 25 and over have primary, middle, high school, and higher education, respectively. The literacy rate of people aged 15 years and above is 89.4% in Nyaungshwe Township. There are 42,634 households in the township. About 19.5% of total households are female-headed households, and the remaining 80.5% are male-headed households. The average household size is 4.2, and the population density is 130.3 people/km^2. According to the 2014 Myanmar Population and Housing Census Report, 91% of Nyaungshwe Township residents live in rural areas. According to census data in 2014, approximately 67.85% of the Nyaungshwe Township residents primarily use firewood for cooking, followed by electricity (21.55%) and charcoal (10.13%).

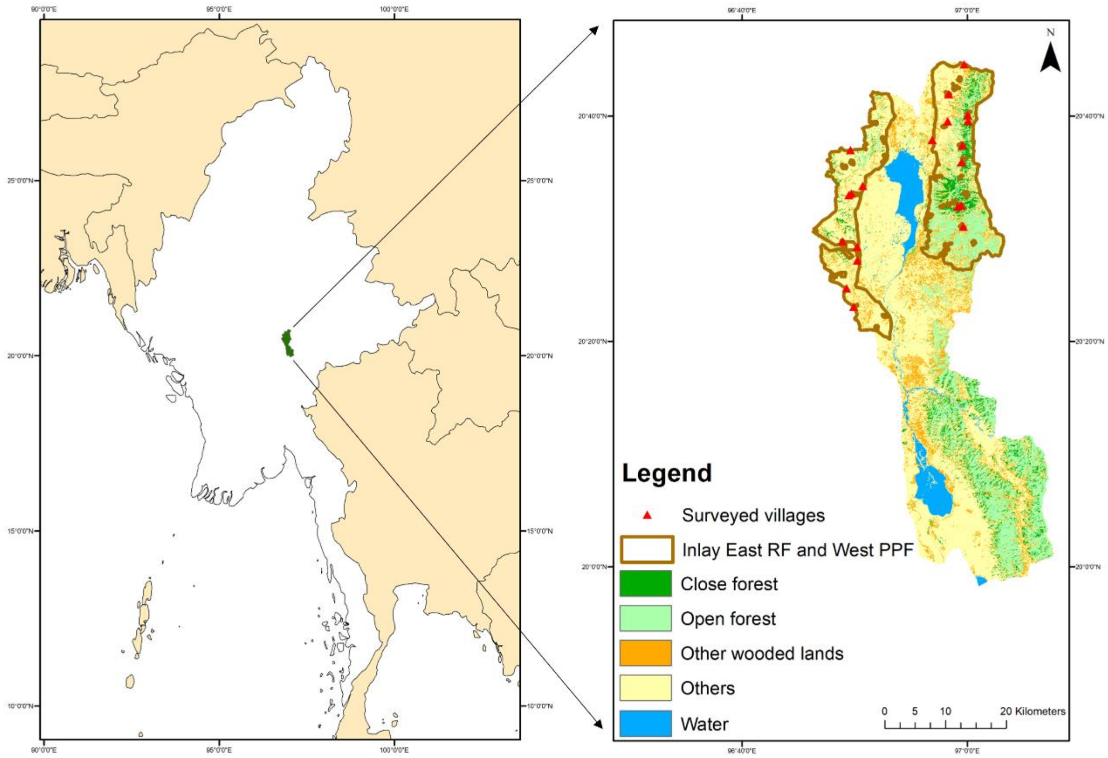

Figure 2.1. Location of the surveyed villages in Nyaungshwe Township, Myanmar.

The country border was obtained from Thematic Mapping (http:// thematicmapping.org/). The boundaries of the township and watershed conservation forests were obtained from the Myanmar Forest Department.

Inlay lake, which has been an ASEAN Heritage Park since 2003, lies in the center of the northern part of Nyaungshwe Township. The eastern and western sides of the lake are bordered by mountain ranges. Watershed conservation forests made up both the eastern and western mountain ranges. According to the internal report of the Forest Department, the watershed conservation forests in the eastern and western mountain ranges have areas of 213.26 km^2 and 140.86 km^2, respectively. The west watershed conservation forest was more deforested and more degraded than the east watershed conservation forest (Figure 2.1.). This study selected villages located in the two watershed conservation forests for analyses for two reasons. First, the areas surrounding Inlay lake have been recognized as deforestation hotspots (Leimgruber et al., 2005; Reddy et al., 2019a, 2019b; Wang and Myint, 2016) and as one of the most forest-degraded watersheds in Myanmar. Second, because the condition of the two watershed conservation forests differed in terms of forest areas and forest loss, this suspected that these areas would be especially appropriate for evaluating the impact of forest degradation on firewood consumption patterns. While 80.96% (172.66 km^2) of Inlay East RF were forest areas, 40.25% (56.69 km^2) of Inlay West PPF were covered with forests. Previous studies reported that Inlay West PPF was under the threat of forest loss due to human pressure (Htwe et al., 2015a; Su and Jassby, 2000).

In this region, some villages have common lands consisting of traditionally village-owned forests. Common land is a forest area that has been traditionally occupied, managed, conserved, and utilized by villagers collectively. Traditionally, villagers managed the surrounding forests for their sustainable use. In some villages, villagers pay money to use firewood from common land and establish village funds for religious purposes. Additionally, in some villages, forests are separated into two zones: the conservation zone of water sources and the extraction zone of firewood resources. Villagers are fully aware of the importance of trees for water availability from water sources; therefore, they do not cut trees in these areas.

2.2.2 Household surveys

Field surveys were conducted in February and March 2017. A total of 143 households were randomly selected from 20 villages for household surveys (Table 2.1.). Thus, approximately 10.16% of the total households were sampled in the surveyed villages.

Table 2.1. Characteristics of surveyed villages

Village name	**Number of households**	**Population**			**Number of sampled households**
		Male	**Female**	**Total**	
Tha ya gon	102	256	228	484	11
Kyauk ye o	201	354	361	715	11
Kon zon	101	254	205	459	11
Loi hkaw ale	89	215	190	405	9
Taung kha mauk	86	176	170	346	9
Chaung zauk	50	143	132	275	6
Hta ein gon	53	128	154	282	6
Taung gya de	28	81	78	159	5
Taung gya le	16	42	50	92	5

Village name	Number of households	Population			Number of sampled households
		Male	Female	Total	
Kyauk hnget	154	386	347	733	12
Nan nwe (North)	76	177	167	344	8
Nan nwe (South)	33	109	94	203	5
Tha bye gon	69	169	160	329	6
Nan li ye u	45	98	84	182	5
Mye byu	70	170	183	353	7
In gyin gon	30	96	83	179	5
Yan kin	53	134	131	265	5
Kyauk taw	30	64	62	126	5
Paw naw	47	105	91	196	5
Dat taw ye u	74	155	159	314	7
Total	1407	3312	3129	6441	143

The semi-structured questionnaires, focusing on household characteristics and firewood consumption patterns, were administered. Household characteristics included variables that may influence firewood consumption, such as household size, farm size, and education. Types of cooking energy, sources of firewood, and firewood consumption were also included in the questionnaire relating to firewood consumption patterns. The sources of firewood were divided into four categories: (1) forest land, (2) non-forest, (3) both forest land and non-forest, and (4) purchases. Here, forest land included natural forests and common land. Non-forest land included areas other than forest lands, such as farms and home gardens.

The amount of firewood consumed was estimated based on the amounts reported by respondents. The amount of firewood consumption was estimated depending on the frequency of firewood collection because this facilitated the ability of respondents to classify their consumption more accurately. There were two classes of firewood collection frequency. The first class was frequent firewood collection, where people collected firewood every day or once every few days. People who frequently collected firewood often carried a bundle of firewood on the head, back, or shoulders. Thus, for people who frequently collected firewood, the stacked volume of firewood consumption was estimated based on the size of the bundle of firewood that the respondent carries. First, the size of the bundle was assumed to be in the shape of a circular cylinder. Next, the respondents estimated the perimeter and length of the bundle. The volume of the bundle was calculated based on these dimensions. The estimated amount of firewood consumed was then converted into annual figures based on the frequency of firewood collection.

Another class was infrequent firewood collection, where people collected firewood once a year. In this case, the amount of firewood consumed on an annual basis was directly estimated from the annual amounts reported by respondents. Although some respondents provided annual volumes of firewood consumption, other households estimated the number and size of the poles (perimeter and length) that they consumed for one year (Figure 2.2.). In this case, the annual firewood consumption was calculated by multiplying the volume of one pole and the number of poles. The volume of one pole was calculated using the perimeter and length of the pole while assuming that poles were cylindrical. Occasionally, respondents provided estimates of annual firewood consumption based on the number of oxcart loads. In this case, I calculated the annual firewood consumption using the converter applied by the Myanmar Forest Department (firewood one cartload = 1.2743 m^3 stacked) and the number of oxcart loads.

Figure 2.2. Stacks of firewood outside houses.

The estimated stacked volume was converted into a solid volume using a conversion factor developed by the Myanmar Forest Department (1.0 m^3 of stacked volume is 0.66 m^3 of solid volume). Then the solid volume was converted to air-dried firewood using a conversion factor developed by Win et al. (2018b) (1.0 m^3 of solid volume = 710 kg of air-dried firewood). Some respondents not only used firewood for cooking but also for drying leaves of *Cordia dichotoma*. The leaves are the main ingredients for making the Burma cigar called “Say baw leik.” Thus, firewood consumption for cooking and other activities was recorded separately. Some households separated the firewood consumption for cooking from total consumption. For example, one-fourth, one-third, or half of the total firewood consumption was used for cooking. Other households estimated the firewood consumption rate for cooking separately from drying.

The firewood consumption for drying leaves of *Cordia dichotoma* was calculated based on the per quantity of *Cordia dichotoma* leaves. First, the annual production of *Cordia dichotoma* was calculated based on the amounts reported by respondents. Because the respondents reported the annual production of *Cordia dichotoma* using the unit called “viss”, which is a weight unit in Myanmar, viss was converted into kilogram by using the conversion factor (1 viss = 1.6329 kg). Then, the firewood consumption for drying leaves of *Cordia dichotoma* per the quantity of the leaves was calculated by dividing the air-dried weight of household firewood consumption for drying the leaves by the total production of the leaves for each household.

The missing values from one household sample were obtained and thus removed this sample from subsequent analyses. I also removed one outlier, in which the income of the household was greater than ten standard deviations of the income mean. In total, 141 samples were used in the analyses.

2.2.3. GIS data

Village locations were created from topographic maps with a 1:50,000 scale, produced by the Survey Department of Myanmar in 2003 using ArcGIS. Initially, I digitized the village boundaries as polygons and assumed that the centroid of each polygon represented a village location. I also used a 30-m resolution digital elevation model (DEM) from the Shuttle Radar Topographic Mission (SRTM) obtained from the United States Geographical Survey (USGS) archives (http://earthexplorer.usgs.gov/) for the elevation data of each village.

A 2015 country-scale forest cover map was obtained from the Forest Department of Myanmar. The map was derived from Indian Remote Sensing-Linear Imaging Self-Scanning System III (IRS-LISS III) and Landsat data. The map included nine classes; three were dense forest, open forest, mangrove, and six other classes were not forest-related (e.g., agriculture and water). Here, the dense forest was distinguished from the open forest by canopy cover. The dense forest is a forest in which canopy cover is greater than 40%, and the open forest is a forest in which canopy cover is below 40%. According to the definition of dense forest and open forest, I assumed that open forest was degraded forest. From the forest cover map, the dense forest cover ratio and open forest cover ratio to the total land area within 5 km from each village location were calculated. I selected 5 km because previous studies evaluating firewood consumption often use this value (Jagger and Kittner, 2017; Jagger and Shively, 2014; Top et al., 2004). My study site was in a mountainous area, and mangrove forest was absent. I also calculated the nearest distance to forests, including both dense and open forests, for each village.

2.2.4. Data analysis

Firewood consumption rate was defined as per capita annual firewood consumption. The per capita consumption was calculated by dividing the total consumption of each household by the number of family members in the household. The firewood consumption rate was then regressed against several factors that could potentially affect firewood consumption. I used data from households that only used firewood for cooking (92 samples in total; see 2.3.2.). A generalized linear model with normal error distribution and an identity link function was used. Per capita annual firewood consumption rate was used as the dependent variable in the analysis. The independent variables included household size, farm size, income, common land (whether they have traditionally village-owned forests or not), support (whether they have participated in awareness-raising or training programs supported by the government), elevation, dense forest ratio, open forest ratio, the nearest distance to forests, and firewood consumption for drying leaves. Household size was defined as the number of family members who were older than 15 years in the household.

A model averaging approach was used because this method can assess the relative importance of various variables. I fitted every possible combination of independent variables and calculated the corrected Akaike's information criterion for small samples (AICc). Delta AICc (ΔAICc), which is the difference in the AICc between the lowest AICc model and another model, was calculated for each model.

Models in which ΔAICc was less than four were selected for model averaging. For each independent variable, the relative importance, which is the sum of the Akaike weights of the models in which the variable was included, was calculated using the selected models. Data analyses were performed in R v. 3.6.1 (R Core Team, 2019). I used the "MuMIn" package (Barton, 2020) for model averaging and relative importance calculations.

2.3. Results

2.3.1. Household characteristics of surveyed villages

The surveyed villages are inhabited by different ethnic groups, namely Pa-O (63%), Taungyo (21%), Intha (14%), and others (1%). Household size ranged from 1 to 10 family members. The average household size was 4.7. Only five percent of the sample households were headed by females, and the others were male-headed households. About 76% of the population in the sample households was from the age group older than 15 years. Most of the household heads (72%) were educated in primary school. Approximately 22% of household heads completed middle school education, and 4% completed higher education. The average annual household income was 2182 USD. Agriculture was the major income source for approximately 51% of the respondents, while 42% earned income from both agriculture and other activities, such as livestock raising, laboring, and the collection of non-timber forest products. The remaining 7% of household heads conducted non-farming work. With the exception of non-farming households, households possessed a wide range of agricultural land area (0.4-11 ha).

2.3.2. Sources of cooking energy and firewood consumption

Approximately 65% of the sample households (i.e., 92 households) used only firewood for cooking, and 20% of the sample households used firewood combined with other energy for cooking (Figure 2.3.). The remaining households used electricity or both electricity and charcoal. Agricultural residuals showed that the largest share of additional energy used came from firewood, followed by electricity. The average annual per capita firewood consumption rates were 530 kg and 298 kg for households that only used firewood and households that used both firewood and other energy sources, respectively. The average annual firewood consumption for drying *Cordia dichotoma* and the average annual production of *Cordia dichotoma* were 2,915 kg and 1,419 kg, respectively. The average firewood consumption for drying *Cordia dichotoma* per the quantity of *Cordia dichotoma* was 3 kg/kg.

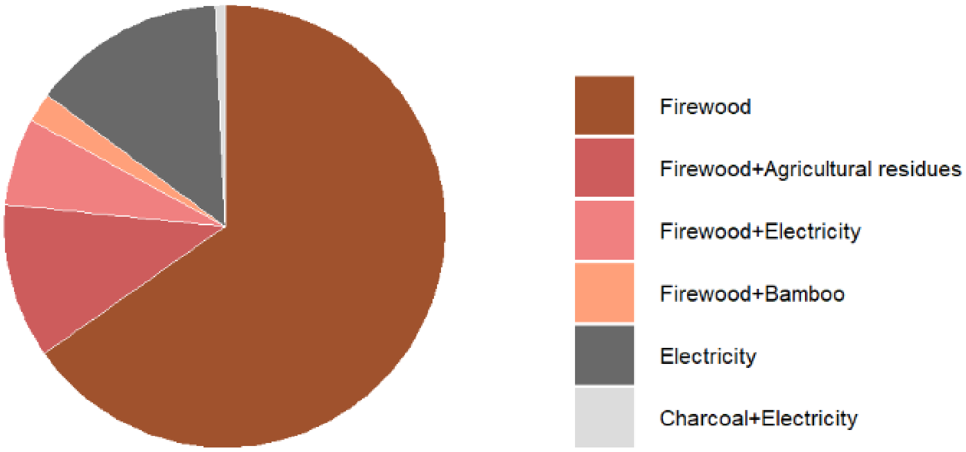

Figure 2.3. Sources of energy used for cooking.

The sources of firewood originated from forests and non-forests (Figure 2.4.). While approximately 55% of households that used only firewood collected firewood exclusively from forests, 28% and 13% of them collected firewood from non-forests and both forests and non-forests, respectively. Approximately 75% of households that used both firewood and agricultural residuals collected firewood from only forests, but only 11% of households that used firewood and electricity collected firewood from forests. Households that used firewood and bamboo primarily collected firewood from non-forests. Firewood collectors were mostly males, especially heads of the household. The households in which household heads conducted firewood collection alone accounted for approximately 45% of the whole households.

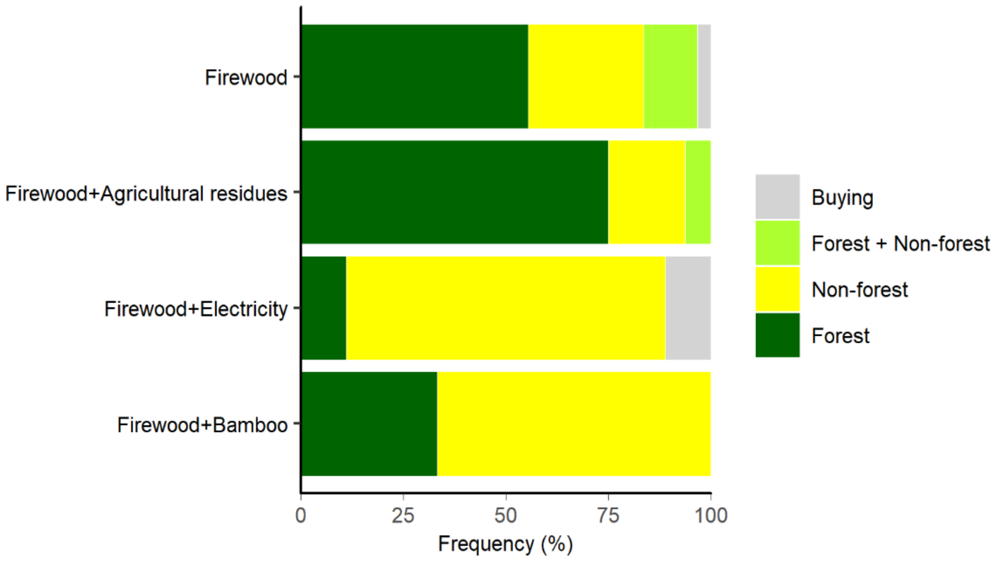

Figure 2.4. Sources of firewood used for cooking.

2.3.3. Factors affecting firewood consumption

When I evaluated the factors affecting firewood consumption patterns of users who only used firewood, 27 models remained (Table 2.2.) after selection based on ΔAICc. All models included household size and elevation. Open forest ratio, firewood consumption for drying leaves, farm size, and common land were included in 26, 25,19, and 15 models, respectively. Other variables were included in 12 models or less. The estimates of relative importance showed that household size, elevation, and open forest ratio were important variables, followed by firewood consumption for drying and farm size (Figure 2.5.). Household size, open forest ratio, and elevation were negatively associated with firewood consumption (Figure 2.6.), but firewood consumption for drying leaves was positively associated with firewood consumption. Farm size had a largely positive effect on firewood consumption, but the 95% confidence interval of farm size included both negative and positive numbers.

Table 2.2. AICc model ranking of the selected models.

Models	k	AICc	ΔAICc	AICc weights
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Common land	6	1387.45	0.00	0.12
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size	5	1387.66	0.20	0.10
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Common land+Support	7	1388.39	0.94	0.07
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Support	6	1388.64	1.19	0.06
Open forest ratio+Household size+Firewood for drying leaves+Elevation +Common land	5	1389.05	1.60	0.05
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Common land+Dense forest ratio	7	1389.24	1.78	0.05
Open forest ratio+Household size+Firewood for drying leaves+Elevation	4	1389.68	2.23	0.04
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size +Dense forest ratio	6	1389.70	2.24	0.04
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Common land+Support	6	1389.72	2.26	0.04
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Common land+Distance to the nearest forest	7	1389.88	2.43	0.03

Models	k	AICc	ΔAICc	AICc weights
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Common land+Income	7	1389.90	2.45	0.03
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size +Income	6	1390.01	2.55	0.03
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Distance to the nearest forest	6	1390.06	2.60	0.03
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Common land+Dense forest ratio+Support	8	1390.14	2.69	0.03
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Support	5	1390.40	2.94	0.03
Open forest ratio+Household size+Elevation+Farm size	4	1390.42	2.97	0.03
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Common land+Dense forest ratio	6	1390.65	3.20	0.02
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Dense forest ratio+Support	7	1390.68	3.22	0.02
Household size+Firewood for drying leaves+Elevation+Farm size+Common land	5	1390.75	3.30	0.02
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Common land+Income+Support	8	1390.90	3.44	0.02

Models	k	AICc	ΔAICc	AICc weights
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size +Common land+Support+Distance to the nearest forest	8	1390.91	3.46	0.02
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Income+Support	7	1391.04	3.59	0.02
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Farm size+Support+Distance to the nearest forest	7	1391.06	3.61	0.02
Open forest ratio+Household size+Elevation+Farm size+Support	5	1391.20	3.74	0.02
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Common land+Income	6	1391.21	3.76	0.02
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Common land+Dense forest ratio+Support	7	1391.27	3.82	0.02
Open forest ratio+Household size+Firewood for drying leaves+Elevation+Common land+Distance to the nearest forest	6	1391.45	4	0.02

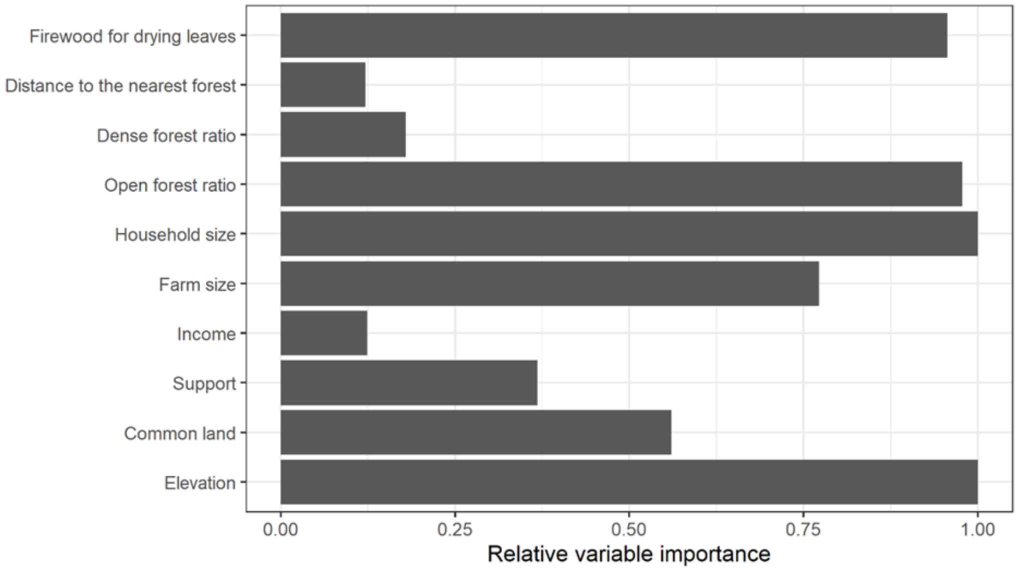

Figure 2.5. Relative importance of independent variables.

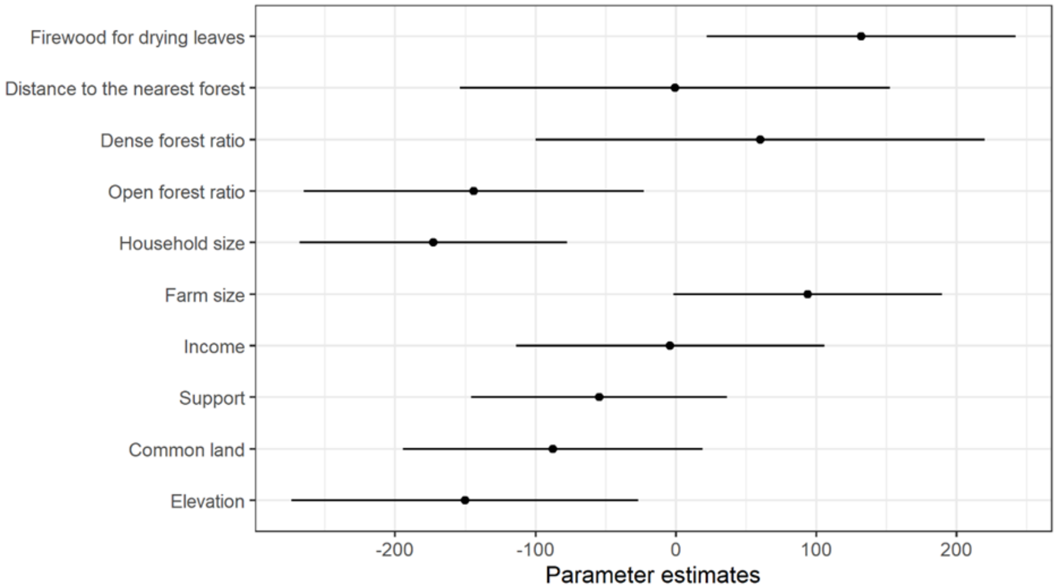

Figure 2.6. Parameter estimates of independent variables used to conduct model averaging.

Black dots and lines represent coefficient estimates and 95% confidence intervals, respectively.

2.4. Discussion

2.4.1. Firewood consumption patterns of local communities

Firewood is essential for the daily lives of more than 80% of sample households in the study area. Approximately two-thirds of households relied exclusively on firewood for cooking, and 20% consumed firewood in addition to other types of energy. Agricultural residues were the most used alternative energy sources. This finding is not surprising because agricultural residues are an easily accessible source. Households in this study cultivated *Cordia dichotoma*. Residues from the farming of *Cordia dichotoma* leaves could be used as a substitute for firewood. The second-highest share was the mixed-use of firewood and electricity. The results suggested that some households still used firewood or charcoal as cooking energy, despite having access to electricity. Firewood might thus be used as a backup source of cooking energy when electricity is not available. This assumption is confirmed by the sources of firewood for households that used firewood and electricity. Only 11% of households collected firewood from forests, and more than 70% of households collected firewood from non-forests, thus suggesting that firewood collected near houses was used as a backup source of energy.

The average annual per capita firewood consumption was 530 kg in this study when the households used only firewood. This value is similar to the values of per capita firewood consumption reported from Kenya (292-620.5 kg) (Kituyi et al., 2001), India (390.55-1022 kg) (Bhatt and Sachan, 2004), Cambodia (491.28 kg) (San et al., 2012), and Sri Lanka (496.4 kg) (Wijesinghe, 1984). However, the estimated per capita firewood consumption of this study is lower than that reported in the Bago region of Myanmar (780 kg) (Win et al., 2018b). Why the estimate of this study is lower is unclear. Differences in forest conditions may provide a potential explanation because the coverage of the degradation area negatively affected firewood consumption patterns. This study area is one of the most forest-degraded watersheds in Myanmar; thus, firewood consumption may be lower in this area compared with other areas.

2.4.2. Factors affecting firewood consumption patterns

This study clearly showed that the open forest ratio negatively affected average annual per capita firewood consumption, indicating that forest degradation decreases firewood consumption. There are several potential explanations for why forest degradation might reduce firewood consumption. Previous studies have noted that households that can easily collect firewood often waste firewood (e.g. Top et al., 2004). Consistent with this observation, the results suggest that households in forest-degraded areas tend to avoid wasting firewood. Alternatively, households in forest-degraded areas may decrease food consumption to cope with the scarcity of firewood. Scheid et al. (2018) showed that decreasing the number of daily meals cooked is one of the main strategies for coping with firewood scarcity in Tanzania. Thus, the results potentially suggest that forest degradation has made households not only reduce the wasteful use of firewood but also its essential use for cooking.

I found that the nearest distance to forests was a poor predictor of firewood consumption and that the open forest ratio had a strong effect on the firewood consumption rate. In contrast, previous studies have shown that the distance to forests was inversely related to the firewood consumption rate (e.g., Jagger and Shively, 2014; Top et al., 2004). This inconsistency might be explained by the fact that the nearest distance to forests was calculated without considering the quality and the area of the forests. For example, the nearest distance to forests is calculated assuming that households would collect firewood from the nearest forest. However, this assumption may not be accurate if households use more distant forests because the nearest forest is too small or degraded to provide an adequate supply of firewood. Thus, the nearest distance to forests may not necessarily be an informative variable when forests are located in regions with degraded or fragmented forests.

Firewood consumption for drying leaves of *Cordia dichotoma* had a positive effect on the per capita firewood consumption. Because of the demand for firewood for the drying process, people who dried leaves collected more firewood than people who did not dry leaves. People who dry leaves may thus waste firewood because they have access to sufficient stocks of firewood. This study also confirmed that household size had a negative effect on per capita firewood consumption. This finding indicates that larger households used firewood more efficiently, and this observation has also been made in various countries, including Kenya (Kituyi et al., 2001), Cambodia (San et al., 2012; Top et al., 2003), and Myanmar (Win et al., 2018a, 2018b). Elevation had a negative effect on the per capita firewood consumption rate. However, Win et al. (2018b) suggested that elevation had a positive effect on the per capita firewood consumption rate by comparing firewood consumption in different countries, given that more firewood is needed for heating in high-elevation areas. Why the results of this study differed from the results of Win et al. (2018b) is unclear. One possibility is that influence of elevation on the per capita firewood consumption may differ depending on the elevation range of the study area. This study was only focused on a specific region in Myanmar in contrast to the former study, which was conducted at a broader spatial scale.

Farm size affected the annual per capita firewood consumption. This result indicated that larger farm size resulted in higher firewood consumption rates; however, the 95% confidence interval of farm size included both negative and positive values. This finding was consistent with the findings of previous studies. For example, Démurger and Fournier (2011) showed that the increase in farmland resulted in increased firewood consumption. Song et al. (2018) also found a positive relationship between the area of dryland planted and firewood consumption. In contrast to farm size, the existence of common land had a negative effect on the per capita firewood consumption rate, but the 95% confidence interval of common land included both negative and positive values. Why the existence of common land had a negative effect is unclear. One possible reason is that households that own common land may use firewood efficiently to promote the conservation and sustainable use of the forests on common land.

2.4.3. Forest degradation and firewood consumption

Previous studies have shown that firewood collection causes forest degradation (Baland et al., 2010; Démurger and Fournier, 2011; Heltberg et al., 2000; Kirubi et al., 2000; Specht et al., 2015; Trossero, 2002). In contrast, this study revealed that forest degradation also decreased firewood consumption. Thus, I conclude that forest degradation and the decrease in firewood consumption mutually affected each other. Although previous studies have warned that forest degradation stemming from firewood collection may contribute to environmental problems, such as reductions in biodiversity and biomass stocking (Song et al., 2018), the results of this study showed that forest degradation directly affected local livelihoods via reductions in energy usage. How households managed to decrease firewood consumption in response to forest degradation is unclear and was beyond the scope of this study. One possibility is that households may adapt to firewood scarcity driven by forest degradation via an unsustainable strategy, such as eating fewer meals (e.g., Scheid et al. 2018). More research is needed to assess the role of forest degradation in maintaining local livelihoods.

2.5. Conclusions

This study evaluated the impact of forest degradation on firewood consumption patterns in a rural area of Myanmar. The results showed that household size, elevation and forest degradation were the most important factors affecting per capita annual firewood consumption. I also showed that forest degradation reduced per capita annual firewood consumption. Combined with the results of previous studies suggesting that firewood collection causes forest degradation, I conclude that forest degradation and decreases in firewood consumption mutually affected each other. Additional research is needed to assess the role of forest degradation in maintaining local livelihoods.

Chapter 3

Measurement of the efficacy of community forests in avoided deforestation in the buffer zone of Inlay Lake Biosphere Reserve, Myanmar

3.1. Introduction

Deforestation is a critical issue in the tropical domain (Agrawal et al., 2008; Hansen et al., 2013; Kim et al., 2015; Seymour and Harris, 2019), particularly in Southeast Asian countries (Achard et al., 2002; Austin et al., 2017; Estoque et al., 2019; Hansen et al., 2008; Imai et al., 2018; Paradis, 2021; Vadrevu et al., 2019). Tropical deforestation had disastrous effects on species diversity (Betts et al., 2017; Dirzo and Raven, 2003), carbon (Busch and Engelmann, 2017; Houghton et al., 2015; Tyukavina et al., 2015), and climate (Alkama and Cescatti, 2016; Costa and Foley, 2000; Lawrence and Vandecar, 2015). In response to deforestation, each national government have been employing different forest conservation programs (Angelsen, 2010; Börner et al., 2016; Ojanen et al., 2017; Robinson et al., 2014; Tafoya et al., 2020). Some forest conservation programs are merely designed to target places, while some conservation initiatives target both places and people (Börner et al., 2020). For example, protected areas have been a long-time standard approach to conserve forest in the tropical forests (Burivalova et al., 2019; Geldmann et al., 2013; Laurance et al., 2012), frequently resulting in negative socioeconomic outcomes of local communities due to strict protection (Oldekop et al., 2016). Because strictly protected areas alone could not guarantee effective conservation of tropical forests, other conservation approaches were also essential for forest conservation (Ellis and Porter-Bolland, 2008; Miteva et al., 2019; Nepstad et al., 2006; Porter-Bolland et al., 2012). Thus, governments are increasingly working on strategies that focused on both conservation and human development (e.g., CF)(Bowler et al., 2012; McKinnon et al., 2016).

CF is a kind of decentralized forest management with the prime objectives of forest conservation and livelihood improvements (Charnley and Poe, 2007; FAO, 2011b; Maryudi et al., 2012; Santika et al., 2019, 2017). It was initiated in tropical developing countries between the 1970s and 1990s (Poffenberger, 2006) and became one of the important forest governance trending programs in the 21^{st} century (Agrawal et al., 2008). The success of CF is associated with positive outcomes of ecological sustainability and socio-economic benefits of local communities (Pagdee et al., 2006). Assessments on forest cover or condition (tree density, basal area) provided evidence of ecological sustainability of CF (Maryudi et al., 2012). Of these, the measurement of forest cover change is an objective way of evaluating CF effectiveness on forest conservation (Dalle et al., 2006; Porter-Bolland et al., 2012) using the combination of remote sensing and GIS technologies (Casse and Milhøj, 2011; Gautam et al., 2004). Coupled with the accessibility of satellite data, forest cover change studies based on advanced technology are being extensively researched (Browder, 2002; Ellis and Porter-Bolland, 2008; Gautam et al., 2002; Nepstad et al., 2006). However, such evaluations on forest conservation might not provide credible results without using robust statistical analyses.

The conventional way of comparing forest cover change between inside and outside conservation areas might show biased results because of confounding factors and spillovers (Andam et al., 2008; Blackman, 2013). This approach failed to account for confounding factors associated with both conservation interventions and outcomes, and therefore resulting in bias (Baylis et al., 2016; Ferraro, 2009). For example, a simple comparison of forest loss between inside and outside of conservation area might provide a lower forest loss inside the area, implying that conservation is successful. However, the positive outcome might be smaller or disappear using the quasi-experimental method (Burivalova et al., 2019). Until recent years, evaluation designs for CF effectiveness that used quasi-experimental approaches were limited (Bowler et al., 2012). On the other hand, recently, impact evaluations on CF were gaining in popularity and employed in the studies (Oldekop et al., 2019; Rasolofoson et al., 2015) with the aims of avoiding biased comparison and covariate imbalance between CF and non-CF areas (Pelletier et al., 2016). Recent studies suggested a growing need for research on CF effectiveness using impact evaluations due to insufficient information on CF management (Torres-Rojo et al., 2019).

Impact evaluation is an evidence-based approach that makes the empirical evaluation of program and policy impacts (Ferraro and Hanauer, 2014). Comparison of outcomes with and without conservation intervention is a common empirical design for assessing the performance of conservation interventions (Miteva et al., 2012). It measures the causal effects of conservation interventions compared with credible counterfactual scenarios (what would have happened if there had been no conservation intervention) (Ferraro and Hanauer, 2014; Ferraro and Pattanayak, 2006). This method is based on the assumptions that (i) the areas with and without conservation intervention are similar in characteristics that affect outcomes, and (ii) there is no spillover from conservation intervention to surrounding areas (Miteva et al., 2012). If the assessments deviate from these assumptions, the estimates will be biased. The quasi-experimental designs can be used to estimate the counterfactual outcome. The statistical matching approach, a popular quasi-experimental design for impact evaluations, plays an increasingly important role in conservation science (Schleicher et al., 2020).

There has been a strong geographical research bias towards evaluating CF management in terms of forest conservation (Casse and Milhøj, 2011), institutional arrangements (Hajjar et al., 2016), and forest conditions (Bowler et al., 2012) because most studies in the globe were conducted in South Asia (Clare and Hickey, 2019). Due to the heavy bias in South Asian countries, evidence of CF might not represent other regions (Hajjar et al., 2016), resulting in poor outcomes in general (Di Marco et al., 2017). For impact evaluations on forest conservation of CF, there are some examples in Madagascar and Indonesia in tropical developing countries than South Asia (Rasolofoson et al., 2015; Santika et al., 2019, 2017). However, tropical countries with large forest areas are still under study on the effectiveness of conservation strategies (Burivalova et al., 2019; Burivalova et al., 2019). Because impact evaluations have location-specific nature, it is important to conduct further studies in different areas for a better understanding of the ecological outcomes of CF (Pandit and Bevilacqua, 2011).

Myanmar is a tropical developing country that ranked one of the top ten countries for a tremendous annual forest loss during the previous three decades (FAO, 2010b, 2016, 2020a). Due to severe deforestation in Myanmar (Leimgruber et al., 2005; Wang and Myint, 2016; Yang et al., 2019), understanding the effectiveness of forest conservation activities is central to policymakers for designing and advancing avoided deforestation programs. CF is one of the forest conservation programs in Myanmar. CF has been extensively implementing for improving forest conditions and local livelihoods across the country since the 1990s. However, despite the existence of CF in

Myanmar for about 25 years, there is no impact evaluation on forest conservation yet. Thus, this study examines empirical evidence of CF performance on conserving forests between 2000 and 2019 in two watershed conservation forests in the buffer zone of Inlay Lake Biosphere Reserve.

3.2. Materials and methods

3.2.1. Study area

The study area covers two watershed conservation forests in Nyaungshwe Township, Taunggyi District, the southern Shan State, Myanmar (Figure 3.1.). Nyaungshwe Township, the buffer zone of Inlay Lake Biosphere Reserve, has an area of 1454.04 km^2 and lies between 19°58′ and 20°45′N and 96°46′ and 97°7′E. Inlay lake is the second largest freshwater lake in Myanmar and is located at an elevation of 890 m. Inlay lake is surrounded by two limestone mountain ranges with the highest elevations of 2000 m which are parallel to the lake from the north to the south. The Sindaung range is in the east of the lake, and the Letmaunggwe, Thandaung, and Udaung ranges lie to the west (Su and Jassby, 2000). The foot of mountain ranges is about one to several kilometers distance from the lake (Sidle et al., 2007).

A total of 29 streams flows into the lake: 17 from the east, 11 from the west, and one from the north. Of these, four streams, namely Nam Lat Chaung, Nei Gyar Chaung (Yay Pei Chaung), Kalaw Chaung (Thann Daung Chaung), and Bilu Chaung (Indein Chaung) are perennial, and the remaining streams seasonally flow into the lake. The areas of two watershed conservation forests, namely Inlay East Reserved Forest and Inlay West Protected Public Forest, are 213.26 km^2 and 140.86 $km^{2,}$ respectively. According to the internal report of the Forest Department, 172.66 km^2 (80.96%) and 56.69 km^2 (40.25%) of Inlay East RF and Inlay West PPF were forest areas. They occupy two forest types, which include dry forest and deciduous dipterocarp forest.

In Myanmar, there are two types of forest areas under the Forest Department, namely RF and PPF. RF can be classified into five categories – commercial, local supply, watershed protection, environment and biodiversity conservation, and other reserved forests. Outside reserved forests, PPF is declared for conservation of water, soil, arid-zone forests, mangrove forests, environment and biodiversity, and sustainable production. While RF mostly has commercial values, PPF has lower commercial values and is more accessible to local communities for subsistence use (Forest Department, 2020). RF and PPF did not differ in terms of law enforcement. Here, both RF and PPF serve as watershed conservation forests. In 2000, CFs were introduced in the study area and established in RF, PPF, and unclassified forest, which is forest located in land at the disposal of the government. There are two types of CFs, namely plantation and natural forest conservation.

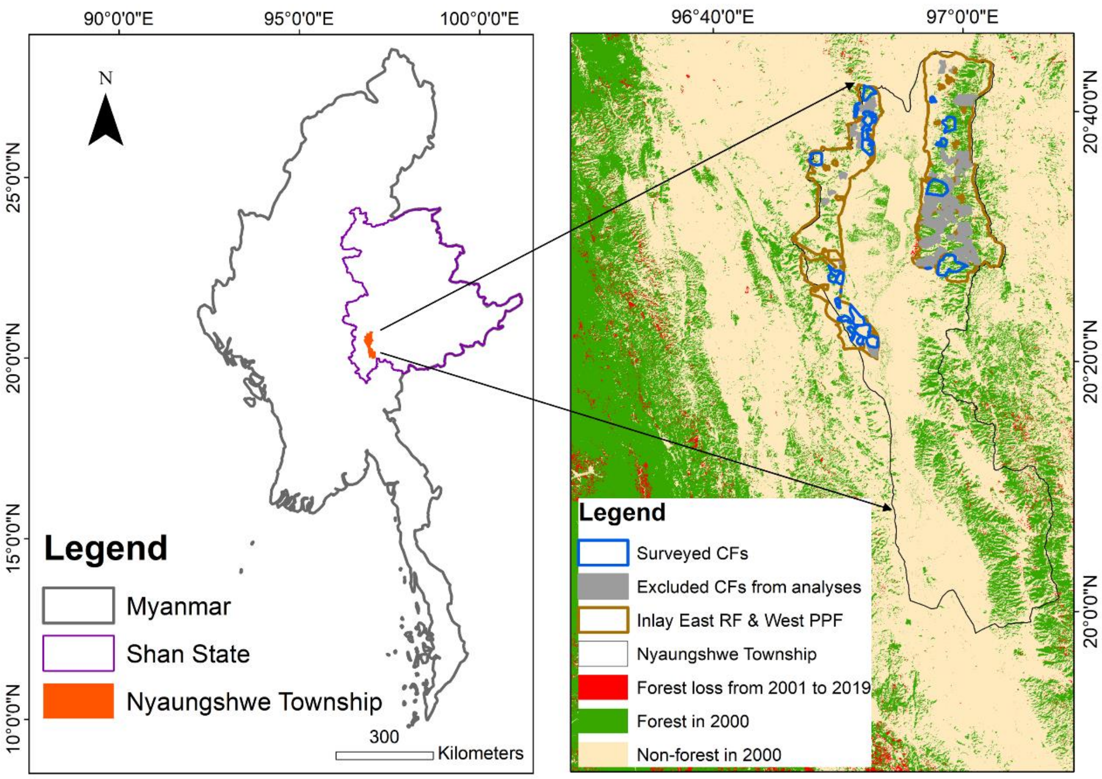

Figure 3.1. Location of the surveyed CFs in Nyaungshwe Township, Myanmar.

The country boundary from Thematic Mapping and the Shan State boundary from the Myanmar Information Management Unit-MIMU (http://themimu.info/) were used. The Myanmar Forest Department provides the boundaries of the township, RF, and PPF. The Global Forest Change dataset published by Hansen et al. (2013) was used for forest cover mapping.

Residents in two watershed conservation forests mainly earn their livelihoods from agriculture. On-land cultivation is conducted in flat areas between the lake and the mountains. It includes paddy fields (*Oryza Sativa* L.), dry land (yar) cultivation, wetland (le) cultivation, and horticulture. Upland cultivation practices include shifting cultivation, field terraces, and agroforestry systems (Htwe et al., 2015b). Shifting cultivation adopted by upland communities became permanent cultivation due to population growth and cultivation of cash crops such as turmeric, ginger, onion, garlic, maize, and sebesten trees (*Cordia dichotoma*) (Michalon et al., 2019). More than 60% of the lake catchment areas have permanent or seasonal cultivation (Pradhan et al., 2015). A large area of 13–15 km range of agricultural fields was found in the western mountain ranges (Sidle et al., 2007). Deforestation and agricultural expansion were dominant in the catchment areas (Htwe et al., 2015b; Karki et al., 2018), and deforestation caused by shifting cultivation extensively occurred in the western watershed (Htwe et al., 2015b; Su and Jassby, 2000).

3.2.2. Data

For the forest cover assessment, I used the global forest change dataset (2000-2019) published by Hansen et al. (2013), which provided the tree canopy cover for the year 2000, forest cover gain 2000-2012, and annual forest cover loss in the year 2001-2019. Forest was defined as tree cover with more than 30 percent based on the previous study of assessing the tree cover threshold for forest cover mapping in Myanmar (Lwin et al., 2019). Using this threshold, I classified the tree canopy cover 2000 into forest and non-forest layers. Deforestation was defined as forest pixels in 2000 and forest loss from 2001 to 2019. If the pixels were forests in 2000 and no forest loss from 2001 to 2019, it was defined as no deforestation. Forest gain was not considered when identifying "deforestation" and "no deforestation".

I used the CF boundaries obtained originally from the Forest Department of Nyaungshwe Township and updated by Kyaw et al. (2021). The original CF boundaries include errors, and hence, the boundaries were updated based on the field survey and the interviews of local villagers. The detailed procedure for producing the updated CF boundaries was in Kyaw et al. (2021). The elevation data with a 30-m resolution from SRTM was obtained from USGS. The slope map was created from the digital elevation model. The point features of villages and towns were downloaded from the Myanmar Information Management Unit. Totally 519 villages located within 2-km buffer of the township and nine town points in the surroundings of the study area were used as geographic proximities to sample points. The stream layer was obtained from the

Myanmar Forest Department. The road features in the east and west of the lake were created from topographic maps (1:50,000 scale) of the Myanmar Survey Department produced in 2003 using ArcMap.

3.2.3. Methods

Forest conservation type of CFs was exclusively included in the analyses of CF effectiveness. A total of 76 CFs was established for the purpose of natural forest conservation, and 71 of the 76 CFs were located inside the boundaries of two watershed conservation forests for the analyses on paper. The analyses were targeted at the earliest CFs established in Inlay East RF and Inlay West PPF between 2000 and 2001. Thus 45 CFs established after 2001 were excluded from the analyses. Of these earliest CFs, one CF was outside of the two watershed conservation forests and another CF had to withdraw from the registered list because people migrated from their village to other places. In addition, the village close to the border of Inlay West PPF managed two CFs which were located at different places. While one CF was inside the forest boundaries, another CF was located outside. In such case, CF outside the forest boundaries was not considered for the assessment. At last, I totally excluded three CFs from the analyses due to CF locations and registration status. After the exclusion of three CFs, 23 CFs remains to be analyzed.

At first, I made a simple comparison of deforestation between inside and outside CFs by computing the percentage of deforestation from 2001 to 2019. Such comparison between inside and outside CFs could bias because they were different in characteristics such as distance to the nearest village and town, and also not random. Thus, I then used matched sampling, one of the most robust methods (Rosenbaum and Rubin, 1985), to reduce bias in estimating the causal treatment effect (Stuart, 2010). Next, I applied propensity score matching among the matching methods, which is a popular approach to estimate causal treatment effects in the observational data (Caliendo and Kopeinig, 2008; Olmuş et al., 2019). The nearest neighbor algorithm was employed because this method was fairly successful in reducing bias (Rosenbaum and Rubin, 1985). Nearest neighbor propensity score matching selects a matching partner for the treated group from the control group based on the closest propensity scores (Caliendo and Kopeinig, 2008; Rosenbaum and Rubin, 1985). This method always estimates the "average effect of the treatment on the treated" (ATT) for the causal effects (Stuart, 2010). Here, inside CFs and outside CFs were treated and control groups, respectively. I also examined separately the effects of CFs, which were located in RF and PPF, on the effectiveness. At last, I checked spillover around CF areas using the definitions of the treated group as outside CF areas located within 1 km of CF boundary and the control groups as outside CF areas located greater than 1 km of CF boundary.

The dependent variable was binary, indicating that the pixel was deforested (1) or not (0) from 2001 to 2019. Covariates were selected based on previous studies (Lonn et al., 2019; Mon et al., 2009), including that elevation, slope, distance to the nearest village, distance to the nearest town, distance to the nearest stream, and distance to the main road. Ten percent of all pixels that were forests in 2000 were randomly selected for the analyses (Table 3.1.). Data analyses were conducted in R v. 3.6.3 using the 'MatchIt' package (Ho et al., 2011; R Core Team, 2020).

Table 3.1. Number of treated and control samples used in the matching analyses

Analysis	Treated samples	Control samples	Matched
Inside CFs vs outside CFs (overall)	1885	12550	1885
Spillover (overall)	2467	10083	2467
Inside CFs vs outside CFs (RF)	1194	9619	1194
Spillover (RF)	1692	7889	1692
Inside CFs vs outside CFs (PPF)	653	2806	653
Spillover (PPF)	735	2099	735

3.3. Results

3.3.1. Deforestation from 2001 to 2019

In RF and PPF, forest areas decreased by 0.19 km^2 (1.12% of forest areas in 2000) inside CFs and 2.57 km^2 (2.28% of forest areas in 2000) outside CFs (Table 3.2.). In RF, deforestation inside and outside CFs were 0.07 km^2 and 2.33 km^2, showing 0.64% and 2.67% of forest areas in 2000, respectively. In PPF, inside and outside CFs had 0.12 km^2 and 0.24 km^2 in deforested areas and deforestation inside CFs (2.01%) was higher than those outside CFs (0.95% of forest areas in 2000).

Table 3.2. Deforestation from 2001 to 2019 inside and outside CFs

	Total area (km^2)	Forest area in 2000 (km^2)	Forest area in 2019 (km^2)	Deforestation (2001 and 2019)	
				Area (km^2)	%
RF&PPF					
Inside CFs	42.29	16.93	16.74	0.19	1.12
Outside CFs	325.75	112.52	109.95	2.57	2.28
RF					
Inside CFs	16.11	10.96	10.89	0.07	0.64
Outside CFs	187.58	87.21	84.88	2.33	2.67
PPF					
Inside CFs	26.18	5.97	5.85	0.12	2.01
Outside CFs	138.17	25.32	25.08	0.24	0.95

3.3.2. Impacts of community forestry using matching method

The summary Tables S1-S6 and Figures S1-S12 show the propensity scores and covariate balance before and after matching (see Apendix I). Land characteristics between inside and outside CFs were different. Before the matching, areas inside CFs in both RF and PPF were located at lower elevations and near distances to the village, town, stream and road compared to the areas outside CFs. However, there were higher slopes inside CFs than outside CFs. Before matching, CFs in PPF also had similar characteristics of covariates, indicating that CFs were lower elevated, higher slope areas, and closer to the village, town, stream, and road than outside of CFs. Unlike CFs in PPF, CFs in RF were far from village and town. Other characteristics were the same as CFs in PPF. The distributions of propensity scores improved after the matching (see Figures S1, S3, S5, S7, S9, S11). The standardized mean difference between the covariates of two groups (inside and outside CFs) became smaller and close to zero (see Figures S2, S4, S6, S8, S10, S12).

According to the propensity score matching, CFs in RF and PPF had lower deforestation (0.9%) than outside CFs, but the significant level was marginal (p-value = 0.0503) (Table 3.3.). The result of the spillover check showed a positive estimate of the ATT but was not statistically significant. When CFs were separately analyzed based on CF (RF or PPF) locations, there was a difference in effectiveness between CFs in

RF and PPF. In RF, CFs showed a significant reduction in deforestation compared to outside CF areas at 2.68% (p-value = <0.001). The spillover result showed that outside CFs within 1 km from CF boundary reduced deforestation than the areas greater than 1 km buffer, but not significant value. In PPF, CFs could not prevent deforestation compared to outside CF areas. For spillover check, ATT had a positive value but not a significant level.

Table 3.3. Average treatment effect on treated for deforestation

	ATT		
	Estimate	**Standard error**	**P-value**
CFs in RF & PPF	-0.0090	0.0046	0.0503
Spill-over	0.0004	0.0041	0.921
CFs in RF	-0.0268	0.0054	<0.001
Spill-over	-0.0071	0.0053	0.18
CFs in PPF	0.0092	0.0068	0.1766
Spill-over	<0.0001	0.0060	1.0000

3.4. Discussion

In simple comparison with outside CFs in RF and PPF, inside CFs had lower deforestation. However, CFs showed no significant evidence of reducing deforestation after accounting for selection bias and covariate imbalance. A similar finding was reported by a country-wide study in Madagascar, showing that community forest management was poor at reducing deforestation (Rasolofoson et al., 2015). Community forests could not guarantee ever for the success of avoided deforestation (Bowler et al., 2012; Pelletier et al., 2016). Because degraded forests not to meet the needs of local communities were assigned as CFs (Anderson et al., 2015), community members failed in cooperative works when resources were extremely scarce (Bardhan, 1993).

The reasons for the ineffective performance of CFs in the study area might be due to human interventions (firewood collection and agricultural practices). According to CFIs, community forest user groups (CFUGs) are allowed to extract forest resources from CFs without negatively impacting the sustainability of CFs. Outsiders who are non-community forest user groups have no access to forest resources from CFs.

Firewood was the principal forest product, and firewood dependency was relatively high in the township because 67.85% of households used firewood as cooking energy (Department of Population, 2015b). For firewood demands, illegal cutting of firewood from surrounding villages occurred inside CFs. Because local communities, both CFUGs, and outsiders, highly demanded firewood as a daily commodity for cooking, they put too much pressure on CFs, causing forest loss.

Another concern is related to the firewood extraction pattern of firewood collectors. CF villages have local rules for firewood extraction on sustainability. For example, they applied to lop off some parts of the branches of the trees or coppice the trees for sustainable consumption. However, illegal firewood collectors cut the trees based on their preference and accessibility without considering the sustainability, causing adverse effects on CFs. A study in the Central Himalayas also indicated that forest decline occurred in community-managed forests because people did not follow the rule of tree cutting for forest conservation (Balooni et al., 2007). On a global scale, Hajjar et al. (2021) found that the probability of joint double-positive outcomes related to income and environmental indicators (forest cover, forest condition, and biodiversity) decreased when community members did not observe the local forest rules.

Another possible reason why CFs did not reduce forest loss is upland cultivation, especially shifting cultivation. Shifting cultivation was dominant in western mountain ranges and resulted in severe deforestation (Htwe et al., 2015b; Su and Jassby, 2000). Due to heavy deforestation in these areas, CFs could not deter deforestation on average and also for the separate performance of CFs in PPF. Avoided deforestation might be difficult for CFs in higher deforested areas driven by shifting cultivation. This finding contrasts with previous studies (Pfaff et al., 2014; Santika et al., 2017) because they observed that the performance of local communities was better in higher human intervention areas than areas with low interventions. Also, Pelletier et al. (2016) suggested that CFs must be located in higher deforestation areas to mitigate deforestation. Although CFs in PPF could not reduce deforestation compared to outside CFs, CFs in RF showed significant evidence of reducing deforestation. There are some examples of different performances of CFs across spatial scales with land-use histories (Santika et al., 2019, 2017) and types of CF (Rasolofoson et al., 2015). This study confirmed that CF performances were diverse in areas with deforestation pressure.

It is important to note that people may shift the extraction of forest resources to surrounding forests due to conservation programs such as CF (Ota et al., 2020; Pfaff and Robalino, 2017; Schreckenberg and Luttrell, 2009). Here, there was no spillover for the significant reduction in deforestation of CFs in RF, implying that CF effectiveness did not impact surrounding forests. One reason might be that CFs were located in RF, where people could extract forest resources from RF for subsistence use. Thus, the potential for deforestation within 1-km buffer of CFs decreased. However, in the case of PPF and overall effect, spillovers did not occur in areas where there was no significant avoided deforestation (Börner et al., 2020).

On average, community forests were not effective at reducing deforestation relative to outside CFs. However, I observed significant evidence of avoided deforestation inside CFs compared to outside CFs in RF. Because this study was conducted at the local scale, I could not generalize about the performance of CFs on reducing deforestation across the country. Pelletier et al. (2016) found that community forest management was more effective in reducing forest degradation and enhancing carbon stock than reducing deforestation. Degraded forest areas were the high priorities for establishing CFs (Maryudi et al., 2012). Assessment on reducing forest degradation is also essential to prove whether CF could improve forest conditions in degraded areas. This study focused only on avoided deforestation of CFs and therefore reducing forest degradation of CFs should be evaluated as further research.

3.5. Conclusions

I evaluated the performance of CFs in deterring deforestation compared with outside CFs in two watershed conservation forests. This study showed that CFs were ineffective in reducing deforestation in general, but CFs in RF was of great significance to avoided deforestation. In conclusion, CFs have different impacts of avoided deforestation depending on anthropogenic pressure. Because CFs are located in different social, cultural, and geospatial contexts, CF effectiveness will also vary in these contexts. CF establishment based on impact evaluations might reach the ecological and socio-economic objectives of CF.

Appendix I

Table S1: Summary of covariate balance before and after propensity score matching using inside CFs of RF and PPF as treatment

	Before Matching			After Matching		
	Means Treated (n=1885)	**Means Control (n=12550)**	**Standardized Mean Difference**	**Means Treated (n=1885)**	**Means Control (n=1885)**	**Standardized Mean Difference**
Elevation (m)	1208.33	1337.37	-0.8067	1208.33	1202.97	0.0335
Slope (˚)	21.65	19.66	0.2302	21.65	21.07	0.0666
Distance to the nearest village (m)	1173.61	1206.68	-0.0677	1173.61	1183.22	-0.0197
Distance to the nearest town (m)	12717.38	13623.10	-0.1486	12717.38	12755.63	-0.0063
Distance to the nearest stream (m)	186.34	350.30	-1.0421	186.34	179.67	0.0424
Distance to the nearest road (m)	2981.57	4037.05	-0.6188	2981.57	2904.47	0.0452

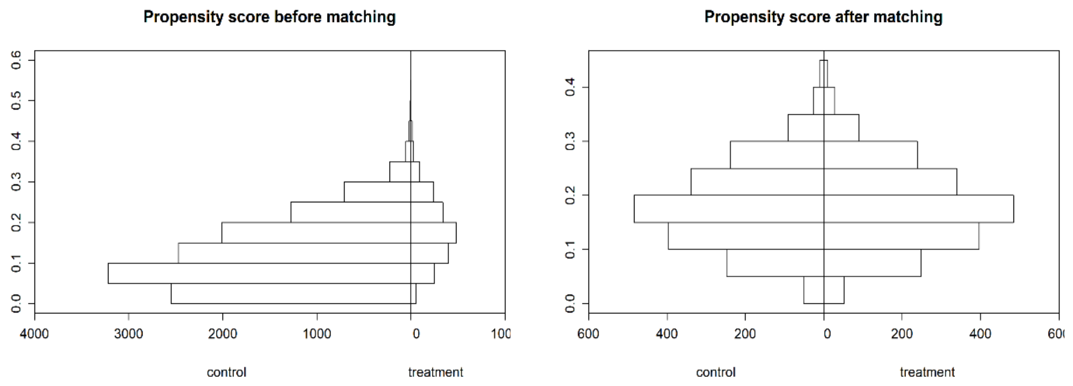

Figure S1: Propensity scores before and after matching using inside CFs of RF and PPF as treatment

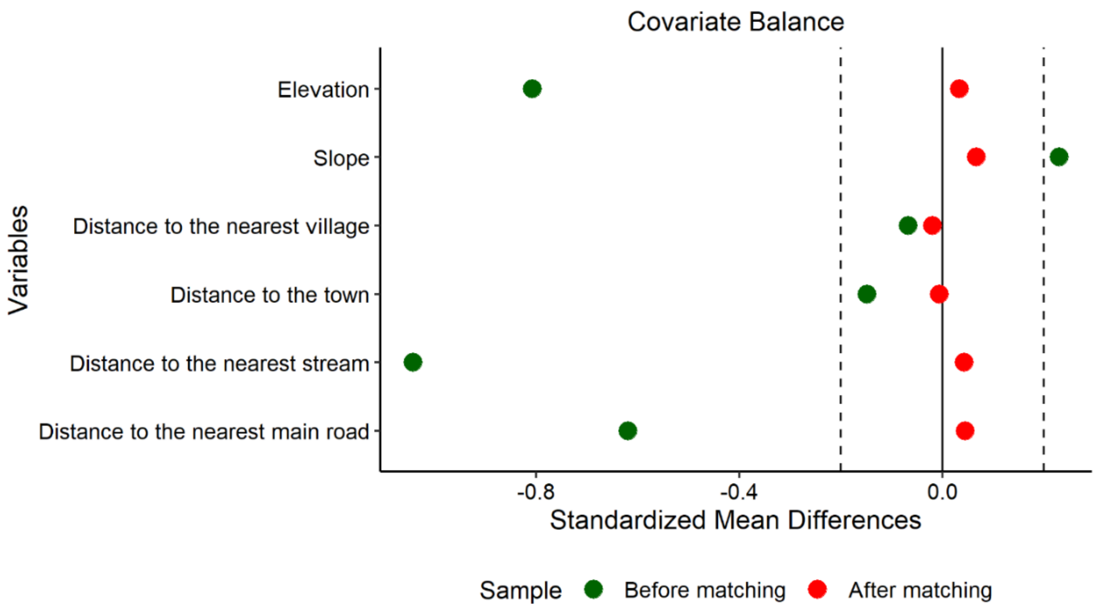

Figure S2: Covariate balance before and after matching using inside CFs of RF and PPF as treatment

Table S2: Summary of covariate balance before and after propensity score matching using outside CFs within 1 km buffer in RF&PPF as treatment for spillover check

	Before Matching			**After Matching**		
	Means Treated (n=2467)	**Means Control (n=10083)**	**Standardized Mean Difference**	**Means Treated (n=2467)**	**Means Control (n=2467)**	**Standardized Mean Difference**
Elevation (m)	1218.70	1366.41	-0.8307	1218.70	1220.32	-0.0091
Slope (˚)	19.63	19.66	-0.0041	19.63	19.28	0.0384
Distance to the nearest village (m)	1218.81	1203.71	0.0307	1218.81	1221.23	-0.0049
Distance to the nearest town (m)	12280.22	13951.66	-0.2404	12280.22	12631.73	-0.0506
Distance to the nearest stream (m)	205.82	385.64	-1.1701	205.82	203.01	0.0183
Distance to the nearest road (m)	3562.31	4153.20	-0.2847	3562.31	3511.22	0.0246

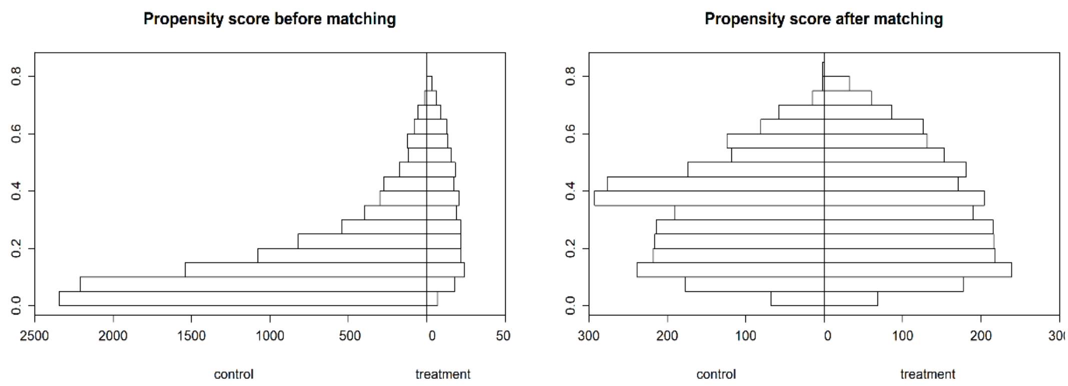

Figure S3: Propensity scores before and after matching using outside CFs within 1 km buffer in RF&PPF as treatment for spillover check

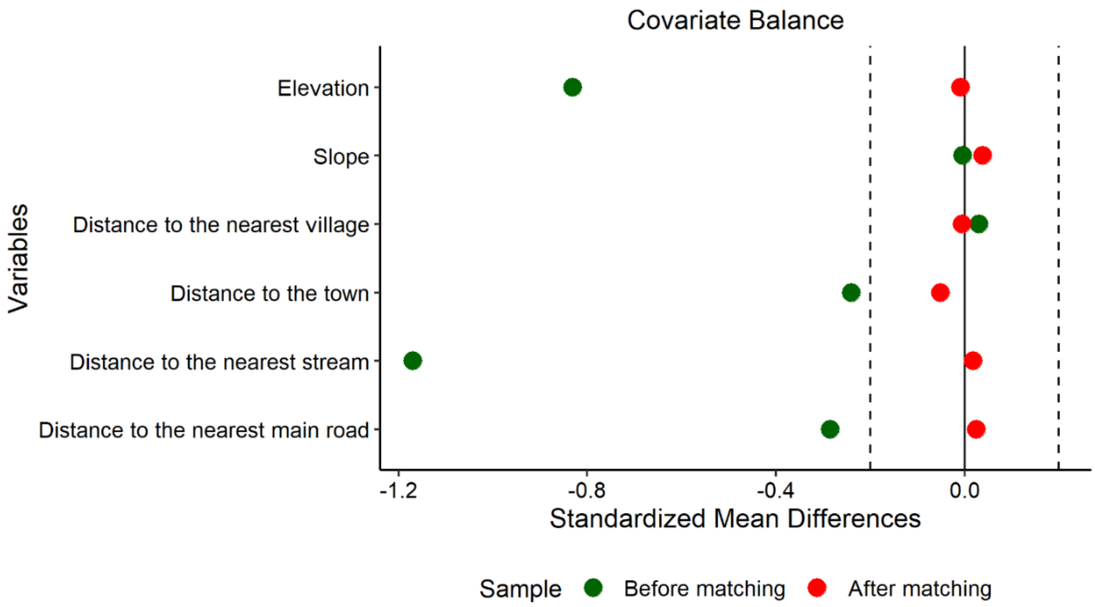

Figure S4: Covariate balance before and after matching using outside CFs within 1 km buffer in RF&PPF as treatment for spillover check

Table S3: Summary of covariate balance before and after propensity score matching using inside CFs of RF as treatment

	Before Matching			After Matching		
	Means Treated (n=1194)	**Means Control (n=9619)**	**Standardized Mean Difference**	**Means Treated (n=1194)**	**Means Control (n=1194)**	**Standardized Mean Difference**
Elevation (m)	1239.77	1385.22	-0.9366	1239.77	1227.91	0.0764
Slope (˚)	23.13	20.41	0.3384	23.13	22.64	0.0609
Distance to the nearest village (m)	1226.35	1164.02	0.1196	1226.35	1221.80	0.0087
Distance to the nearest town (m)	13871.19	12822.53	0.1527	13871.19	13014.84	0.1247
Distance to the nearest stream (m)	159.05	386.15	-1.9595	159.05	149.74	0.0803
Distance to the nearest road (m)	3547.63	4548.74	-0.5824	3547.63	3317.23	0.1340

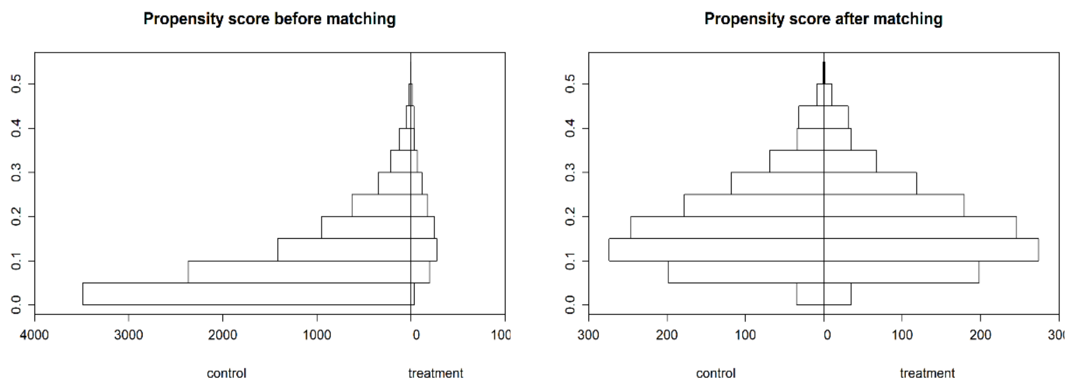

Figure S5: Propensity scores before and after matching using inside CFs of RF as treatment

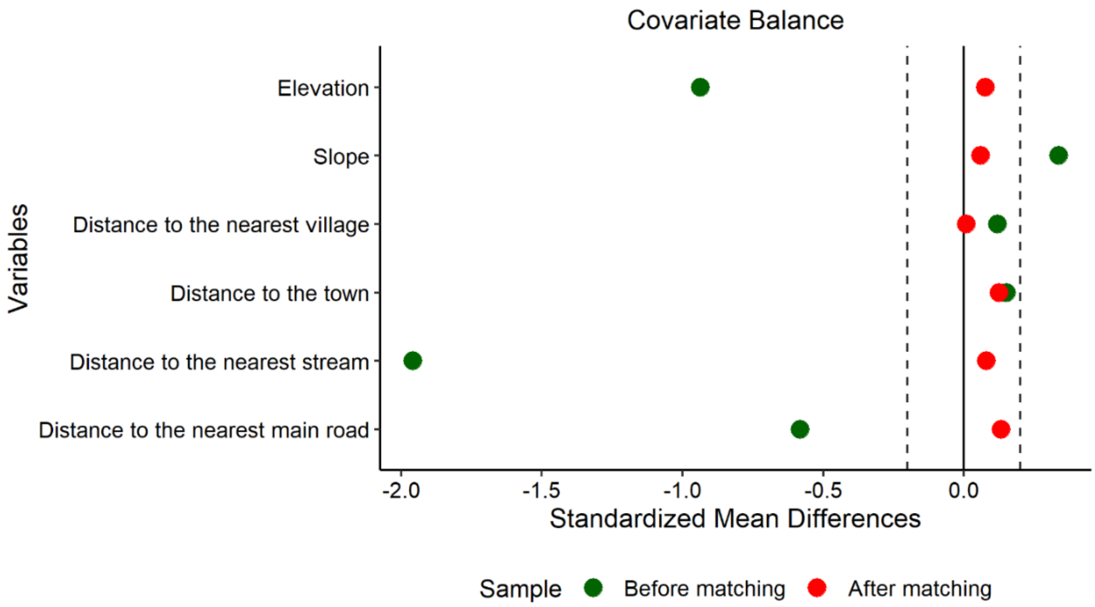

Figure S6: Covariate balance before and after matching using inside CFs of RF as treatment

Table S4: Summary of covariate balance before and after propensity score matching using outside CFs within 1 km buffer in RF as treatment for spillover check

	Before Matching			**After Matching**		
	Means Treated (n=1692)	**Means Control (n=7889)**	**Standardized Mean Difference**	**Means Treated (n=1692)**	**Means Control (n=1692)**	**Standardized Mean Difference**
Elevation (m)	1250.82	1412.22	-0.8951	1250.82	1261.65	-0.0600
Slope (˚)	20.96	20.32	0.0765	20.96	20.44	0.0619
Distance to the nearest village (m)	1232.80	1169.64	0.1424	1232.80	1214.85	0.0405
Distance to the nearest town (m)	12029.82	13032.83	-0.1310	12029.82	12104.60	-0.0098
Distance to the nearest stream (m)	208.90	420.19	-1.4599	208.90	231.34	-0.1551
Distance to the nearest road (m)	4191.03	4587.87	-0.1993	4191.03	4173.11	0.0090

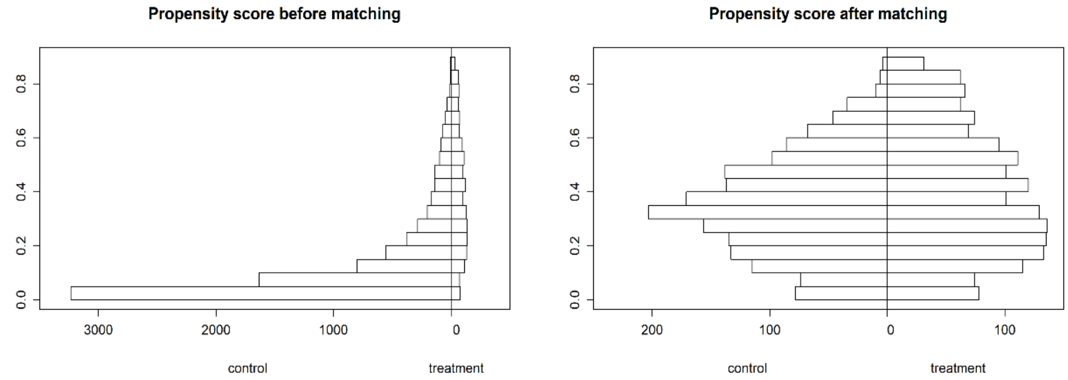

Figure S7: Propensity scores before and after matching using outside CFs within 1 km buffer in RF as treatment for spillover check

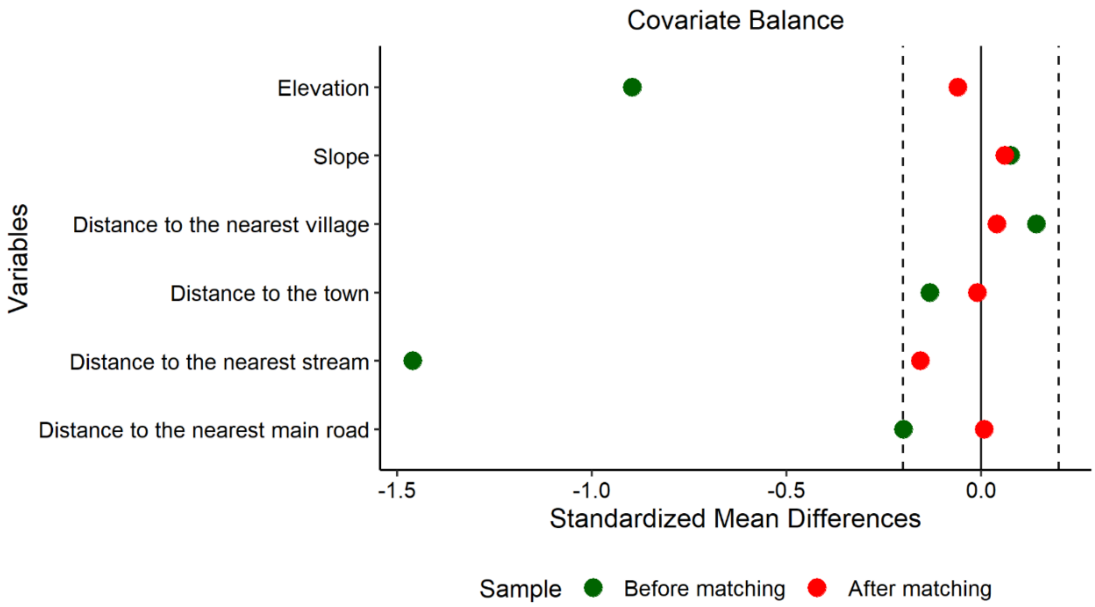

Figure S8: Covariate balance before and after matching using outside CFs within 1 km buffer in RF as treatment for spillover check

Table S5: Summary of covariate balance before and after propensity score matching using inside CFs of PPF as treatment

	Before Matching			**After Matching**		
	Means Treated (n=653)	**Means Control (n=2806)**	**Standardized Mean Difference**	**Means Treated (n=653)**	**Means Control (n=653)**	**Standardized Mean Difference**
Elevation (m)	1144.84	1176.61	-0.2076	1144.84	1130.65	0.0927
Slope (˚)	18.75	16.69	0.2194	18.75	17.49	0.1343
Distance to the nearest village (m)	1166.24	1302.13	-0.2893	1166.24	1125.94	0.0858
Distance to the nearest town (m)	11816.63	16229.34	-0.9672	11816.63	12238.42	-0.0924
Distance to the nearest stream (m)	217.68	274.38	-0.2909	217.68	224.56	-0.0353
Distance to the nearest road (m)	2033.46	2427.53	-0.2650	2033.46	2130.32	-0.0651

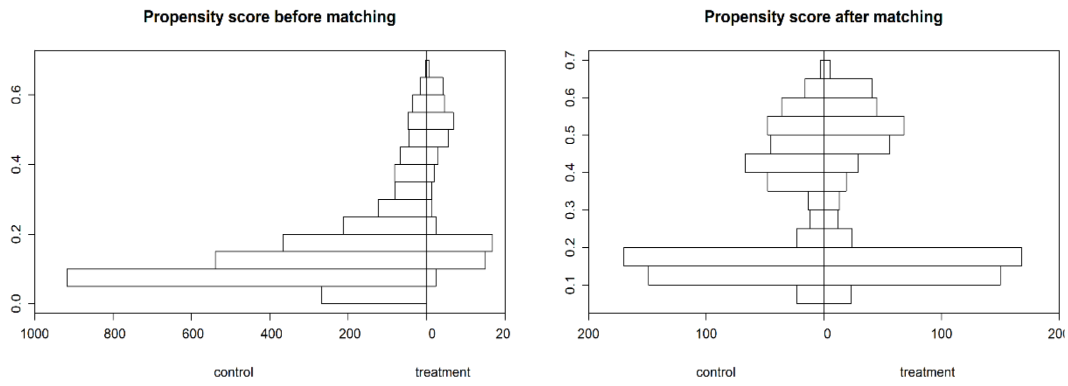

Figure S9: Propensity scores before and after matching using inside CFs of PPF as treatment

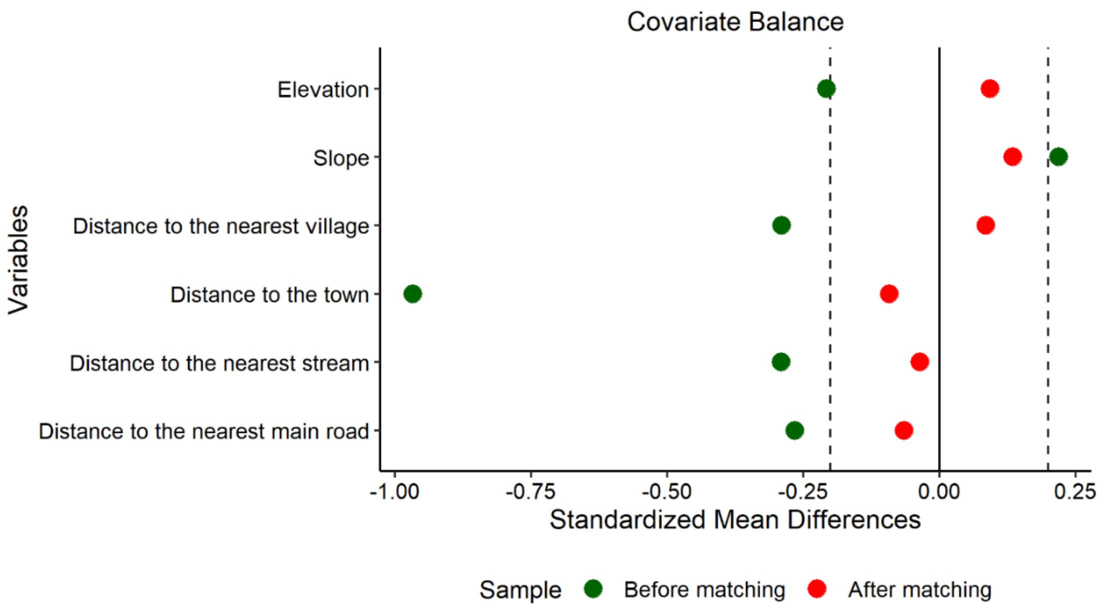

Figure S10: Covariate balance before and after matching using inside CFs of PPF as treatment

Table S6: Summary of covariate balance before and after propensity score matching using outside CFs within 1 km buffer in PPF as treatment for spillover check

	Before Matching			After Matching		
	Means Treated (n=735)	**Means Control (n=2099)**	**Standardized Mean Difference**	**Means Treated (n=735)**	**Means Control (n=735)**	**Standardized Mean Difference**
Elevation (m)	1160.08	1186.67	-0.1694	1160.08	1169.88	-0.0625
Slope (˚)	15.28	17.08	-0.2018	15.28	15.37	-0.0107
Distance to the nearest village (m)	1202.67	1328.56	-0.2041	1202.67	1227.51	-0.0403
Distance to the nearest town (m)	12564.68	17402.97	-1.0254	12564.68	13982.49	-0.3005
Distance to the nearest stream (m)	222.29	297.69	-0.4416	222.29	192.55	0.1741
Distance to the nearest road (m)	2187.13	2511.60	-0.2213	2187.13	2425.03	-0.1623

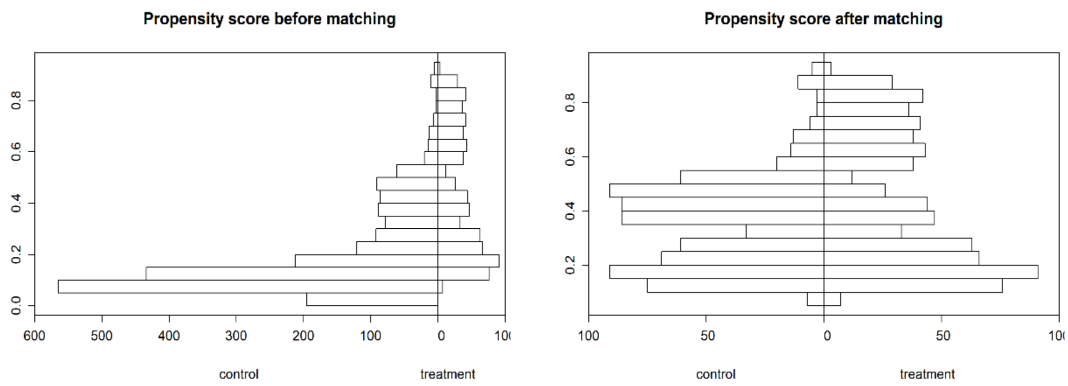

Figure S11: Propensity scores before and after matching using outside CFs within 1 km buffer in PPF as treatment for spillover check

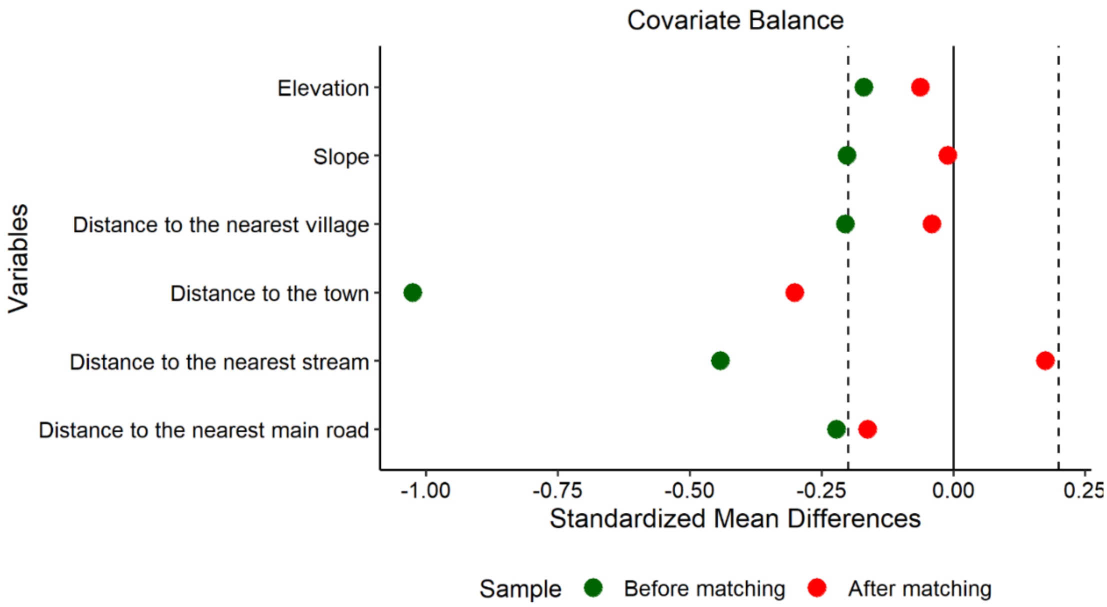

Figure S12: Covariate balance before and after matching using outside CFs within 1 km buffer in PPF as treatment for spillover check

Chapter 4

Geographical factors trump community factors in deforestation risk in two watershed conservation forests in Myanmar

4.1. Introduction

Forests in tropical regions, which make up 45% of the world's forests, have experienced and continue to experience severe deforestation, although the rate of deforestation has slowed since 1990 (FAO, 2020b). Deforestation in tropical regions adversely affects the carbon cycle (Baccini et al., 2017), biodiversity (Lewis et al., 2015; Newbold et al., 2014), and climate (Alkama and Cescatti, 2016; Costa and Foley, 2000; Lawrence and Vandecar, 2015). There is thus a pressing need to mitigate deforestation in tropical regions. Although there are several approaches for mitigating deforestation, approaches that are compatible with the needs of local communities are essential given that many people living in and around the world's tropical forests depend on forest resources for cooking and heating (Kyaw et al., 2020; Win et al., 2018b), hunting (Robinson and Redford, 1994), and income (Charlery and Walelign, 2015; Dash et al., 2016; Mamo et al., 2007).

CF, which refers to forest management in which local community members play an active role in management activities, can provide both ecological and socio-economic benefits (Burivalova et al., 2017; Rasolofoson et al., 2017). Since the concept of CF was introduced in the late 1970s (Gilmour, 2016; Pandit and Bevilacqua, 2011), CFs have become widely established in tropical countries (e.g., Rasolofoson et al., 2017, 2015; Santika et al., 2017). However, the effectiveness of CF for mitigating deforestation is still debated, as some studies have shown that CF positively affects forest conservation (e.g., Casse and Milhøj, 2011; Min-Venditti et al., 2017; Ota et al., 2020; Santika et al., 2019, 2017), whereas others have shown that the effects of CF on forest conservation are limited (e.g., Casse and Milhøj, 2011; Rasolofoson et al., 2015). One reason for this inconsistency is that a variety of site-specific factors can affect the effectiveness of CF (e.g., Casse and Milhøj, 2011; Lonn et al., 2018; Oldekop et al., 2019; Pagdee et al., 2006; Santika et al., 2019, 2017).

Numerous studies have attempted to identify the factors affecting the effectiveness of CFs (e.g., Baynes et al., 2015; Pagdee et al., 2006). Geographical factors such as elevation and the distance from the nearest village are important considerations for newly established CFs, as the locations that are most likely to succeed as CFs can be determined before their establishment. Some studies that have identified the geographical factors affecting the effectiveness of CF (e.g., Agrawal and Chhatre, 2006; Lonn et al., 2018; Perez-Verdin et al., 2009; Thakur et al., 2020) have revealed that the accessibility to CFs affects the success of forest conservation. The characteristics of the local community managing CFs are also important to consider when evaluating the likelihood of success for a CF program. Previous studies have evaluated the importance of community characteristics such as group size (Agrawal and Chhatre, 2006; Oldekop et al., 2010; Perez-Verdin et al., 2009; Yang et al., 2013), forest dependence (Dietz, 2003; Jumbe and Angelsen, 2007; Okumu and Muchapondwa, 2020; Soe and Yeo-Chang, 2019), and leadership (Brooks et al., 2013; Gutiérrez et al., 2011; Zulu, 2008) in determining the success of CFs or community-based conservation projects. As numerous factors can affect the effectiveness of CFs, evaluation of the importance of these factors is critically important for the successful implementation of CF.

Another reason for the inconsistency among studies regarding the effectiveness of CFs is that previous studies have often been poorly designed and have not used robust indicators for evaluating the effectiveness of CFs (Bowler et al., 2012). As satellite remote sensing can capture large areas of quantitative forest cover change, an increasing number of studies have used satellite-derived datasets to more robustly assess the success of CFs (Hajjar and Oldekop, 2018). These studies have mainly used causal inference to assess forest conservation effectiveness (e.g., Oldekop et al., 2019; Putraditama et al., 2019; Santika et al., 2017) and have compared the effectiveness of CFs with non-CF areas. However, few studies have characterized variation in conservation effectiveness among CFs. As studies identifying casual effects often only use geographical factors, meteorological factors, and census-derived community characteristics (e.g., population density), whether community characteristics that cannot be collected from censuses (e.g., forest dependence and leadership) affect the conservation effectiveness of CFs remains unclear. Here, I evaluated the importance of geographical factors and community characteristics using satellite-derived forest cover change datasets, which can provide more robust information for conservation managers and policymakers.

Myanmar is the largest country in mainland Southeast Asia and has a population of ca. 51 million (Department of Population, 2015c). Approximately 70% of the population lives in rural areas and depends on forests for their basic needs, such as cooking, heating, and shelter. Forests in Myanmar make up 42.19% of the country's total area (FAO, 2020a) and have experienced severe deforestation for decades (Bhagwat et al., 2017; Estoque et al., 2018; Shimizu et al., 2017); Myanmar has the third-highest deforestation rate globally, according to annual net forest cover loss from 2010 to 2015 (FAO, 2016). The main drivers of deforestation are agricultural expansion and the extraction of forest resources (e.g., firewood, charcoal, timber, and household materials) (Htun et al., 2013; Leimgruber et al., 2005; Mon et al., 2012; Shimizu et al., 2017; Veettil et al., 2018; Webb et al., 2014; Yang et al., 2019). To accommodate the needs of local communities and improve forest conditions, the participation of local communities in forest management in Myanmar was formally initiated by the CFIs in 1995. The government's target is to place 9186 km^2 under CF management by 2030. As of March 2020, 32% of this target has been achieved. Identifying the factors that affect the success of forest conservation is critically important for enhancing the effectiveness of the management of already established CFs and for ensuring the effectiveness of new areas placed under CF management in Myanmar.

The aim of this study was to explore the factors driving deforestation in CFs in the buffer zone of Inlay Lake Biosphere Reserve, Myanmar, with a special focus on the roles of geographical factors and community characteristics.

4.2. Case study context: community characteristics of CFs in Myanmar

This study focused on three community characteristics—forest dependency, leadership, and group size—because previous studies have suggested that these characteristics are particularly important.

4.2.1. Forest dependency

There are a variety of ways to measure forest dependencies, such as economic dependence on forests, the non-economic benefits provided by forests, the environmental services of forests, and the monetary worth of forest products (Akamani et al., 2015; Nerfa et al., 2020; Power, 2006). The effect of forest dependency on the outcome of CF can vary. For example, some studies have shown that forest dependency increases participation in CF activities and achieves successful outcomes (Gatiso, 2019; Lise, 2000). However, other studies have shown that heavy forest dependency can lead to decreased forest cover and reduce the success of CF (Balooni et al., 2007; Chhatre and Agrawal, 2008; Okumu and Muchapondwa, 2020). An analysis of a large dataset indicated that forest dependency was not associated with forest conditions (Gibson et al., 2005).

CFs in Myanmar are established to provide basic needs for local communities in addition to forest conservation. According to CF instructions, the establishment of CF is permitted in areas where forests have the potential to meet local needs, including forest products and income. Those who depend on forests can apply for the establishment of CFs. Thus, the relationship between forest benefits and local communities has been considered since the initiation of CF. The resources collected from CFs vary depending on the region. CFUGs often collect firewood from CFs (e.g., Kyaw et al., 2020). In addition, seasonal crops, fodder, firewood, and thetke (*Cylindrical imperator*) are the main forest products of plantation-type CFs in the dry zone (Hlaing and Inoue, 2013). Wood, non-timber forest products, mud crab (*Scylla serrata*), and nypa palm (*Nypa fruticans*) are also extracted from mangrove CFs in delta areas (Feurer et al., 2018). Although previous studies of forest dependency in the CFs of Myanmar have been conducted in different parts of the country, including the dry zone and delta areas (e.g., Feurer et al., 2018; Hlaing and Inoue, 2013), they have focused exclusively on forest dependency in terms of livelihood strategies (Feurer et al., 2018) and participation in CF activities (Hlaing and Inoue, 2013). For example, Feurer et al. (2018) reported that CF members earned higher forest income from mangrove CFs than non-CF members. The effect of forest dependency on deforestation in CFs remains unclear.

4.2.2. Leadership

Leadership is thought to greatly affect the success of resource management (Evans et al., 2015; Van Laerh oven, 2010). However, only a few studies have quantified the effect of leadership on the outcomes of resource management (Evans et al., 2015).

Most studies have defined leadership based on the presence or absence of a leader (e.g., Gutiérrez et al., 2011; Pagdee et al., 2006; Van Laerhoven, 2010). A previous analysis of a cross-national dataset showed that the presence of leaders has a positive effect on CF management.

In Myanmar, the CF chairman should be unanimously elected by CFUG members according to the 2019 instructions. Being respected, fair, knowledgeable, and sociable are considered desirable qualities of CF chairmen per the procedures of CF in 2016. Although a previous case study of 4 CFUGs in Myanmar aimed to qualitatively characterize the effect of leadership on the participation of CFUG members in CF activities (Hlaing and Inoue, 2013), no quantitative studies to date have evaluated the effect of leadership on deforestation.

4.2.3. Group size

Group size, which has various effects on cooperative activities (Barcelo and Capraro, 2015; Capraro and Barcelo, 2015; Pereda et al., 2019), greatly affects the success of CF (Agrawal, 2001; Pagdee et al., 2006). An increasing number of studies have focused on group size, but the effect of group size is still debated because the findings of previous studies are often inconsistent. For example, one study showed that cooperation was difficult to achieve for large groups involved in CF activities (Negi et al., 2018). However, studies from Nepal and India found that larger forest groups tended to be more successful because more people were involved in monitoring and management activities (Balooni et al., 2007; Nagendra et al., 2005).

According to 1995 CFIs in Myanmar, households that seek to establish CFs are grouped into CFUGs. In the 2019 instructions, a CFUG is defined as a group formed by households residing for five consecutive years in or within 8 km from the forest. This group includes households interested in forest activities as well as those dependent on forests for their livelihoods. Group size is not specified in both sets of instructions. The lower limit of group size is described in the Standard Operating Procedures of CF in 2016; thus, a proper balance between group size and forest size is required when a CF is established. Although CF studies in Myanmar have analyzed the social and economic attributes of CF group members (Feurer et al., 2018; Hlaing and Inoue, 2013; Lin, 2005), no studies to date have focused on group size.

4.3. Materials and methods

4.3.1. Study area

This study was conducted in CFs established in two watershed conservation forests—Inlay East Reserved Forest and Inlay West Protected Public Forest—in Nyaungshwe Township, Taunggyi District, southern Shan State, Myanmar (Figure 4.1.). Nyaungshwe Township is located between 19°58′ and 20°45′ N and 96°46′ and 97°07′ E.

The climate is humid and subtropical with three seasons: summer (March–June), rainy (July–October), and winter (November–February). The mean air temperature ranges from 21.9 to 31.3°C (Thin et al., 2020). The average annual precipitation is 928 mm (Michalon et al., 2019), and approximately 70% of the annual rainfall occurs during July, August, and September in the southwest monsoon (Re et al., 2018). The geology of the western part of Inlay lake primarily comprises Mesozoic carbonate rock and Tertiary clastic sedimentary rock (Aung et al., 2019). The eastern part is primarily composed of Lower Paleozoic carbonate and clastic sedimentary rock. The forest types of Nyaungshwe Township include dry forest and deciduous dipterocarp forest. I selected Nyaungshwe Township because it has one of the longest histories of CF management in Myanmar. The total land areas of Inlay East RF and Inlay West PPF are 213.26 and 140.86 km^2, respectively. According to the internal report of the Myanmar Forest Department in 2019, approximately 172.66 km^2 (80.96%) of Inlay East RF is covered with forests, and approximately 56.69 km^2 (40.25%) of Inlay West PPF is forested.

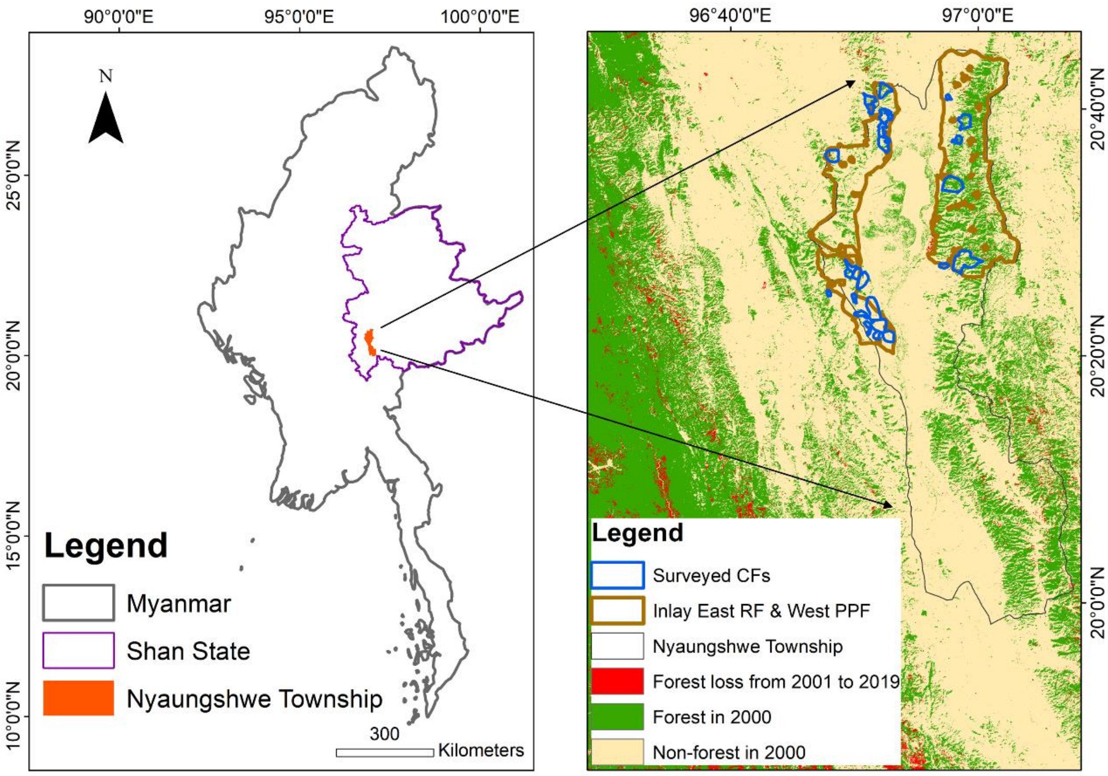

Figure 4.1. Location of the study area in Myanmar.

The country border was obtained from Thematic Mapping. The boundary of the Shan state was obtained from MIMU. The boundaries of the township, RF, and PPF were obtained from the Myanmar Forest Department. Forest cover change data were downloaded from Global Forest Change 2000–2019 Data (Hansen et al., 2013).

The CFs in Myanmar can be classified into two categories: natural forest conservation areas and plantations. As the aim of this study was to evaluate the effectiveness of the forest conservation of CFs, I focused exclusively on the CFs of natural forest conservation areas. According to the 2019 internal report of the Forest Department, Myanmar, 76 CFs were registered as natural conservation areas in the two watershed conservation forests. Out of the 76 CFs, the earliest CFs, which were established between 2000 and 2001, were the focus of our study. One CF established in 2001 in Inlay West PPF is soon going to be terminated because of the migration of the local people. Another CF near the West PPF was located outside of the two watershed conservation forests. I thus excluded these two CFs from analyses. I examined a total of 24 CFs in our study. When CFs were located on the border of the watershed conservation forests and included areas both outside and inside of the watershed conservation forests, the areas outside of the forest boundaries were included in analyses. The CFs used in this study ranged in elevation from 893 to 1696 m and slope from 1°to 51°.

4.3.2. Data

The Global Forest Change dataset, a global map with a spatial resolution of 30 m derived from Landsat images, was used to assess forest cover change from 2000 to 2019 (Hansen et al., 2013). The dataset provides tree canopy cover for the year 2000, annual forest loss from 2001 to 2019, and forest gain during 2000–2012. Tree cover in 2000 was defined as canopy closure for all vegetation taller than 5 m in height. Forest loss was defined as a change from a forest to a non-forest state. Forest gain was defined as a change from a non-forest to forest state from 2000–2012. Areas with greater than 30% tree cover were defined as forest per a previous assessment of the accuracies of different tree cover thresholds for forest cover mapping derived from the Global Forest Change dataset in Myanmar (Lwin et al., 2019). The overlap of forest loss and gain pixels was assessed because forest loss and gain often occurred in the same pixels. Forest loss was defined as the change in pixels from forests in 2000 to non-forests from 2001 to 2019. If tree canopy cover was still forested in 2019, it was not defined as forest loss.

CF boundaries were obtained from the Forest Department of Nyaungshwe Township, Myanmar. As the accuracy of the CF boundaries was unclear, I confirmed the boundaries through a field survey with the help of CFUGs (see Section 4.3.3.). A DEM with a 30 m resolution from SRTM was acquired from USGS. The slope values were identified using the elevation data. The locations of villages were downloaded from MIMU. A total of 519 villages (including villages located in a 2 km buffer of Nyaungshwe Township) were included in the analyses.

4.3.3. Field survey

The semi-structured group interviews were conducted in the 24 CF villages between November and December 2019. In some CFs, two, three, or four villages are combined; in such cases, data from these villages were pooled. There were approximately ten respondents in each group interview. All respondents were members of CFUGs, and the CF chairman was included if one was designated. I informed the respondents of the academic purpose of the interviews before the interviews began. CFUGs were queried about household characteristics, such as ethnicity, education status, livelihood activities, and types of cooking energy, along with community characteristics related to CFs, including forest dependency and CF activities. Forest dependency was defined as the extraction of forest resources from CFs to meet basic needs. CFUGs were asked whether they have extracted forest resources from CFs. If CFUGs indicated that they had extracted forest resources, information on the forest resources extracted from CFs was recorded. I collected information on CF activities since the establishment of CFs. I also asked whether there was a CF chairman and whether the CF chairman participated in the CF activities, as leadership was defined based on the participation status of the CF chairman (see Results).

I also collected information on the CF boundaries in multiple ways. I first consulted the CF locations and a CF map in the Management Plan book. CFs are usually demarcated by prominent features in the landscape, such as valleys, mountain ranges, villages, roads, and streams. In the field survey, I confirmed the location of prominent features described in the Management Plan book and the locations of CF boundaries from CFUGs by showing the CF map received from the Forest Department of Nyaungshwe Township and a satellite map. I also visited some of the CF boundaries where the demarcation pillars are established with the help of CFUGs and took the coordinates of the pillars using a global navigation satellite system (GNSS; GPSmap 62SJ, Garmin Ltd., Schaffhausen, Switzerland). I finally updated the CF boundaries using the positions of demarcation pillars and prominent features with a satellite map in ArcGIS 10.6.

4.3.4. Data analysis

I performed a generalized linear mixed model (GLMM) with a binomial distribution and a logit link function. The GLMM model was applied in R version 3.6.3 using the “lme4” package (Bates et al., 2015; R Core Team, 2020). I used forest fate in 2019 relative to the baseline forest cover in 2000 as the binary response variable (1 = forest loss; 0 = no forest loss). I used forest dependency, leadership, group size, CF area, forest cover ratio, elevation, slope, distance to the nearest village, and distance to the CF boundary as independent variables (Table 4.1.). Forest dependency was a binary variable that indicated the presence (1) or absence (0) of forest dependency. I assigned

1 to 17 CFs in which forest resources were extracted and 0 to the other CFs based on the results of the group interviews (see Section 4.4.1.). Leadership was also a binary variable: 0 corresponded to strong leadership, and 1 corresponded to all other scenarios. Previous studies categorized leadership based on the presence of a leader (Gutiérrez et al., 2011; Pagdee et al., 2006). As some CF chairmen did not participate in any CF activities in this study, the presence of a leader did not necessarily reflect leadership. Thus, I considered the performance of CF chairmen in CF activities in addition to the presence of CF chairmen. Last, I assigned strong leadership to CFs that had a CF chairman who managed, organized, and participated in CF activities. Weak leadership was assigned to the other CFs. Group size is the number of households involved in CF activities in the CF in the year in which it was established. CF area refers to the area of the CF, and forest cover ratio refers to the proportion of forest pixels to non-forest pixels in the CF in 2000. The forest cover ratio was used to examine whether the baseline forest cover affected the outcomes of community management. Distance to the nearest village was calculated as the distance between the given pixel and the closest village. Distance to the CF boundary was measured as the distance between the given pixel to the nearest CF boundary. I included the identity (ID) of CF as a random effect. Before the analysis, I standardized group size, CF area, forest cover ratio, elevation, slope, distance to the nearest village, and distance to the CF boundary.

Table 4.1. Summary statistics for the response and independent variables used in the GLMM model.

Variables	**Unit**	**Mean**	**Median**	**Min.**	**Max.**
Response variable					
Forest loss (1)	Binary (0,1)				
No forest loss (0)					
Independent variables					
Community characteristics					
Forest dependency	Binary (0,1)				
Leadership					
Group size	Number of households	87.8	95.0	18.0	400.0
Geographical factors					
CF area	ha	377.8	271.0	33.7	711.8
Forest cover in 2000	Proportion (%)	46.5	41.0	1.8	73.2
Elevation	m	1212.0	1188.0	893.0	1696.0
Slope	Degree	21.4	20.9	0.7	50.7
Distance to the nearest village	m	1178.0	1132.1	54.4	2440.1
Distance to the CF boundary	m	271.2	208.8	0.2	1055.6

Twenty percent of pixels (4094 pixels) were randomly selected from the forest pixels in 2000. AIC-based model selection and model averaging approaches were used to estimate the relative importance of independent variables. I regressed independent variables against every possible combination of dependent variables and calculated delta AIC (ΔAIC), which is the difference in the AIC between the lowest AIC model and another model. Models with ΔAIC smaller than four were selected for model averaging, and relative model importance, which is the sum of Akaike weights, was calculated from the selected models. I used the “MuMIn” package for standardization, model selection, and averaging (Barton, 2020).

4.4. Results

4.4.1. Community characteristics related to CFs

CFUGs in 15 CFs collected firewood from their forests for use in cooking. Four CFUGs in 15 CFs collected poles to build schools, monasteries, houses for teachers, and houses for CFUGs, in which meeting the needs of the poor was high-priority. In addition, CFUGs in two CFs collected medicinal plants, leaves (*Dipterocarpus tuberculatus*), bamboo, and bamboo shoots; however, neither of these CFUGs collected firewood. Overall, CFUGs in 17 CFs (i.e., 15 CFs and two CFs) extracted forest resources for subsistence needs such as cooking.

Among the 24 CFs (Table 4.2.), two did not have a CF chairman or conduct CF activities. There was one CF that had a CF chairman, but no CF activities had been conducted since the establishment of this CF. The other 21 CFs have conducted CF activities, including planting, patrolling, wildfire protection, and participation in the training program. In these 21 CFs, three did not have a CF chairman. The CF chairmen of 13 of the 18 CFs with a CF chairman have managed, organized, and participated in CF activities. The CF chairmen of the other five CFs have not participated in CF activities.

Table 4.2. Characteristics of 24 CFs.

CF Status			**Number of CF**
CF Chairman	**CF Activities**	**Chairman Participation in Activities**	
No	No	No	2
Yes	No	No	1
No	Yes	No	3
Yes	Yes	Yes	13†
Yes	Yes	No	5
Total			24

† All CF activities were stopped in one CF among the 13 CFs.

In 11 of the 13 CFs in which the CF chairmen have managed, organized, and participated in the CF activities, more than one CF activity has been implemented since the CF's establishment. Although several CF activities ceased a few years after CF establishment, 12 CFs among these 13 CFs have continued to carry out at least one CF activity. One CF among the 13 CFs stopped all CF activities but did conduct planting and patrolling when the CF was first established. I thus categorized this CF as "weak leadership," and I assigned "strong leadership" to the other 12 CFs in which the CF chairman participated in CF activities. "Weak leadership" was also assigned to all other remaining CFs.

CFs under strong leadership had active, sociable, and respected CF chairmen, but CF chairmen had no power over people in CFs under weak leadership. An active CF chairman has an interest in CF and he knows very well about CF. He could explain how CFUGs conserved their forests from the illegal cuttings of outsiders, managed their forests in sustainable terms and harvested firewood from their forests for sustained yields. An inactive CF chairman was not qualified to comment on CF because he did not know what happed in CF. In some cases, the CF chairman did not even participate in the group discussion. Regarding conflict management, an active CF chairman tried to reach a resolution of the conflict. In contrast, an inactive CF chairman could not resolve the problem.

4.4.2. Factors affecting deforestation

There were 23 models with ΔAIC values of less than four (Table 4.3.). Distance to the nearest village and slope were present in all models. Distance to the CF boundary was present in 22 models. The remaining variables were in six models. Distances to the nearest village, slope, and distance to the CF boundary were the most important variables, followed by elevation, forest cover ratio, and leadership (Figure 4.2.). Distance to the nearest village and slope were negatively related to the probability of deforestation, whereas the distance to the CF boundary was positively related to the probability of deforestation (Figure 4.3.). Elevation was negatively related to the probability of deforestation in CFs, but the 95% confidence interval included both positive and negative parameter estimates. Leadership was positively related to the probability of deforestation but with a 95% confidence interval that spanned both positive and negative parameter estimates. The coefficients of community characteristics other than leadership also had 95% confidence intervals that encompassed both positive and negative parameter estimates.

Table 4.3. AIC model ranking of the component models.

Models	k	AIC	ΔAIC	AIC Weights
Distance to the CF boundary + Distance to the nearest village + Slope	3	448.22	0.00	0.14
Distance to the CF boundary + Distance to the nearest village + Elevation + Slope	4	449.15	0.93	0.09
Distance to the CF boundary + Distance to the nearest village + Forest cover ratio + Slope	4	449.57	1.35	0.07
Distance to the CF boundary + Distance to the nearest village + Leadership + Slope	4	449.81	1.59	0.07
Distance to the CF boundary + Distance to the nearest village + Group size + Slope	4	450.07	1.84	0.06
Distance to the CF boundary + Distance to the nearest village + Dependency + Slope	4	450.17	1.95	0.05
CF area + Distance to the CF boundary + Distance to the nearest village + Slope	4	450.19	1.96	0.05
Distance to the CF boundary + Distance to the nearest village + Elevation + Leadership + Slope	5	450.58	2.36	0.04
CF area + Distance to the CF boundary + Distance to the nearest village + Elevation + Slope	5	450.98	2.76	0.04
Distance to the CF boundary + Distance to the nearest village + Elevation + Group size + Slope	5	451.02	2.80	0.04
Distance to the CF boundary + Distance to the nearest village + Elevation + Forest cover ratio + Slope	5	451.10	2.88	0.03
Distance to the CF boundary + Distance to the nearest village + Dependency + Elevation + Slope	5	451.13	2.90	0.03
Distance to the CF boundary + Distance to the nearest village + Leadership + Forest cover ratio	5	451.28	3.06	0.03

Models	k	AIC	ΔAIC	AIC Weights
+ Slope				
Distance to the CF boundary + Distance to the nearest village + Group size + Forest cover ratio + Slope	5	451.44	3.21	0.03
Distance to the CF boundary + Distance to the nearest village + Dependency + Forest cover ratio + Slope	5	451.50	3.28	0.03
CF area + Distance to the CF boundary + Distance to the nearest village + Forest cover ratio + Slope	5	451.51	3.28	0.03
Distance to the CF boundary + Distance to the nearest village + Group size + Leadership + Slope	5	451.71	3.49	0.03
Distance to the CF boundary + Distance to the nearest village + Dependency + Leadership + Slope	5	451.74	3.51	0.02
CF area + Distance to the CF boundary + Distance to the nearest village + Leadership + Slope	5	451.80	3.58	0.02
Distance to the CF boundary + Distance to the nearest village + Dependency + Group size + Slope	5	452.03	3.81	0.02
Distance to the nearest village + Slope	2	452.04	3.82	0.02
CF area + Distance to the CF boundary + Distance to the nearest village + Group size + Slope	5	452.05	3.82	0.02
CF area + Distance to the CF boundary + Distance to the nearest village + Dependency + Slope	5	452.15	3.92	0.02

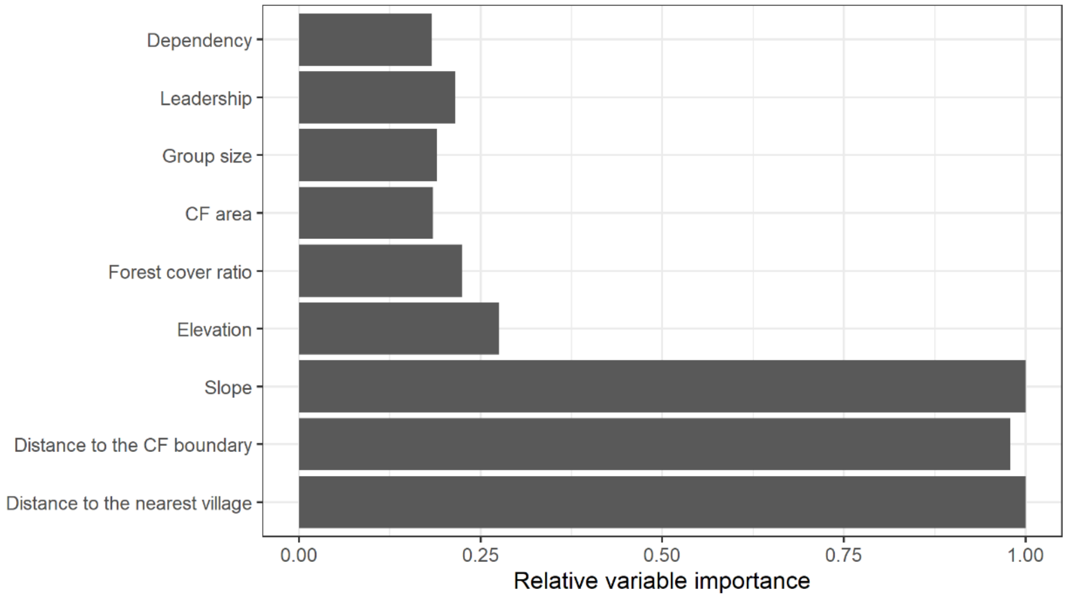

Figure 4.2. Relative importance of independent variables.

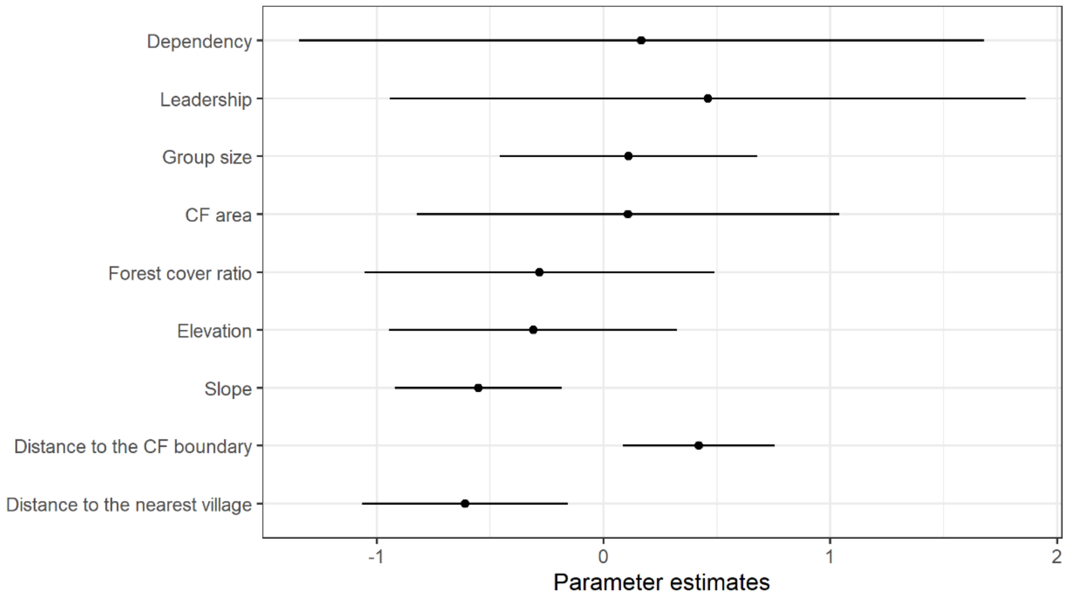

Figure 4.3. Parameter estimates of independent variables used for model averaging. Black dots and lines represent coefficient estimates and 95% confidence intervals, respectively.

4.5. Discussion

In this study, the effects of geographical factors and community characteristics on deforestation in CFs in two watershed conservation forests in Myanmar were examined. Three geographical factors (distance to the nearest village, slope, and distance to the CF boundary) strongly affected the probability of deforestation. The two most important variables, distances to the nearest village and slope, are both related to forest accessibility. Distance to the nearest village was negatively related to deforestation, indicating that forests located closer to human settlements are more likely to experience deforestation. This result is consistent with similar studies conducted in Myanmar (Htun et al., 2013; Mon et al., 2012, 2009), Indonesia (Nugroho et al., 2018), and Mexico (Perez-Verdin et al., 2009). The slope is also known to affect the probability of deforestation (Alix-Garcia, 2007; Busch and Ferretti-Gallon, 2017; Nüchel et al., 2019; Nugroho et al., 2018). In this study, the slope was negatively related to deforestation, indicating that forest loss was higher in areas with lower slopes. It makes sense given that gentle slopes facilitate human activities such as firewood extraction and agricultural expansion.

Distance to the CF boundary showed a similar relative variable importance as distance to the nearest village and slope. Distance to the CF boundary was positively related to deforestation, which suggests that deforestation was more likely to occur far from the CF boundary. This is likely explained by the patrols of CFUGs being concentrated near the edge of the CFs, which were more accessible. CFs are typically demarcated by prominent features in the landscape, such as villages, roads, and streams. Thus, the edges of CFs are often more accessible than the CF interior and can be more easily patrolled; this also explains why illegal logging may occur in areas far from the CF boundary. A similar pattern was observed in a previous study showing that the probability of deforestation was high in closed forests located far from a national park in Myanmar (Htun et al., 2013). Regular patrolling both along the CF boundary and inside CFs is thus essential for slowing deforestation in CFs.

Leadership was the most important factor among community characteristics. Leadership was positively related to deforestation, which indicates that the absence of leadership or weak leadership increased the probability of deforestation. Consistent with previous studies emphasizing the importance of leadership (Gutiérrez et al., 2011; Pagdee et al., 2006; Van Laerhoven, 2010), this study confirmed that leadership contributes to deforestation. However, the 95% confidence interval of the parameter estimate for leadership included both positive and negative values. Thus, there is still some uncertainty regarding the effectiveness of leadership in our study area.

Previous studies on CFs and collective action have examined the effects of group size (e.g., Lonn et al., 2018; Yang et al., 2013). In this study, group size was positively related to deforestation. However, the 95% confidence interval of the parameter estimate of group size included both positive and negative values, and its relative importance was the second-lowest among all variables. Similar results were obtained by a country-scale analysis of forest cover change in CFs in Cambodia. Why group size was not an important variable remains unclear. One possible reason is that the forest use by CFUGs made a limited contribution to deforestation. Firewood collection was the main forest use in this study, and the demand for firewood is likely positively correlated with group size given that firewood is a material that is used on a daily basis by the local people. Thus, group size may reflect the intensity of firewood collection. Previous studies have shown that firewood collection might not be a direct cause of deforestation, especially in Myanmar (Win et al., 2018b), where firewood collection is a major cause of forest degradation (Démurger and Fournier, 2011; Heltberg et al., 2000; Specht et al., 2015). This stems from the fact that the cutting of trees for firewood collection is highly selective: only a few tree species and sizes are typically cut (Win et al., 2018b). Thus, the lack of importance of group size in our analysis might be explained by our study's focus on deforestation, which does not capture the effects of selective cutting. The low relative importance of forest dependency also supports this hypothesis, as forest dependency was largely driven by firewood collection in our study.

Although I considered the potential effects of both geographical factors and community characteristics on deforestation, geographical factors were more closely tied to the probability of deforestation. This may be explained by our focus on deforestation. Although community characteristics made limited contributions to deforestation based on our analysis, they might actually play important roles in forest degradation. Monitoring forest degradation through satellite remote sensing is technically more difficult than monitoring deforestation (Dupuis et al., 2020; Gao et al., 2020b), and improved methods are currently being developed (e.g., Bullock et al., 2020). There is thus a need to develop forest degradation monitoring tools to characterize the importance of community characteristics for CF management.

4.6. Conclusions

This study examined the relative importance of geographical factors and community characteristics in regard to affecting deforestation in CFs. I found that three geographical factors strongly affected the likelihood of deforestation. Of these, distance to the nearest village and slope were the most important variables, which were associated with forest accessibility. I also found that community characteristics were low in relative importance, but leadership was the most important factor among community characteristics. I conclude that forest accessibility is a more important predictor of the probability of deforestation than the other factors. Therefore, the locations of CFs should receive increased consideration when new CFs are established.

Chapter 5

General discussion and conclusions

Forests are essential for the people with the provision of ecosystem services. Globally, 1.6 billion people depend on forests with varying degrees, and about 300-350 million people who live within or near dense forests heavily depend on forests for their basic needs and livelihoods (Chao, 2012). However, human pressures cause adverse effects on forests, such as forest degradation and deforestation (Diwediga et al., 2015; Dlamini, 2017, 2016; Steele et al., 2015; Wessels et al., 2011). Deforestation and forest degradation, which are global environmental issues, reduce the provision of forest resources and other ecosystem services (Lin et al., 2017). Thus, the relation between forests and people gets trapped in a vicious circle of human activities and their effects on forests. In this context, CF is one of the forest conservation programs to reduce forest loss and improve local livelihoods, and it is strongly required to achieve CF success sustainably. Therefore, the assessment of CF effectiveness and its drivers is vital to ensure or improve the program for ecological and social sustainability.

5.1. Firewood consumption patterns of local communities

In Myanmar, about 33 million people are estimated as forest-dependent people who live in or surrounding forest areas (Chao, 2012). They depend on forests for food, fuel, medicine, and shelter. Woodfuel removals were highest in the tropics, especially Southeast Asia countries, from 1990 to 2011 (Köhl et al., 2015). Firewood, one of the main forest products, is the primary cooking energy in Myanmar. Over 80% of rural households use firewood for cooking (Department of Population, 2015a). Wood energy consumption for cooking and heating tends to increase with population growth in the countries, causing forest degradation (Adanguidi et al., 2020; Hoffmann et al., 2018). Conversely, forest degradation may impact on firewood consumption patterns of local communities, and such research scenarios were understudied.

This study endeavored to determine the factors controlling firewood consumption rates of local communities using a regression method. Household size, elevation, and open forest ratio mainly influenced firewood consumption, then followed by firewood consumption for drying and farm size. Larger households were less likely to use firewood through consumption efficiencies. Highland communities also had lower firewood consumption. However, households with larger farm size tended to increase firewood consumption because they might have easy access to firewood from their farms. Also, households that used firewood for drying leaves of *Cordia dichotoma* had a higher potential for firewood consumption for cooking because they stored enough firewood for the processes.

Per capita firewood consumption in the study area (530 kg) was lower compared to the rates in the Bago region (780 kg) (Win et al., 2018b). One possible reason for lower consumption was the poor quality of forests, indicating that forest degradation had a detrimental effect on firewood consumption. Open forest ratio, an indicator of forest degradation, strongly influenced firewood consumption. However, there was little relation between distance to the nearest forest and firewood consumption. In contrast to previous findings (Jagger and Shively, 2014), this study observed that firewood consumption did not mainly associate with the distances of forests and, more importantly, it related to the forest quality. Thus, it should be noted that many variables other than distance might affect firewood consumption and collection because distance had its limitations (Kefa et al., 2018).

The unsustainable firewood harvesting and consumption were associated with the change in forest cover, such as forest degradation in the countries (Ndangalasi et al., 2007; Negi et al., 2018; Specht et al., 2015; Taylor et al., 2011; Thompson et al., 2013). This study confirmed that forest degradation could reduce firewood consumption. Thus, forest degradation was adversely affected by firewood consumption and vice versa. Therefore, planting and growing trees, implementing sustainable management, and harvesting practices are included in the key actions to address woodfuel issues, such as enhancing the availability and sustainability of woodfuel (Harvey and Guariguata, 2021).

5.2. CF effectiveness on reducing deforestation

CF is aimed at conserving the forests and improving the livelihoods of local communities. Assessing CF success or failure, which is one of the research standards (Lund et al., 2018), provides useful information for policymakers to guarantee or improve the program. There is growing evidence that community forests are effective or ineffective in forest conservation and improvement of local livelihoods (Oldekop et al., 2019; Rasolofoson et al., 2017, 2015; Santika et al., 2019, 2017). Although Myanmar had the CF experience over two decades, no research on CF effectiveness had been conducted using robust statistical methods. This study examined the efficacy of CF on reducing deforestation in two watershed conservation forests.

CFs showed mixed effects on forest conservation. While CFs were not effective at reducing deforestation in general and specific analysis for PPF, there was a significant avoided deforestation inside CFs in RF. The reasons for ineffective results might be because human activities (firewood collection and agricultural expansion) accelerated deforestation. Heavy firewood dependency and unsustainable firewood harvesting caused forest cover change. In addition, shifting cultivation raised by upland communities impacts forests, especially in western mountain ranges. Previous studies reported mixed results on CF effectiveness of forest conservation in different countries (Coleman and Fleischman, 2012; Oldekop et al., 2019; Rasolofoson et al., 2015; Santika et al., 2017). The reason for producing heterogeneous results of conservation policies was due to variation in pressures such as deforestation patterns (Börner et al., 2015). Forest conservation policies could not avoid forest cover loss even if these policies have full enforcement and no pressure on deforestation, showing that policies' impacts are associated with location (Börner et al., 2020).

When CFs are established, restrictions are placed on harvesting forest resources to users, particularly outsiders. Thus, people may change their target area for forest extraction from inside CFs to outside CFs, resulting in spillovers. This study found no spillover for CF effectiveness in RF, demonstrating that reduction in deforestation was robust. Regarding ecological outcomes, CF might decrease forest degradation in addition to deforestation. Because degraded forests are restored through CF programs, it is also important to measure CF efficacy of forest degradation and take priority over further research.

5.3. Influencing factors for deforestation risk in community forests

Community forests have been established in countries with geographical, social, cultural, and institutional differences. Geographical factors, community characteristics, and institutional arrangements were influential in shaping the success of CF related to environmental and social-related outcomes and resource access rights

(Hajjar et al., 2021). The importance of institutional factors has been identified in the literature (Casse and Milhøj, 2011; Hajjar et al., 2016; Pagdee et al., 2006). This study characterized the geographical and community characteristics as potential factors influencing deforestation risk in community forests in two watershed conservation forests. The results showed that three geographical factors (distance to the nearest village, slope, and distance to the CF boundary) were critical. Of these, the importance of distance to the nearest village and slope indicated that forest accessibility had a higher potential for deforestation. In addition to forest accessibility, distance to the CF boundary was also highly critical of the possibility of deforestation. Due to the high concentration of patrols in accessible areas, areas far from the CF boundary were under the pressure of deforestation. Thus, it is imperative to do patrols in both accessible areas and large distances from the CF boundary.

Regarding community characteristics, leadership placed great importance on deforestation, implying that absence or weak leadership was linked to the existence of deforestation. After leadership, group size had both positive and negative relationships with the likelihood of deforestation. Group size showed contrasting results of successful community forest management, having a negative or positive or non-linear relationship (Agrawal and Goyal, 2001; Behera, 2009; Heltberg, 2001; Negi et al., 2018; Poteete and Ostrom, 2004). In this study, group size had a poor relationship with the outcome. It implied that forest resources utilization of community members, especially firewood dependency, could not make significant forest cover change in the study area because firewood utilization was a major concern for forest degradation (Heltberg et al., 2000; Negi et al., 2018; Specht et al., 2015). This study showed that accessible areas had a higher probability for deforestation threats, but community characteristics did not directly relate to the potential of deforestation.

5.4. Conclusions

This study concludes from the evidence that firewood consumption of local communities is badly affected by forest degradation. CF may be a great solution to resolve the firewood crisis because the government set the target of establishing community forests (9186 km^2) and meeting 25% of firewood demand by 2030. To meet the ambitious goal of firewood demand, the governments and local communities need to establish community forests successfully. On the other hand, CF is aimed at forest conservation. Impact evaluations of CF are essential for policy makers to redesign or assure the program. In this study, CFs cannot provide significant evidence of forest conservation on average. Their effectiveness on forest conservation is heterogeneous. Geographical factors should be emphasized to ensure the success of new and existing CFs in sustainable terms.

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