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JOURNAL OF FOREST PLANNING is a peer-reviewed periodical that publishes articles, reviews, and short communications. It covers all aspects of forest management, modeling, and assessment such as forest inventory, growth and yield modeling, remote sensing and geospatial information technologies for forest management, forest management planning, forest zoning, evaluation of ecosystem services, managerial economics, and silvicultural systems. Manuscripts regarding forest policy, forest economics, forest environmental education, landscape management, climate change mitigation and adaptation strategies, and drone applications for forest management are welcome. The Journal aims to provide a forum for international communication among forest researchers and forestry practitioners who are interested in the above-mentioned fields.

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CONTENTS

Article

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Evaluating the Condition of Selectively Logged Production Forests in Myanmar: An Analysis Using Large-scale Forest Inventory Data for Yedashe Township

Zar Chi Win[1,2], Nobuya Mizoue[3,*], Tetsuji Ota[4], Tsuyoshi Kajisa[5], Shigejiro Yoshida[3], Thaung Naing Oo[6] and Hwan-ok Ma[7]

ABSTRACT

The conservation of selectively logged tropical forests has received increasing attention, especially under the REDD+ scheme of the United Nations Framework Convention on Climate Change. However, knowledge of the structure of large-scale logged forests remains limited, especially in seasonally dry tropical regions, while there have been many studies on intact old-growth closed-canopy tropical forests. In this study, data from 327 plots were used in a large-scale forest inventory with systematic sampling covering 139,360 ha to reveal the condition of selectively logged mixed-deciduous forest managed traditionally under the Myanmar selection system (MSS). The overall averages (±SE) for the trees > 10 cm DBH were 140 ± 4.95 trees/ha for tree density, 6.18 ± 0.26 m^2/ha for basal area and 66.2 ± 3.17 Mg/ha for aboveground biomass. These values are lower than or close to the lower end of the reported values in undisturbed or even disturbed tropical forests. There were very few harvestable large trees of commercial species. We conclude that there has been widespread large-scale forest degradation in the traditionally logged forest of our study site. The possible reasons for forest degradation include the shorter cutting-cycle than the MSS-standard of 30 years, more illegal logging for timber than legal logging, and local demand for charcoal. Restoration of the degraded forests should be prioritized, together with control of illegal logging.

Keywords: forest degradation, forest inventory, mixed deciduous forest, selective logging, stand structure

INTRODUCTION

Over 400 million ha of tropical natural forest is now in permanent timber estates and selective logging is a widely adopted forest management system in tropical natural forests (Edwards et al., 2014). There has been growing attention on the conservation of selectively logged forests because these forests can retain substantial biodiversity, carbon and timber stocks if collateral damage is reduced and silvicultural treatments are applied (Bicknell et al., 2015; Putz et al., 2012). In contrast, selective logging can lead to an increased likelihood of deforestation within a few years after logging (Asner et al., 2006). Therefore, it remains a challenge to maintain or enhance ecosystem services in selectively logged forests. One of the possible solution is to adopt the reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+), under the United Nations Framework Convention on Climate Change (UNFCCC), since the REDD+ scheme has provided opportunities to manage tropical forests for timber production and carbon emission reduction (Sasaki et al., 2012; Sasaki et al., 2016). Improving understanding of the current condition and future prediction of forest structure

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and growing stock is one of the fundamental steps for sustainable forest management. However, there is currently relatively poor knowledge of the structure of selectively logged forests, especially in seasonally dry tropical forests (Becknell et al., 2012), while there have been many studies on intact old-growth closed-canopy tropical forests (Houghton, 2005; Lewis et al., 2013).

Myanmar has implemented the Myanmar selection system (MSS) since 1856 to produce commercial timber from teak-bearing mixed deciduous forest, which is an important type of seasonally dry tropical forest. In Myanmar, timber extraction is mainly carried out in production forests, under which reserved forests (RFs), protected public forests (PPFs) and unclassed forests are included. For the convenience of management, each RF and PPF is subdivided into compartments according to drainage and geographical situation. MSS operates over the course of 30 year felling cycle, organizing those production forests into felling series, then dividing that felling series into 30 blocks of approximately equal yield capacity (Dah, 2004). Under MSS, the rule is to select and harvest only the mature trees, which have attained the prescribed minimum exploitable girth limit (MGL) within the bounds of carefully calculated Annual Allowable Cut (AAC). The MGL varies with species and forest types (Dah, 2004; Mon et al., 2012b), ranging from 63 cm in diameter (6’ 6” in girth) for teak, and 58–73 cm in diameter (6’ to 7’ 6” in girth) for other hardwood species (Taungoo FD, 2016). To ensure sustained yield of commercial species, AAC is well regulated in accord with the increment of individual tree species, which has taken place over the period of 30-year felling cycle, assuming that 30 years is the required time passage for trees with GBH 1 feet below the MGL to attain the MGL (Kyaw, 2004; Myint, 2012). Another feature of MSS is that elephants are still used for skidding and thus disturbance on residual trees and soil is much lower than skidding with machines. This long history of timber production has given the impression that MSS is an effective practice for sustainable forest management (Dah, 2004; Khai et al., 2016b). However, Mon et al. (2010, 2012a, 2012b) used remote-sensing data to reveal substantial forest degradation occurring in natural forest managed under MSS, even though deforestation did not occur at a large scale. Mon et al. (2012b) suggested that overharvesting beyond the prescribed AAC and illegal logging are likely to be the main reasons for forest degradation. Even though remote sensing is useful to detect changes in canopy cover at large scale, it is difficult to evaluate loss of commercial timber stocks and associated carbon emissions (Sasaki et al., 2016). Khai et al. (2016b) showed from the field survey that repeated logging at shorter interval than the MSS-standard cutting cycle of 30 years can strongly degrade the forest, resulting in stands with very poor stocking, even of commercially lower-value species. They also confirmed that forest degradation was enhanced by illegal logging often taking place one or two years after the legal logging. There have been other field studies to investigate structure of selectively logged forests in Myanmar, but these all are based on experimental plots established over relatively small areas (Oo and Lee, 2007; Thein et al., 2007; Tun et al., 2016). These experimental plots were often located in areas with good accessibility such as close to the road (Tun et al., 2016), and the representativeness across the mesoscale (100–10000 ha) landscape may be questionable (Clark and Clark, 2000).

In this study, we used data from 327 plots in a large-scale forest inventory with systematic sampling covering 139,360 ha to reveal the condition of selectively logged production forest in Myanmar at the landscape scale. We evaluated stocking (tree density, basal area, biomass and species richness), structure (diameter distribution) and composition of species grouped by economic values and compared the findings with previous studies in tropical forests.

MATERIALS AND METHODS

Study Site

Our study area is located in Northeastern part of Bago Mountain Range in Yedashe Township, Myanmar (Fig. 1). Yedashe Township has an area of 2618.7 km^2, of which about 76.6% is covered with forests (Forest Department, 2014). The climate is tropical monsoon climate, and the average annual rainfall and temperature are about 2000 mm and 32°C respectively. The major forest type in our study site is moist tropical mixed deciduous forest. This forest contains the finest teak (*Tectona grandis*), which is usually associated with pyinkado (*Xylia xylocarpa*). This type of forest possesses a considerable mixture of species and the majority of species are deciduous, although evergreen dominance occurs occasionally. There are 17 RFs and one PPF in Yedashe Township. The RFs were constituted to maintain a sustained yield of forest products and to conserve the environmental factors, and there is no public right for extraction of forest products or utilization of land for other purposes. The PPFs were constituted for the welfare of the people, to meet their requirements for forest products according to stipulated legal rights and privileges, and to discourage encroachment into the RFs. The PPFs are sources of supply for minor forest products other than restricted reserved trees legally granted by right and commercial timber is also extracted from PPFs. The RFs and PPF in Yedashe are among the best teak-bearing production forests in Myanmar and have been managed under MSS since the end of the 19th century. However, in 2016, the government decided to implement a logging ban for 10 years across the whole Bago Mountain Range, including our study site.

Among the 17 RFs and the single PPF in Yedashe Township, this study focuses on 5 RFs and the PPF (Kyaukmasin RF, Lonyan RF, Saingya RF, Sabyin RF, West Swa RF and Yoma PPF), which are all located on the western side of the Township (Fig. 1).

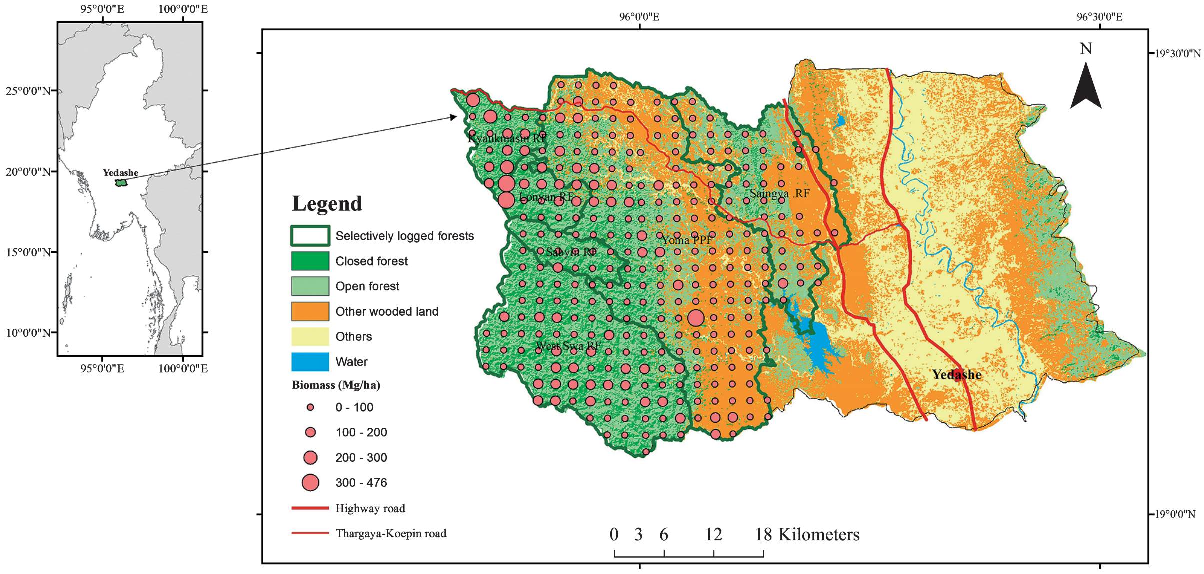

Fig. 1 Location of sample plots in six selectively logged production forests of Yedashe Township, Taungoo District, Myanmar. Different size of the circle symbols indicates differences in biomass (Mg/ha). The World Borders Dataset provided by Thematic Mapping (http://thematicmapping.org/) was used as the country border. Administrative boundary provided by the Myanmar Information Management Unit (http://www.themimu.info/) was used as the township boundary. Data of land cover, reserved forest and protected public forest boundary were obtained from the Forest Department of Myanmar. Land cover was created using Landsat Landsat 8 OLI data captured between November 2104 and March 2015 under the project on "Strengthening Myanmar's National Forest Monitoring System-Land Use Assessment and Capacity Building (TCP/MYA/3501)" implemented by the cooperation of FAO and FD, Myanmar from 2014 to 2016.

Table 1 Forest characteristics of the five reserve forests (RFs) and the public protected forest (PPF)
The values are presented for the trees ≥ 10 cm DBH.

Stand Characteristics	Kyaukmasin	Lonyan	Sabyin	Saingya	West Swa	Yoma	Total or mean ± SE
Area of RFs/PPF (ha)	7,177	5,580	5,150	24,762	33,890	62,801	139,360
Number of sample plot	20	12	12	43	83	157	327
Tree Density (trees/ha)	155 ± 17.6^{a}	176 ± 19.6^{a}	197 ± 24.4^{a}	93.2 ± 12.5^{b}	197 ± 7.7^{a}	113 ± 6.8^{b}	140 ± 4.95
Basal Area (m^2/ha)	11.8 ± 1.7^{a}	9.2 ± 1.1^{a}	6.6 ± 0.8^{ab}	2.7 ± 0.4^{c}	8.3 ± 0.4^{a}	5.0 ± 0.4^{b}	6.18 ± 0.26
Biomass (Mg/ha)	140 ± 21.4^{a}	102 ± 13.3^{ab}	64.1 ± 7.6^{bcd}	25.0 ± 4.10^{c}	88.2 ± 4.09^{b}	54.0 ± 4.36^{d}	66.2 ± 3.17
Species richness per plot	12.1 ± 1.07^{a}	11.1 ± 1.41^{a}	12.0 ± 1.59^{a}	4.21 ± 0.43^{b}	9.98 ± 0.38^{a}	7.02 ± 0.41^{c}	9.54 ± 0.25

Note: The same alphabets were based on the Tukey test, indicating no difference among five RFs and PPF for each of four metrics.

Forest Inventory

A forest inventory was carried out in March 2013 by the project on "Capacity Building for Developing REDD^{+} Activities in the Context of Sustainable Forest Management (2012–2015)" by the International Tropical Timber Organization (ITTO) and Forest Department, Myanmar. The systematic equal-distance sampling method was applied, covering six selectively logged mixed deciduous forests in Yedashe Township (Fig. 1). The sample plot size was 0.25 ha in a 50 m × 50 m square plot, and the plot interval was 2 km. A total of 327 sample plots were surveyed, accounting for 81.75 ha in total. Sampling intensity was 0.06% of the forest area. These plots cover 139,360 ha of the five RFs and the PPF, including a total of 257 compartments. Distribution of sample plots and sample size is presented in Fig. 1 and Table 1. A nested plot design was applied (Fig. 2). In each 50 m × 50 m plot, all trees ≥ 20 cm diameter at breast height (DBH; 1.3 m) were recorded, and in plot B (Fig. 2; 25 m × 25 m small plot), trees with DBH ≥ 10 cm and < 20 cm were also counted. Species identification was carried out with the assistance of the

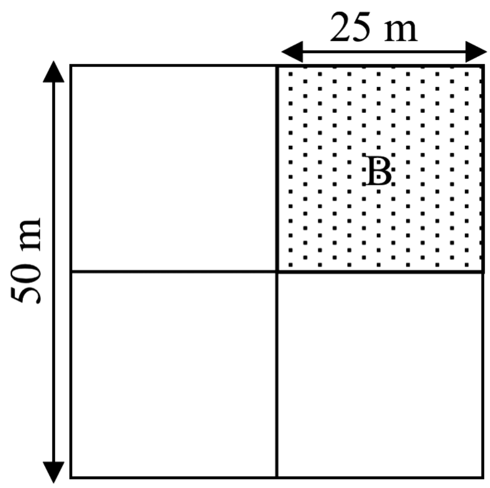

Fig. 2 Sample plot design. In 50 m × 50 m plot, all trees ≥ 20 cm DBH were enumerated, and in subplot B (25 m × 25 m), small trees (10 cm DBH ≤ trees < 20 cm) were also enumerated.

local Forest Department's staff and villagers. Common names were changed into botanical names referencing the book of "A Checklist of the Trees, Shrubs, Herbs, and Climbers of Myanmar" (Kress et al., 2003).

Data Analysis

Data were summarized for each of the five RFs and the PPF in terms of tree density (trees/ha), basal area (m^2/ha), aboveground biomass (Mg/ha) and species richness per plot. Differences among the five RFs and the PPF were confirmed using ANOVA and the Tukey honest significant difference post-hoc test. Since the average annual rainfall of the study area is about 2000 mm, biomass estimation per tree (kg) was conducted using the aboveground biomass equation developed by Brown (1997) for tropical moist forest:

$$\text{Biomass per tree} = 42.69 - 12.800\ \text{DBH} + 1.242\ (\text{DBH})^2 \quad (1)$$

In Myanmar, tree species are classified into teak and a further five groups according to economic value. Teak represents the most valuable species, and Group I is the second class including pyinkado, followed by Group II to V in order of decreasing commercial value. Stand structure was evaluated from the frequency of DBH classes at 10 cm intervals, which were further divided into species groups distinguished by commercial value.

RESULTS

Stand Density, Basal Area, Biomass and Species Richness

The 327 plots included 5,948 trees > 10 cm, and 157 tree species were recorded from 116 genera and 47 families. Overall averages for all the plots were 140 ± 4.9 trees/ha for tree density, 6.2 ± 0.3 m^2/ha for basal area, 66.2 ± 3.2 Mg/ha for biomass and 9.54 ± 0.25 for species richness per plot (Table 1 and Fig. 1). Among the five RFs and the PPF, Kyaukmasin RF had the highest average values of basal area (11.8 m^2/ha) and biomass (140 Mg/ha), and species richness per plot (12.1). In contrast, the lowest values were found in Saingya RF; 93.2 trees/ha for tree density, 2.7 m^2/ha for basal area, and 25.0 Mg/ha for biomass and 4.21 for species richness per plot. Yoma PPF had the second lowest values. The Tukey test (Table 1) showed that there was no significant difference ($p > 0.05$) among four of the RFs (Kyaukmasin, Lonyan, Sabyin and West Swa) in the three metrics except for biomass, whereas Saingya RF and Yoma PPF tended to be significantly lower values than the other four RFs ($p < 0.05$) except for a few cases.

Size Structure and Commercial Species Composition

Among the measured 5,948 trees of 157 species, teak (*Tectona grandis* L.f.) was the most abundant in tree number (9.3%), followed by pyinkado (*Xylia xylocarpa* (Roxb.) Taub.) (8.9%), binga (*Mitragyna rotundifolia* (Roxb.) Kuntze) (7.7%), yon (*Anogeissus acuminata* Wall.) (5.3%) and thit-pagan (*Millettia brandisiana* Kurz) (3.6%). Among the six commercial species groups, Group V contained the highest proportion of the total number of trees (40.6%), followed by Group II (19.1%), and the values for the other groups were similar around 10% (Fig. 3).

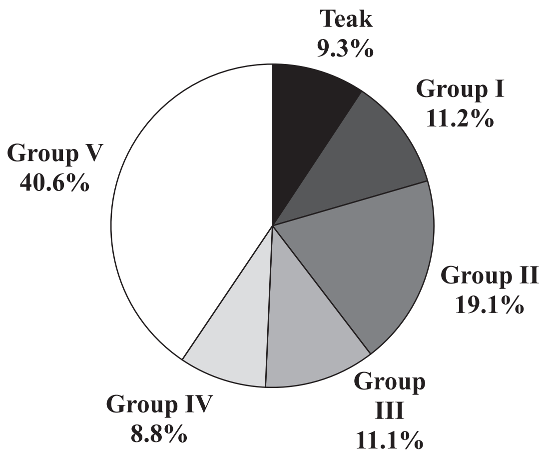

Fig. 3 Overall species composition by economic group. The values (%) were calculated by dividing the total individual of the species in each group by total number of individual of all species. Teak is one of the most economically valuable timber species, and among Group I to V, the higher the group number, the lower the economic value.

The DBH distribution mainly followed a pattern of a reverse-J shape for each of the RFs and the PPF (Fig. 4). Overall, the majority of trees (63.9% of total trees) were in the lowest DBH class of 10–19.9 cm, and only 0.59% were within the class of DBH ≥ 60 cm. No tree with DBH > 50 cm was found in Sabyin and Saingya, and only about one tree per ha was observed in diameter class of DBH ≥ 50 cm in West Swa and Yoma (Fig. 4, Table 2). Kyaukmasin RF contained a higher number of large size trees than the other RFs and the PPF. In most cases, except for Saingya RF, at least 10 trees/ha were found for trees with DBH ≥ 10 cm of each species group for each RF and the PPF. However, very few trees/ha were found for trees with DBH ≥ 50 cm (Fig. 4, Table 2).

DISCUSSION

Forest Condition Compared with Other Studies

Our average values of stand characteristics (140 trees/ha for tree density, 6.2 m^2/ha for basal area, and 66.2 Mg/ha for biomass) were lower or close to the lower end of reported values in various tropical forests. Stock in mature tropical forest is generally assumed to increase along precipitation gradients (Becknell et al., 2012). One of the largest stock in tropics was found in intact old-growth closed-canopy tropical forest in the largest biogeographic regions of Central Africa, Borneo and Central/East Amazonia; 425, 602 and 579 trees/ha of tree density, respectively; 31.5, 37.1, 29.0 m^2/ha for basal area, respectively; and 429, 445 and 341 Mg/ha of biomass, respec-

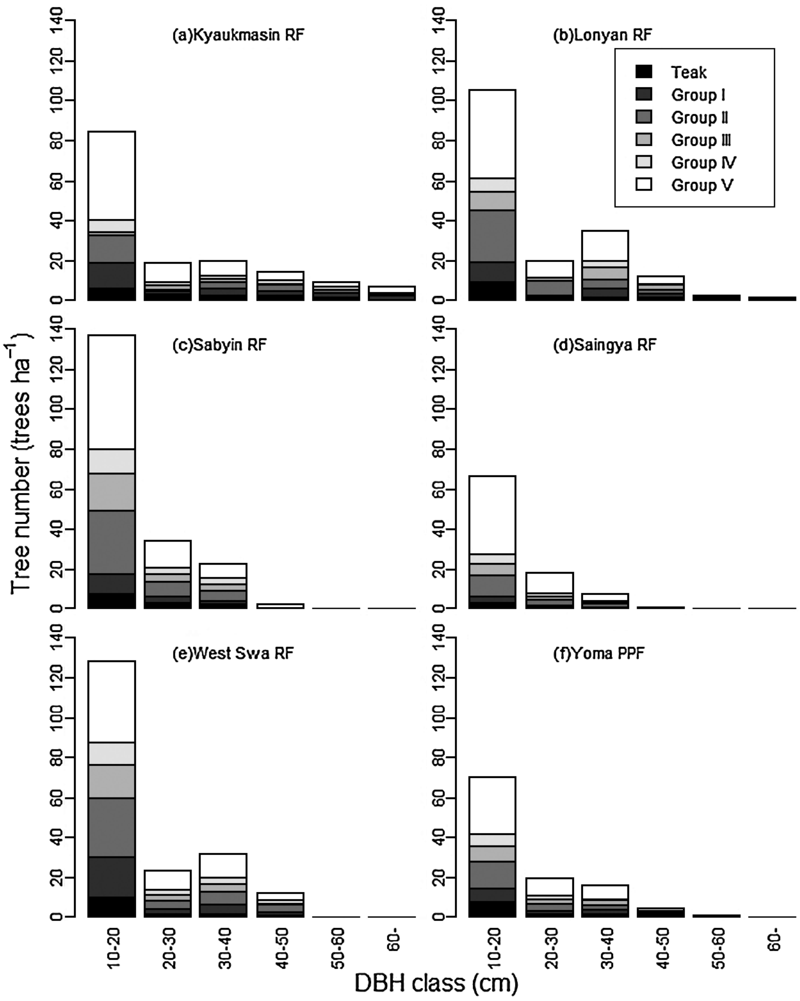

Fig. 4 Frequency of diameter at breast height (DBH) classes for each of the five reserve forests (RFs) and the public protected forest (PPF), with classification of commercial species groups.

Table 2 Tree number per ha for trees ≥ 10 cm or 50 cm diameter at breast height (DBH) for commercial species groups

	Kyaukmasin		Lonyan		Sabyin		Saingya		West Swa		Yoma	
	10 cm ≥	50 cm ≥	10 cm ≥	50 cm ≥	10 cm ≥	50 cm ≥	10 cm ≥	50 cm ≥	10 cm ≥	50 cm ≥	10 cm ≥	50 cm ≥
Teak	16.4	1.6	15.0	0.3	14.0	0.0	5.8	0.0	14.7	0.0	12.8	0.13
Group I	24.2	4.4	17.0	1.0	13.7	0.0	3.2	0.0	29.0	0.0	11.5	0.33
Group II	22.6	1.8	40.7	0.0	45.0	0.0	15.7	0.0	44.0	0.1	20.6	0.05
Group III	6.2	0.6	19.3	0.0	25.7	0.0	8.0	0.0	24.6	0.0	12.1	0.15
Group IV	12.2	1.8	11.3	1.0	18.3	0.0	6.5	0.0	18.3	0.1	9.5	0.31
Group V	72.8	5.8	73.0	2.0	80.0	0.0	54.0	0.0	66.4	0.1	46.6	0.48
Total	155	16.0	176	4.3	197	0.0	93.2	0.0	197	0.4	113	1.5

tively (Lewis et al., 2013). In mature seasonally dry tropical forests, the above ground biomass ranged from 39–344 Mg/ha; and the biomass increased from ca. 50 to 300 Mg/ha with increasing mean annual precipitation from 600 to 2000 mm (Becknell et al., 2012). Thus, our study site, with annual precipitation of ca 2000 mm, could potentially reach around 300 Mg/ha biomass if the forest were not disturbed. The much lower value of overall average biomass in our study site (66.2 Mg/ha) indicates that the selectively logged forests had been strongly exploited.

The large-scale inventory-based biomass is often lower than the plot-based values because large-scale inventory tends to cover disturbed forest. For example, Brown and Lugo (1992) indicated that the mean inventory-based biomass (225 Mg/ha) for moist tropical forests in Southeast Asia was lower than that from the plot-based value for mature forests in the same region (350 Mg/ha). In the case of Myanmar, Brown (1997) showed using inventory data that the biomass range of mixed deciduous forest was 45–135 Mg/ha and our data had a similar range of 25–140 Mg/ha among averages of the five RFs and the PPF. Khai et al. (2016b) compared degraded vs non-degraded stands under high vs low cutting frequency in selective logged forests in the Bago Mountain Range of Myanmar, which is the same range of our study. Their stand characteristics were 41 vs 176 trees/ha of tree density, 8.25 vs 16.4 m^2/ha of basal area and 108 vs 203 Mg/ha of biomass for degraded vs non-degraded stands, respectively. Our basal area values and biomass for each of the RFs and the PPF were much lower than those of the non-degraded stand, and two of the RFs and the PPF (Sabyin, Saingya and Yoma) had much lower values than those of even the degraded stand. In the non-degraded stands in Khai et al. (2016b), two most valuable species, teak and Group I species, represented 12.8% and 9.9% of total stand density, respectively, accounting for 22.5 tree/ha and 17.5 tree/ha. Similar fractions of the commercial species were also found in our study (9.3% for teak and 11.2% for Group I species). In terms of tree density, however, the numbers of those species in our study were obviously lower than those in Khai et al. (2016b), especially in Saingya RF and Yoma PPF. These results indicate that large-scale forest degradation occurred substantially in our study site, and some areas are heavily degraded.

The DBH distribution clearly indicated that there were almost no large-trees with DBH ≥ 50 cm for all the species groups except for Kyaukmasin RF (Fig. 4, Table 2). This indicates that timber productivity is currently quite low and will most probably remain like this for the near future because the minimum diameter cut limits are larger than 60 cm for most species in Myanmar. Our results support the government decision in 2016 for a 10-year logging-ban in the whole Bogo Mountain range. However, further study is needed to estimate the potential growth rate of such degraded forest so that we can discuss how efficient the 10-year logging ban will be for the recovery of the forest.

Possible Reasons for Forest Degradation

There are two main reasons for the large-scale forest degradation in selectively logged production forests in our study site. First, over-harvesting with a shorter interval than the MSS-standard 30 years. Indeed, the governmental official records showed that 58% of the 257 compartments within our study site had conducted logging operations at least twice in the 23 years between 1991 and 2013 (The official data were available under permission by Forest Department at Taungoo District and Yedashe Township). This deficient practice is carried out because Myanmar's forests have been facing high pressure from increased resource utilization associated with population growth and high demand from neighboring counties, and the country had been heavily reliant on earnings from export of timber, particularly between 1990 and 2000 (Khai et al., 2016b; Mon et al., 2012b). The second reason is illegal logging for timber production, which is the cutting of trees without the permission by the government. Win et al. (2018a) established 10 km of 20-m-wide transects in the logged forests, which are within our study area, and showed that tree number and basal area reduction resulting from illegal logging was 9.93- and 3.89-fold greater, respectively, than those of legal logging. In addition, illegal logging increased considerably after legal logging and targeted larger, high-quality trees for timber in areas with better accessibility. Repeated operations over shorter intervals for road construction are likely to make a temporary road more physically stable, resulting in increasing accessibility and making illegal logging operations easier to conduct (Khai et al., 2016b). Therefore, the government should enforce existing rules that require a 30-year logging cycle and that logging roads be decommissioned and rendered impassable after the cessation of legal logging operations. Financial incentives of the REDD+ scheme have potentials to make it happen to prevent premature re-entry logging and to adopt reduced-impact logging plus other improvements in forest management (adopting forest certification and DNA timber tracking to prevent illegal logging) (Sasaki et al., 2016).

There was large variation in structure and stocking among the five RFs and the PPF; Saingya RF and Yoma PPF were significantly lower than the other four RFs in terms of species richness, tree density, basal area and biomass (Table 1). This might be because of their proximity to town and villages, and they are the only RF and PPF encroached by local people in Yedashe Township (Fig. 1). In addition, Saingya RF was more degraded than Yoma PPF (Table 1). This finding indicates that an assumption that RFs under strict protection status have more stocking than less-regulated PPF (Tun et al., 2016) is not necessarily valid. Rural people living in our study site largely depend on firewood or charcoal for daily cooking and the charcoal demand would increase pressure on surrounding forests (Win et al., 2018b). Therefore, local demand for charcoal is also likely to be a reason for the forest degradation in this region. Win et al. (2018c) estimated that the forest area to meet woodfuel demand could decrease by almost 40% if single woodfuel use in the rural area switched to the multiple-fuel use of woodfuel and other energy such as electricity and liquefied petroleum gas, which was widely adopted in the urban area. In this regard, developing such other energy sources would be a good option to reduce impacts on forests. In addition, expanding the community own firewood plantations, which have already been initiated by Forest Department of Myanmar, would offset the demand and enhance sustainable woodfuel supply.

We caution that our results from large-scale inventory data over Yedashe Township should be not generalized to other regions in Myanmar. This township is located between the capital city Nay Pyi Taw and the largest city Yangon, which are connected with a highway. Thus, our studied forest is one of the most accessible forests in the country. Further research is needed using large-scale inventory data in other regions to generalize structure and stocking of selectively logged production forests in Myanmar.

CONCLUSIONS

Using data from large-scale forest inventory with 2-km-mesh systematic sampling covering an area of 139,360 ha, we evaluated the forest condition in traditional selectively logged production forests. Stocking (tree density, basal area and aboveground biomass) was lower or near the lower end among reported values and large, harvestable trees of commercial species were almost exhausted. We conclude that forest degradation with very low productivity is substantial over the large area of the logged forests. Our study supports the government decision of a 10-year logging ban for the Bago Mountain Range. Restoration for these degraded forests is urgent and illegal logging should be controlled. Financial incentives under the REDD+ scheme likely contributes to deal with such forest degradation in production forests.

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