

A study on the sustainable management of natural teak forests in Myanmar

(ミャンマーにおけるチーク天然林の持続的経営に関する研究)

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Abstract

Myanmar has been experiencing natural teak forest degradation, consequent affect of over-exploitation of teak above the prescribed cut limit, and challenging of restoring its degraded forests. The un-sustainable way of teak production from the natural forests of Myanmar is the main driving factor to point out the currently applied Brandis yield model for Annual Allowable Cut (AAC) of teak and to propose an alternative model for the yield regulation of teak. This study was composed of five chapters: introduction, study site and data set, preliminary analysis of teak conditions in natural forests, developing alternative approach for yield regulation, discussion and conclusion.

Under the system of Myanma Selection System (MSS), it was believed that the future consistent supply of teak would be ensured by following AAC with the prescribed girth limit for exploitable teak trees and felling cycle of thirty-year. Through the preliminary analysis on existing yield model, this study addressed that no forest stands had been harvested in accordance with AAC. Decreasing girth limit and shortening felling cycles were observed in the selected research site. In fact, this yield regulation model was developed over centuries for the sustainable teak productivity of the virgin natural forests which were almost untouched by disturbances. The author also examined disturbance finding in each girth class of teak stock. The loss of younger stems of teak between two felling cycles was suggested mainly due to illegal logging by local people staying near the forest sites.

To resolve the drawbacks of existing yield model, the new model was developed by considering the utility of maturities as an index in the sustainable management of natural teak in stand levels. The concept of the maturity is to check whether the trees in each girth class moved to next higher class over years and if moved, the maturity was considered increase. As long as we found the maturity increase across the girth classes, that stand could be considered as stable and chosen for harvest. While Brandis' method was applicable only for the forests with the excess amount of mature trees, the new one would be feasible to apply in

the current situation of natural forests which has been facing the problems of degradation and over-exploitation of timber in Myanmar.

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Acronyms and Abbreviation

AAC	Annual Allowable Cut
ARR	Annual Rate of Recruitment
APFSOS	Asia-Pacific Forestry Sector Outlook Study
BSS	Brandis Selection System
FAO	Food and Agriculture Organization of the United Nations
FC	Felling Cycle
FD	Forest Department
FRA	Global Forest Resources Assessment
MSS	Myanma Selection System
MTE	Myanma Timber Enterprise
PFE	Protected Forest Estate
PPF	Protected Public Forest
RF	Reserved Forest

Some Common Terms used in Myanmar Forest Management

<i>Terms</i>	<i>Definitions</i>
<i>Annual Allowable Cut:</i>	<i>The allowable cut expressed on an annual basis (unit as number of trees or tons in volume)</i>
<i>Annual or Periodic Yield:</i>	<i>The volume or number of stems that can be removed in a specific area in one year, or during a specified period, respectively</i>
<i>Elephant Logging</i>	<i>The work of elephant in timber extraction, such as stumping, skidding logs from one place to another, conducted under the selective harvesting system in Myanmar.</i>
<i>Felling Cycle</i>	<i>The planned period, in years, within which all parts of a forest zoned for wood production and being managed under a selection silvicultural system should be selectively cut for logs.</i>
<i>Girdling:</i>	<i>The process of killing trees without felling, which consists of cutting a broad band around a tree at breast height, right through the bark and sapwood until the heartwood is reached in order to season the timber and make it floatable. It was the traditional method applied in natural teak trees in Myanmar.</i>
<i>Myanma Selection System (MSS):</i>	<i>A method of harvesting tree species of prescribed minimum girth limits within the boundary of the annual allowable cut (AAC).</i>
<i>Sustained Yield</i>	<i>The regular, continuous supply of the desired produce to the full capacity of the forests</i>
<i>Growing Stock:</i>	<i>The sum-total of all trees, by number or volume or biomass, growing within a particular area of interest.</i>
<i>Reserved Forest</i>	<i>Land constituted as “reserved forest” under Forest Law (1992) which is property of Government.</i>
<i>Protected Public Forest</i>	<i>Land constituted as “protected public forest” under Forest Rules (1992) which is property of Government.</i>
<i>Un-classed Forest</i>	<i>Any forest land or waste land or any other land “recorded” in land records as forest land but not notified in gazette as “reserved” or “protected public forest” under Forest law (1992) and Forest Rules (1995).</i>

Sources: Guidelines for management of tropical forests (FAO, 2007); Country Report, Myanmar (FRA, 2010)

Chapter 1

Introduction

1.1 Teak and Its Role in Myanmar

Teak (*Tectona grandis*) is indigenous only to four countries of Southeast Asia: India, Myanmar, the Lao People's Democratic Republic and Thailand. However, teak plantation has been established in warm climates throughout the world. It mostly occurs in dry and moist deciduous forests growing together with other deciduous trees species such as *Legumes*, *Lagerstroemia* species, *Terminalia* species and bamboos (Thein et al., 2007).

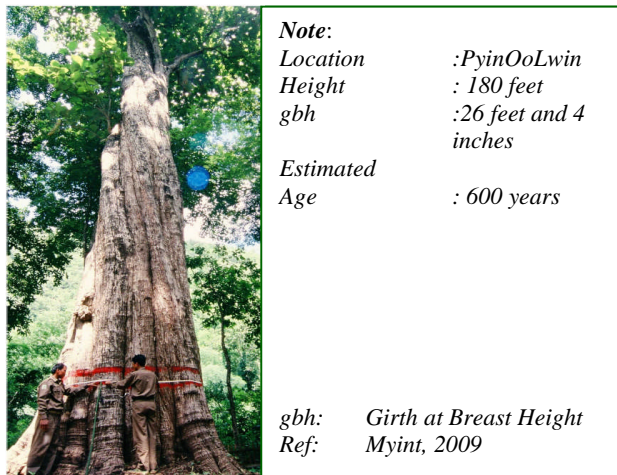


Photo 1.1 Biggest teak tree found in Myanmar

Teak grows best in localities with annual rainfall of 1,250 to 3,750 mm, minimum temperature of 13 to 17°C and maximum temperature of 39 to 43°C, and elevation below 1000m. In the lower slopes with improved soil depth and good drainage, teak becomes comparatively more abundant and is of better quality. Waterlogged depressions, soggy and stiff clayey soils are not favorable areas for teak. It is a light-demanding species and able to tolerant fire. It begins flowering and seeding about 20 years from the seedling. It is said that under favorable

conditions, teak attains a diameter of 24 inches (girth 72 inches) at the age of 80 years. When fully mature over 7 feet in girth, it attains a height of 100 to 150 feet. (Pandey and Brown, 2000)

Teak is one of the most commercially important timbers in the world. Its reputation of teak timber is due to its matchless combination of qualities: termite, fungus and weather resistance, lightness with strength, attractiveness, workability and seasoning capacity without splitting, cracking, warping or materially altering shapes (Hoe, 1969). To ship building, teak primarily owes its century's old and worldwide reputation. In its home country, it is the major timber for building, bridge and wharf construction, piles, furniture, cabinet work, railway carriages, wheel spokes and felloes and general carpentry. Therefore, it is aptly said that "there is virtually no use to which timber can be put for which teak cannot be employed." (Kadambi, 1993, cited in Myint, 2002). One such example for ship is Edwin Fox built of Burmese teak (Myanma Teak) in 1853, now preserved as the oldest teak ship in New Zealand. Historical buildings and bridge built of teak in Myanmar are proof of teak durability over centuries (Photos 1.2 and 1.3).



Photo 1.2 Shwe-nan-daw Kyaung
(Teak Monastery) in Mandalay,
Myanmar.

*Note: Built as Royal Palace by King
Mindon in the mid-nineteenth century*



Photo 1.3 U Bein Bridge in Amarapura,
Myanmar

*Note: Built by a town mayor, named U Bein
in 1849 and the longest teak bridge in the
world with the length of 1.2 km.*

Among teak indigenous countries, Myanmar has been well known for its teak reserves and quality, and its expansive forests (Bryant 1997). Teak in Myanmar term is “Kyun” and also called “Shwe-wa” (golden teak) to denote its golden yellowish ting in color as well as its expensiveness in value as Gold. It is no exaggeration to say that Myanma teak was thoroughly appreciated by the British. Many accounts reveal that a proliferation of superior quality teak trees grows only in Myanmar.

Teak has been one of Myanma major foreign exchange earners since 17th century. It is said that 75 percent of the teak available in the world market is produced out of Myanmar (Aye, 2003). The annual potential yield of teak is believed to be around 0.3 million hoppus tons (0.6 million cubic meters) (Table 1.1). Myanmar annually exports an average of 110,000 hoppus tons in log form and another 80,000 tons in value added form. Myanma teak is welcome everywhere.

Table 1.1 Exports of Myanma teak and other hardwoods

Fiscal Year	Teak		Hardwoods	
	Volume (ton)	Vale ('000,000 \$)	Volume (ton)	Vale ('000,000 \$)
2001-2002	200,500	237	285,600	76
2002-2003	205,600	231	308,000	81
2003-2004	281,100	249	390,800	93
2004-2005	319,200	252	496,800	121
2005-2006	333,100	287	636,700	171

Source: Central Statistical Organization; Selected Monthly Economic Indicator, Oct 2007(Cited in Myanmar Forestry Outlook Study, 2009)

Such an outstanding tree species deserves special attention as regards to its silviculture as well as its timber production. It is said that natural teak has now almost become endangered species (Kashio & White, 1998). The growing stock of teak needs to be maintained under a sustained yield basis. The problem of maintenance and increase of the stock, as well as the tending of the natural teak bearing forest is worthy of consideration at some length (Kermode, 1964; cited in

Myint, 2002). Therefore, it is a must-do obligation for the forest managers to pay special attention on such a precious tree species called golden teak.

1.2 Background of Natural Teak-bearing Forests in Myanmar

1.2.1 Current Status of Forest Resources in Myanmar

Myanmar is still rich in forest resources. According to FRA 2010, forests area is amounted to be about 33 million hectares which is about 49% of the total land areas of the country. The forest areas are classified as Permanent Forest Estate (PFE) comprising of reserved forest (RF), protected public forest (PPF) and protected areas system (PAS), and Un-classed Forest (UF) (Table 1.2). It is noted that about 19 million hectares of total forests are under the Permanent Forest Estate (PFE). The rest of forest areas are under the category of Un-classed forests (UF). All belong to “State” except community forests which are owned by local people with long term lease permission of Government. It is noted that 41,000 ha of forest areas in 2005 are under community forests (FRA, 2010).

Table 1.2 Status of Myanma forest in 2006

Forest Classification		Area (million ha)	% of Total Land Area (67.66million ha)
PFE	Reserved Forest (RF)	12.34	18.24
	Public Protected Forest (PPF)	3.99	5.90
	Protected Area System (PAS)	2.66	3.93
Un-classed Forest (UF)		14.02	20.72
Total		33.01	48.79

Ref: Myint, 2011

Despite of still owning a large portion of forest resources, the trend of forest area in Myanmar is likely to decrease according to FRA (2010) estimation and forecasting (Table 1.3).

Table 1.3 Estimated forest cover in Myanmar

Year	Forest Cover (million ha)	% of Total Land Area
1990	39.22	57.97
2000	34.87	51.54
2005	33.32	49.25
2010	31.77	46.96

Source: Country Report, Myanmar (FRA, 2010)

1.2.2 Diversity of Forest Types in Myanmar

As a result of great variation in rainfall, temperature, soil and topography, different forest types are found in Myanmar (Table 1.4).

Table 1.4 Main forest types in Myanmar

Forest Type	% of Total Land Area
1) Mixed deciduous forest	39
2) Hill and mountain evergreen forest	26
3) Tropical evergreen forest	16
4) Dry forest	10
5) Deciduous dipterocarp forest	5
6) Tidal swamp forest	4
Total	100

Source: Forest Department (Myanmar)

Among those different types of forests, the mixed deciduous forests are the best home of teak in Myanmar as well as in the world. In nationally, the remnant natural teak forests covered approximately 16.5 million ha of the entire forest area in 1993 and it was about 70% of the world's remaining teak forests.

1.2.3 Distribution of Natural Teak-bearing Forests in Myanmar



Photo 1.4 Natural teak-bearing forest in Myanmar

In Myanmar natural forests, teak occur scattered in mixture with a large number of other hardwood species. It is noted that the teak forest is not in the pure form. It generally accounts for 4 to 12% of the entire forest composition at a yield of only 7-12 trees per hectare. Thus it is a precious resource across the globe. Myanmar good teak forests with highest density are found in Bago Yoma (Mountain ranges) which was once regarded as the true home of Teak (Kermode 1964; Zin, 2005). According to Myint (2011), teak forests still own about 13.5 million ha, of which 10.8 million ha are designated for timber productivity and the rests are for protection. Teak plantation in Myanmar still plays a minor role in forestry and it accounts to be about 0.3 million ha which are intended only for restoration of the denuded areas.

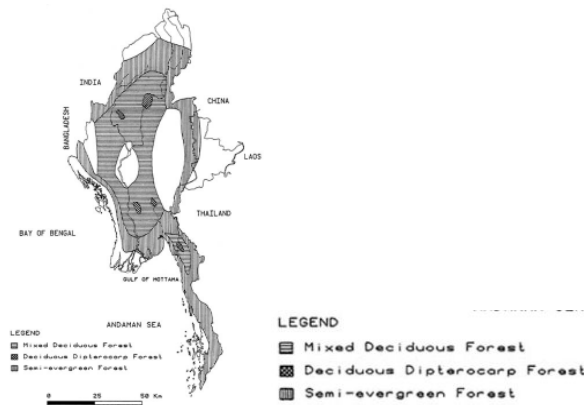


Figure 1.1 Distributions of natural teak forests in Myanmar

The teak-bearing forests in Myanmar are not primeval virgin forest anymore. Almost all of them has been affected by man and described as secondary forests. Some accessible areas have been heavily exploited for teak, other valuable species and even bamboos. Some of the less accessible forests had remained almost untouched except for girdling and extraction of mature teak trees scattered at wide intervals in the mixed forests (Kermode 1964). The main target of managing teak-bearing natural forests has been teak extraction which has been conducting under the selection logging system or Myanma Selection System (MSS) (Bryant 1997; Thein, 2007). Nowadays, Myanma dense natural forests with a premium quality of teak have been degraded and shrunk so rapidly. According to FRA (2010), the annual deforestation rate in Myanmar is estimated to be 310,000 ha (Table 1.5).

Table 1.5 Deforestation rate in Myanmar

Period	Annual Change Rate	
	(,000ha)	(%)
1990_2000	-435	-1.2
2000_2010	-310	-0.9

Source: Global Forest Resources Assessment, (FRA, 2010)

1.3 Background of Forest Management in Myanmar Natural Forest

The forest management in Myanmar has a historical background over the centuries. Myanmar Kings declared Teak trees as a Royal property and teak extraction was regulated through the girdling system. Urged by the greed for the usage of teakwood for ship building, the British fought three wars against Myanmar in the years of 1824, 1852 and 1885 (Zaw, 1997). Teak monopoly system was ended after the first war and the teak forests were extensively used by private firms. Consequently, the forest resources were severely depleted. Soon after the annexation of Bago in 1852, the British government declared the teak forest as State property appreciating the system practiced at the time of Myanmar Kings and introduced scientific forest management system so called Brandis Selection System in 1856. The historical review of Myanmar forest management covering three main periods: Pre-colonial, Colonial and Independent up to present is presented in Annex (1).

1.3.1 Girdling Method

Teak girdling is the traditional method of killing trees without felling which was once applied for natural teak forests in Myanmar. It consists of cutting a broad band around a tree at breast height, right through the bark and sapwood until the heartwood is reached. This is to season the timber and make it floatable. Under this method, mature teak trees are selected to be girdled and left standing for 3 years before being felled to get dry teak at the time of felling season. Girdling teak was a must-do operation because the only practical method of bringing teak log to the main port of Yangon in those days was by floating it down the streams and the rivers. With regard to girdling teak, Brandis (1896) stated that “this excellent practice, as a matter of course, I maintained, but one of the many battles I have to fight during my Indian career was against those who condemned this practice as useless, as barbarous, as injurious to the timber, and likely to damage the reputation of Burma Teak, while others describe girdling as the outcome of German Theories. In reality, it was an old Burmese practice, to which the good reputation of Burma was mainly due.” From the other point of view,

three years' lag time of harvesting after selection has prevented the teak stocking from over-exploitation.



Photo 1.5 Girdling operation of teak



Photo 1.6 Dead teak tree in standing

The practices of girdling, planting and levying a fee on all of teak have been conducted throughout the rule of Myanma Kings as well as the British colonial government (Win, 1998). However, the girdling teak was gradually stopped in some accessible areas and green teak extraction has been started since 1980 up to the present.

1.3.2 Elephant Logging

In Myanmar, timbers are extracted by the combination of animal and mechanical power. No doubt that the elephants are the main power in timber extraction from the teak forests which are too jangled and mountainous, while Buffalo power can be used only on flat terrain for short hauling distances and smaller trees. It is said that about 1700 elephants are owned by the Myanma Timber Enterprise.

There are three stages of timber extraction in Myanmar namely (Mar, 2007; Zaw, 1997);

- 1) 1st stage involves felling trees and dragging logs from the stump of felled trees to the measuring points.



Photo 1.7 Elephant work in 1st stage of extraction (Dragging logs to measuring point)

- 2) 2nd stage involves transportation of logs from the measuring points to the river depot, railing sidings, and log yards.



Photo 1.8 Elephant work in 2nd stage of extraction (Dragging logs from measuring point to river depot)

- 3) 3rd stage involves transportation of logs from the river depots, railing sidings and log yards to Yangon which is the main port for timber export, by means of rafting, railing and trucking.

Elephants are indispensable in the 1st stage of extraction, and this work of elephant is termed as “Stumping”. They are also necessary in the 2nd stage of transportation where floating is applied for transportation of logs from the measuring points to the river rafting depot. It is said that using animal power is the cheapest and environmentally friendly operation. In Myanmar, heavy machines are used mainly for road construction and trucking of logs while the work of elephants still occupies in stumping and skidding in which no machine can replace it to work in such a complex natural forest. Therefore, the work of timber extraction in Myanmar is generally called ‘Elephant logging’. As elephants are

essential work force for timber industry in Myanmar, they are being taken good care for their health by the Myanmar Timber Enterprise. It was noted that a fully trained elephant costs about US\$6,000-10,000 to pursue in Myanmar (Zaw, 1997).

1.3.3 Myanmar Selection System

The forest management in Myanmar is mainly based on its natural teak forests which are managed under the Myanmar Selection System, MSS (formerly Brandis Selection System, BSS). The system involves adoption of felling cycles, prescription of exploitable trees, girdling or marking of exploitable yield trees, girdling of defective teak trees, thinning of congested teak stands, removal of other trees interfering with the growth of young and old teak trees, enumeration of trees left, doing special silvicultural operations in bamboo flowering areas, and fixation of annual yield or annual allowable cut (AAC).

In the operation of the MSS, all of the natural and planted forests are managed by setting different working circles under the forest working plans. Each working circle has formulated to meet its own purposes of forest management (Table 1.6).

Accordingly, teak extraction from the natural forests is mainly carried out from the PWC consisting of a group of reserved forests (RF) and protected public forest (PPF). The working circles are divided into felling series for the convenient of working according to drainage and geographical situation. The felling series are subdivided into 30 blocks (as felling cycle) which are approximately 250 hectares in size. Under MSS, one block per year is harvested and the whole felling series is worked in the course of a 30-year felling cycle. In each block due for harvest, marketable trees with girth at breast height (gbh) at or above the fixed exploitable limits are selected and cut. The extracted volume must be within the bounds of the AAC, which is determined for each felling series based on the principle of sustained yield management (Dah, 2004).

Table 1.6 Types of working circles of forests in Myanmar

Working Circles (WC)	Purposes
1) Non wood forest products WC (NWFPWC)	For meeting non-wood forest product requirement
2) Production WC (PWC)	For meeting timber (teak and other hardwoods) requirement
3) Planted Forest WC (PFWC)	For meeting timber requirement through artificial regeneration
4) Community Forestry WC (CFWC)	For meeting fuel-wood and other minor products for local community
5) Watershed Forest WC (WFWC)	For meeting conservation of soil and water resources
6) Mangrove Forest WC (MFWC)	For utilizing and conservation of coastal mangrove forests
7) Protected Area System WC (PASWC)	For conservation of National Parks and Sanctuaries

Source: Country Report, Myanmar (FRA, 2010)

As mentioned above, MSS was initially developed for the management of teak, which is the main species in the market demand. However, teak does grow together with other thousand species of hardwoods in the natural forests (Table 1.7). In 2000, teak has the highest percent of share in the growing stock of natural teak forest.

Table 1.7 Composition of growing stock of teak together with other hardwood species between 1990 and 2000

Local Name	Scientific Name	1990		2000	
		Volume (million m ³)	% Share	Volume (million m ³)	% Share
Kyun (Teak)	Tectona grandis	241.91	8.63	149.40	5.21
Thabye	Eugenia spp.	59.41	2.12	96.95	3.38
In	Dipterocarp spp.	221.40	7.90	75.98	2.65
Taukkyan	Terminalia tomentosa	111.61	3.98	58.09	2.02
Pyinkado	Xylia xylocarpus	285.44	10.18	46.65	1.63
Thadi	Protium serrate	18.30	0.65	44.48	1.55
Ingyin	Pentacme siamensis	103.51	3.69	41.46	1.45
Theta	Shorea oblongifolia	65.42	2.33	19.92	0.69
Total of top spp.		1,107.00	39.50	532.93	18.58
Others		1,695.72	60.50	2,336.11	81.42
Grand Total		2,802.72	100.00	2,869.04	100.00

Source: APFSOS II(Myanmar), 2009

For teak –associated hardwood species, MSS was later modified to apply by defining related girth limits and cutting cycles. As shown in figure 1.3, AAC application under MSS was not only intended for teak but also for other hardwood species.

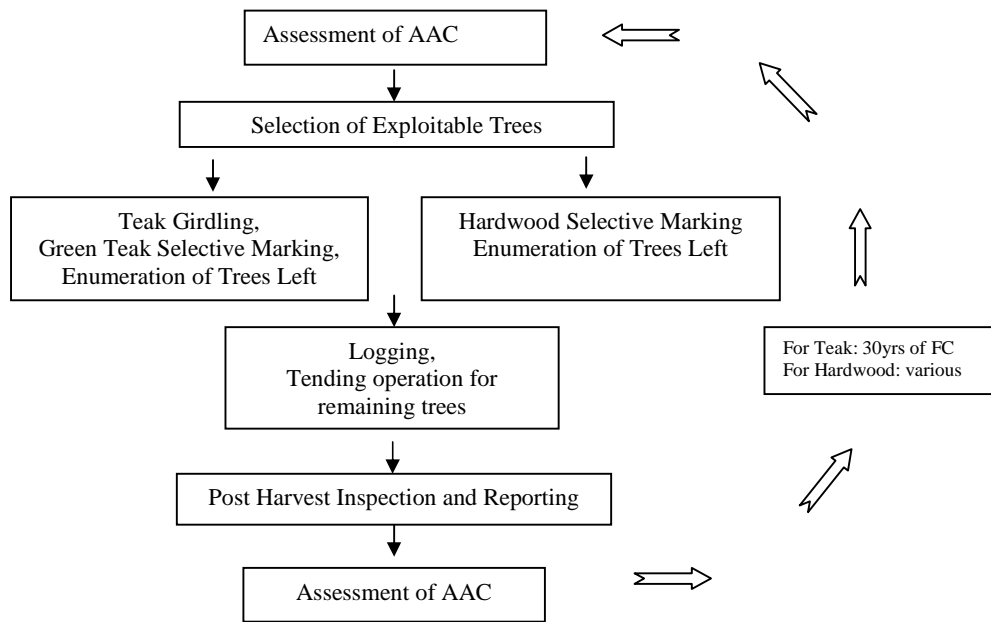


Figure 1.2 Process of Myanmar selection system (MSS)

Source: Forest Department

Teak girdling and hardwood selection felling marking (S.F marking) are conducted in conformity with the working plans and AAC that has been set under the systematic forest inventories. Those operations are conducted by the Forest Department (FD) while the Myanmar Timber Enterprise (MTE) is responsible for harvesting of teak and hardwoods from the forests in accordance with the field exploration reports by FD. The step-by-step silvicultural operations of MSS before Timber Exploitation(Y-), during Timber Exploitation(Y) and after Timber Exploitation(Y+) are shown in Annex (2).

It is believed that MSS is the only feasible system to manage the multi-species complex forests of Myanmar where only a few species are extracted out of nearly a thousand species growing together in the forests (Zaw, 1997; Dah, 2004).

However, there are some drawbacks in applying MSS in the field work, especially in the harvesting operation. It is said that timber extraction is often conducted depending on current need instead of AAC limit at the time of extraction and the felling cycle limit of 30-year designated by AAC has been neglected. Another drawback of MSS is just selecting the best teak trees to be cut,

that are not a good idea for long term. The growing stock and natural regeneration of teak are fast declining due to successional changes in forest types, repeated severe annual forest fires, fuel wood crisis, and other over exploitation (Keh, 2000). Because of the complicated nature of natural forests and insufficient resources, there is weak in accuracy in tree selection-marking to check harvestable trees or yield trees and in enumeration of the un-yield trees for the future yield calculation.

1.3.4 Yield Estimation for AAC

Bransnett (1985) stated that methods of estimating the desirable yield can be controlled by area, volume and number of trees. Yield regulation by the number of trees is usually used in large, irregular tropical forests which are often composed of many species, only a few of which are marketable (Osmaston, 1984).

There are three methods of yield regulation by size-classes: The French Method of 1883 so called Melard's Method; The Regulation Area Method so called Melard's Method of 1894, and Yield Regulation by Number of Trees so called Brandis' Method. In Myanmar, Brandis's method so called the Brandis Selection Method, BSS (now known as MSS) has been applying since 1856 in the management of natural teak bearing forests. This method was originally developed for teak, later applied in other hardwoods species as well.

Dr. Brandis, German forester, is initiator of developing the yield estimation for future productivity of teak. At the time of 1856, there was an excess of large trees of the valuable species over the medium and the small sized trees in many of tropical natural forests (Brasnett, 1895). With the abundance occurrence of mature teak trees but small proportion found in the Burmese (now, Myanmar) natural forests, he decided to install a regular yield system for the assurance of future consistent supply of teak. To do his plan in exploring and managing natural teak forest, he set minimum girth limit for harvestable teak trees and proceeded to carry out enumeration by strips to determine at what rate they could be cut. All trees above 6 feet were considered as Class I (C_I) while Class II (C_{II}) trees were between 4.5 feet and 6 feet in girth. He also estimated the appropriate percentage of trees in each class those were likely to be available for cutting as C_I trees (Brasnett, 1895).

To decide how much rate of mature trees to be cut (AAC), average annual recruitment rate (ARR) to C_I trees was the first thing to calculate by dividing the number of C_{II} trees by the time passage. According to his observation of trees of known age, it took 24 years for teak trees of C_{II} to become harvestable trees as C_I . Accordingly, he prescribed that $1/24^{th}$ of harvestable trees should be cut annually. It was simply defined as follows for the future yield calculation.

$$AAC=ARR$$

The above yield formula implies that only annual increment from C_{II} trees to C_I are considered as the interest of the forests those are supposed to be taken out as annual yield trees and felling of all of the recruitment trees is to be carried out over the felling cycle of the whole forest. After the 1st felling cycle, the whole forest was fully recovered as original one. In the application of that yield formula, there must be sufficient numbers of trees in harvestable size as the original working stock (OWS), so that the forests keep continuous supply for the required numbers of trees to be cut in the next felling cycles. In case where the original working stocks of harvestable trees were more than enough, we could consider as surplus that could be cut in addition to the recruitment rate as follows.

$$AAC=ARR+ [OWS-(\frac{1}{2} FC \times ARR)] /LP.$$

In this formula, liquidation period (LP) is usually 60-year which is decided period of liquidation of the original growing stock of the natural teak forests. As it was initiated by Brandis, the system was named as Brandis Selection System (BSS) as an honor of his attempt. And his formula of yield estimation for AAC is mentioned as Brandis Yield Method. At the time of 1856, most of the natural forests in Myanmar were left untouched, and extra-large trees were frequently found. Therefore, Brandis Yield regulation would likely to lower the stocking level.

The girth limit for teak is changing from time to time depending on the abundance of mature teak trees and current target for teak demand. Starting from 1930, the exploitable minimum girth limit of teak at breast height 4.5 feet (1.4m) has been described as 7.5feet(2.3m) in good forests(moist) and 6.5 feet (2.0m) in poor forests(dry forests). As the growing stocks of teak in most regions have greater growth rates than those in dry region, time of passage from C_{II} to become C_I took different felling cycles (see Table 1.8). Currently, 30-year of felling cycle

is practiced which is also supposed as the required time of C_{II} trees to become C_I of harvestable trees (Kyaw, 2004). In other words, one foot of girth of teak tree would increase during the period of felling cycle and after passing that period, all of the trees from C_{II} would become C_I as harvestable trees.

Table 1.8 Annual yields in different working plans during 1856 and 1892

Working Plan Period under BSS	Time of Passage from C_{II} to C_I (yrs.)	AAC (trees)
1856	24	9,000
1868	72	5,800
1884_1892	38	11,230

Source: Win, 1998

Under the BSS, there was motto saying “Take out only interest without touching the capital”. However, the condition was different from the past. As mentioned above, Brandis’ method seems workable when there is a sufficient amount of original growing stock of C_I trees. It was also stated that Brandis Yield Regulation model is limited to apply the forests with the sufficient amount of mature teaks in the original working stock (Osmaston, 1984). At present, the original growing stock (capital) of natural teak forests has been touched by the human influence and natural disaster as well. It was stated that Myanmar is the fourth country which has the highest total supply and use of illegally harvested timber (Dieter, 2009).

Some researchers have attempted to improve AAC estimation by developing growth models for teak. The growth model developed by Tint and Schneider (1980) was able to estimate growth, mortality and ingrowth of teak stands and then to generate future stand tables. Zin (2005) pointed that instead of modifying the previous yield model, a more reliable approach in yield regulation was an argent need. Accordingly, he proposed an age-independent individual tree model for teak to predict tree diameter growth and also developed a general growth projection system for all species including teak. However, the current yield estimation in Myanma natural forests is still under the long-practiced Brandis’ method. This traditional yield estimation seems not to ensure long term

sustainability by considering any indices through out the harvesting periods. Therefore, this study intended to explore the current yield method by evaluating the timber production of Pyu Kun RF in natural teak forests of Bago Yoma and then to develop an index for assessing harvesting possibility, disturbance tendency multi-temporal sustainability of natural teak forests.

1.4 Objectives of the Study

This study aimed to develop a yield regulation model as an alternative of currently practicing yield method, through introducing the concept of maturity of stands as an index in assessing sustainability of natural teak forests. This study was focus on only timber productivity as harvesting is the main concern towards the sustainable management of natural teak forests in Myanmar. Moreover, teak was chosen as the target species which is the most demanded one in the timber market.

The objectives of this study were as follows:

- 1) To review the current system of forest management of natural teak bearing forests in Myanmar;
- 2) To make comparative analysis of future yield estimation to find out the reality and the theoretical aspect practicing under the Myanma Selection System;
- 3) To propose an alternative yield estimation model for the sustainable forest management in natural teak forests in Myanmar.

Chapter 2

Study Site and Data Set

2.1 Study Area

2.1.1 General Description of Study Area

The study was conducted at one of the Reserved Forests in Bago Yoma region, which is situated in the central part of lower Myanmar. According to Kermode (1964), teak with an exceptional good quality can be found in Bago Yoma area. Bago Yoma means Bago mountain ranges covering with about 5.07 million ha of total land area, of which 1.8 million ha of natural teak bearing forests are found. This region (Annex 3) includes 31 townships, 8 administrative forest districts and 4 divisions. Bago Yoma has been known as a home of teak and it is also the birth place of the scientific forest management called the Myanma Selection System (MSS).

According to districts forest-working plans, production working cycles (PWC) are formed in reserved and protected public forests of Bago Yoma Region for the purpose of teak and other hardwoods production (Table 2.1). Of four divisions under Bago Yoma region, Bago (East) is the place where timber production from PWC is mainly carried out and has also been known for producing good quality of teak.

In Myanmar, teak is graded as Special, Grade I, II and III according to its best quality and price (Annex 4). By stamping specific marks on teak log, teak can be traced back where it comes from and which grade it belongs to. According to the map of Myanmar showing MTE Extraction Departments-Agencies Offices-Agency-wise Hammer marks for teak log, Grade I teak comes mostly from the townships of Taungoo District, where the Agency office is set up to undertake timber extraction operation, which is under the administrative boundary of Bago (East).

Table 2.1 Area allocation of PWC in Bago Yoma Region

Divisions		Districts	PWC(ha)	% of PWC
1) Bago	(East)	Bago	117,976.12	11.34
		Taungoo	404,681.91	38.90
	(West)	Pyi	117,976.12	11.34
		Tharyarwady	88,605.42	8.52
2) Magwe		Magwe	44,220.56	4.25
		Thayet	106,744.23	10.26
3) Mandalay		Yamethin	122,789.15	11.80
4) Yangon		Yangon(North)	37,305.14	3.59
Total			1,040,298.65	100.00

Source: Planning and Statistics Division, Forest Department and Bago Yoma Greening Project

2.1.2 Selection of Study Site as Pyu Kun Reserved Forest

The study was to cover the conditions of teak bearing forest of Bago Yoma which was once home of teak. To assess sustainability of teak production from Bago Yoma, it is necessary to choose one representative reserved forest where necessary data are available. As mentioned above, Taungoo extraction agency of Bago (East) division would be considered the most active region in terms of timber production as it owns the largest area of PWC.

Under Taungoo Extraction Agency belonging 33 RF (Annex 5), Pyu Kun RF is the largest one with 174 compartments of forest stands and has been under timber extraction since 1976. Therefore, Pyu Kun RF was chosen as the study site, assuming that analysis on timber productivity in that site would represent at least Eastern Bago Yoma where good quality of teak produces.

Pyu Kun RF extends over two townships of Pyu and Okatwin under Taungoo District of Eastern Bago Division (Annex 6). It has 174 of the total forest compartments, with the majority of it in Pyu Township. Being the range of average temperature between 23° and 31° with a mean annual rainfall of 1990mm, 63% of mixed deciduous and 37% of evergreen forests belong to Pyu Kun RF (Forest Department, 2005b). This forest type of mixed deciduous forest is found on alluvial soils throughout the teak bearing ranges. According to Kermode (1964),

teak occurs more sparsely than in the lower mixed deciduous forest type, but produces cleaner and straighter boles.

As for annual yield, AAC for Taungoo District is estimated in accordance with Brandis' Method, in which the trees of 6.5 feet in girth and above are categorized as C_I and the trees between 5.5 feet and 6.5 feet as C_{II} , with the survival ration of 95% and 90% respectively (Forest Department, 1995b, 2005b). According to the district forest management plan of Taungoo, AAC of teak from this region is supposed to be 10,085 trees or 36,306 cubic meters at 2 tons per tree under a thirty-year felling cycle.



Photo 2.1 Field work at the Pyu Kun RF (Natural Teak-bearing Forest)



Photo 2.2 Distribution of teak in natural forests of Pyu Kun RF

In the study site, beside thousands of other hardwood species being associated with teak, the abundance of bamboo is also found. For the feasibility of accounting and recording various kinds of hardwood species, 6 groups are classified by their similar quality and market rank. Only teak has specific number of trees in each girth distribution. Table 2.2 demonstrates the natural distribution of teak in Pyu Kun RF.

Table 2.2 Natural distribution of teak in Pyu Kun RF
(Pyu and Okatwin Township)

Species/ Group	Number of trees in each girth class					Total	%
	2' 00"	5' 06"	6' 06"	7' 06"	≥ 8'		
	5' - 5"	6' - 5"	7' - 5"	7' - 11"			
Teak	224,856	27,232	10,749	716	4,299	267,852	16.66
G 1	162,314	18,632	10,749	2,866	23,649	218,210	13.58
G 2	160,967	15,758	4,297	2,148	1,433	184,603	11.48
G 3	80,687	12,894	4,298	2,865	2,864	103,608	6.45
G 4	78,350	15,858	7,162	-	4,299	105,569	6.57
G 5	534,766	39,397	16,471	716	7,878	599,228	37.28
Others	103,230	13,615	3,582	1,433	6,449	128,309	7.98
Total	1,345,170	143,386	57,308	10,744	50,871	1,607,379	100.00

G: Group

Source: Forest Department, 2005b

2.1.3 Location Map of Study Area

The study area is shown in the Figure 2.1 as below.

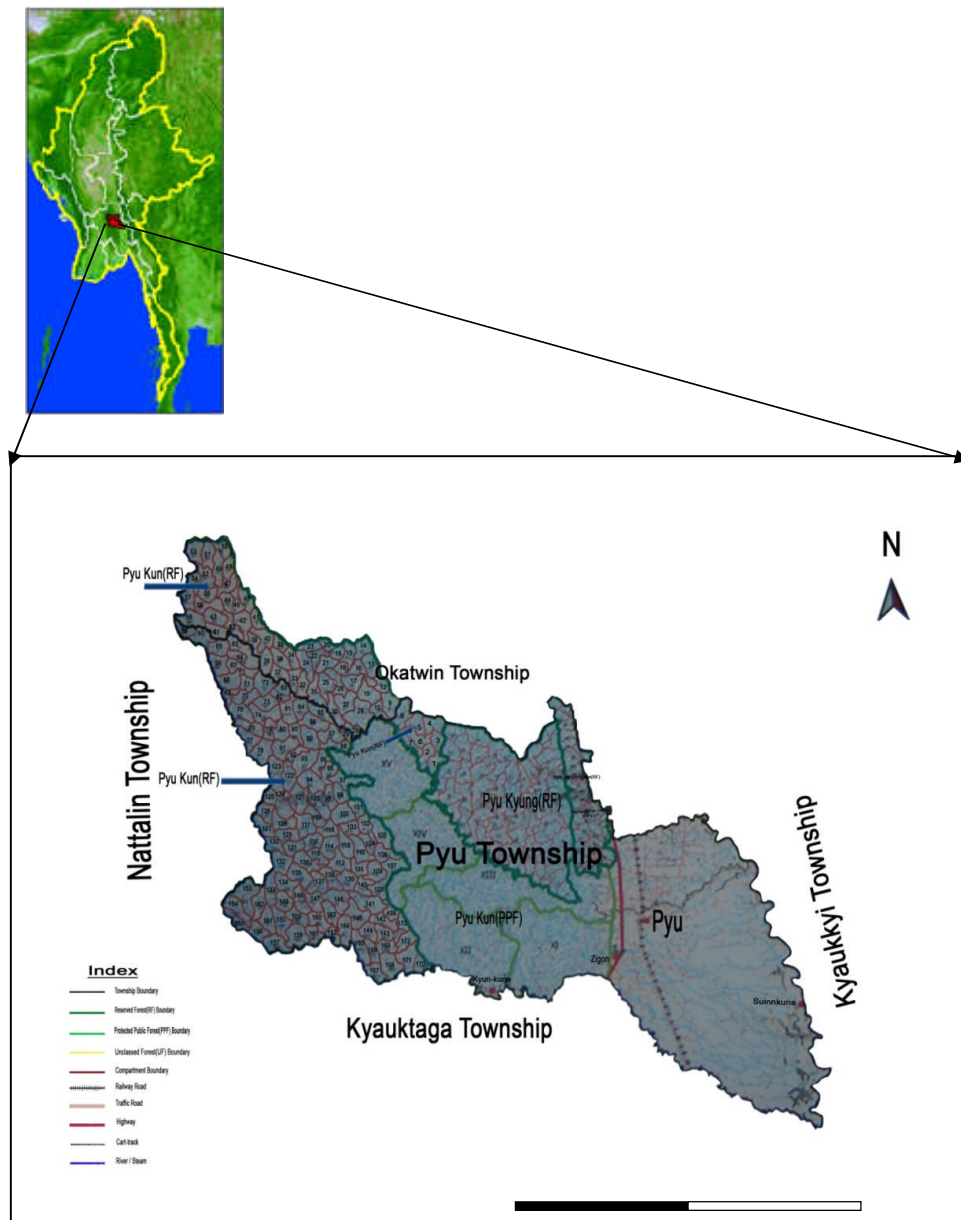


Figure 2.1 Pyu Kun RF with the total of 174 Compartments

Note: 123 compartments are in Pyu Township while 50 are in Okatwin Township and one compartment is extended over these two townships.

Source: Settlements and Land Records Department, Ministry of Agriculture and Irrigation

2.2 Data Sources

2.2.1 Data Availability

The relevant data to the forest conditions of Bago Yoma region were collected from the respective resources such as the Planning and Statistics Division, Forest Department (FD) in Naypyitaw (capital) and Myanma Timber Enterprise (MTE) as well. Forest types and other climatic conditions of the study site named Pyu Kun Reserved Forest were based on the facts and figures of Taungoo District as no information available for each reserved forest located in each Township.

According to Zin, 2004, Permanent Sample Plots (PSP) were installed in Bago Yoma region for the first time in 1982 and re-measured in 1987 and 1992. After that, installed PSP were not properly recognized and no records were available since then. It is said that installing sample plots in complex natural forest is quite difficult to maintain. Therefore, in this study, the forest enumeration data of Pyu Kun RF were mainly used to analysis the growing stock of teak.

Forest enumeration is one of the silvicultural operations of MSS (refer to Annex 2). The operation of forest enumeration is conducted one or three years before timber extraction in selected compartments to investigate how many teak trees are left in those compartments. In case of green teak extraction, the operation is conducted one year before extraction. For the places where teak-girdling operation is still practiced, it is to be carried out three years before extraction. Selected compartments mean the compartments which are planned to conduct timber extraction according to felling cycle of those compartments. One or three year prior to timber extraction, the selected compartments are 100% enumerated; teak trees left are counted starting from 4 feet. Through this operation, it can be checked how many trees from those selected compartments are about to cut and how many are left for future. Based on the enumeration data for trees left, the future productivity of teak from those compartments for the next felling cycle is to be estimated.

In this study, the enumeration data were used to investigate and check out the prescribed and actual cut trees from each compartment. To do so, the compartments which have already data for trees left information are about to used.

More precisely, the compartments which have two felling cycles are to be used so that trees left at the time of previous felling cycle and trees cut at the time of second felling cycle could be traced.

2.2.2 Data Set of Study Site (Pyu Kun RF)

In Pyu Kun RF with the total of 174 compartments, 110 compartments have history of enumeration data for tree lefts at the time of data collection. Out of 110, only 64 compartments were selected as those compartments had two times of harvesting operation. These data were collected from the district forest office (D.F.O) of Taungoo, Forest Department; and Extraction Agency Offices of South Taungoo and South Bago, the Division Office of Deputy General Manager (DGM office), Taungoo, Myanmar Timber Enterprise (MTE), respectively. Then, the data from each source (MTE and FD) were checked thoroughly.

The collected data were composed of numbers and areas of compartments, numbers of felled/girdled trees, numbers of trees left at the time of felling, total production amount (by trees), and time intervals of harvest (Annex 7). The records of girdling or marking trees and left trees are traced back from 1976 up to 2009. In the original data, it was found that harvesting entry is twice in most compartments, some has only once and a few no harvest yet (Table 2.3). Area of each compartments are likely to decrease or increase in case of changing land use of some portions of compartments from time to time.

Table 2.3 Status of harvest in Pyu Kun RF

No. of Compartment	Times of Harvest	Forest Area (ha)		
		Original Area	Area at 1 st Harvest	Area at 2 nd Harvest
64	2	33,007	32,730	31,019
46	1	23,916	23,098	-
13	-	7,474	-	-

Source: Record of Girdling and Tree Left Data, District Forest office (1976-2009)

As explained in previous chapter, instead of diameter, the girth at breast height (gbh) of trees is used, with the unit of feet and inches. According to the enumeration data, the trees are arranged under each girth classes (Annex 7).

The minimum girth limits for exploitable (yield) trees were found varied in this study site. Before 2005, yield trees or harvestable trees are defined as the trees with girth of 7.5 feet and above. After 2005, the minimum girth limit for yield trees becomes 6.5 feet. The trees below minimum girth limit are termed as non-yield trees. According to the rules of MSS, some of teak trees are marked to be girdled or felled, even if they are under the minimum girth limit, under the unfavorable conditions for teak growth such as water-storage areas.

According to the observation data, non-yield trees are counted starting from 4 feet in girth. There is no information available for numbers of teak younger than 4 feet in girth. The following Table 2.4 shows the statistics of 64 compartments in Pyu Kun RF.

Table 2.4 Statistics of the 64 compartments in Pyu Kun RF

Items	Unit	Average	Min	Max	Standard Deviation
Area	ha	517	105	752	143
Teak density					
Before 1 st harvesting (t_1)	Stems/ha	4.23	2.90	13.42	0.15
After 1 st harvesting (t_2)		2.76	2.17	10.03	0.15
Before 2 nd harvesting (t_3)		1.36	1.04	5.13	0.20
After 2 nd harvesting (t_4)		0.48	0.53	3.01	0.05

Chapter 3

Preliminary Analysis of Teak Productivity in Natural Forest

3.1 Introduction

In Myanmar, timber exploitation from natural teak forest has been carried out under the traditional yield model named Brandis' Method. Brandis' method and its formula for estimating AAC has already mentioned in the section 1.3.4. With the current conditions of growing stock of teak, the annual yield was re-adjusted if required (Jalonen et.al., 2009) to maintain the substantial productivity of teak for the future. However, the teak resource in natural forests has been gradually decreasing than before. Although weakness in silvicultural operations might be one of the reasons for causing scarcity of teak resources, controlling the forest conditions through the harvesting operation would be the most effective way to balance the growing stock of teak in terms of sustainability. To do so, it is first necessary to explore the actual harvest by using enumeration data of teak observed in Pyu Kun reserved forest which was chosen as study site (Chapter-2). And then the existing applied method for yield estimation was examined through the comparative analysis between actual and prescribed cut in accordance with AAC. Moreover, disturbance tendency of teak in each girth class was found out for the improvement of natural teak forest management.

3.2 Material and Methods

3.2.1 Data Preparation

To find out the real conditions of timber productivity, the enumeration data from Pyu Kun RF were rearranged depending on its data application. For examining the growing stock conditions before and after harvest, and occurrence of disturbance in natural teak forests, the original set of seven girth classes were used (Table 3.1a). For the comparative analysis by Brandis' Yield Model, four

girth classes were categorized especially by making one foot range of girth between two largest girth classes (Table 3.1b). The unit of area for each compartment was converted into hectare.

Table 3.1 Categories of girth class (gbh) of teak

(a)			(b)		
Girth Class, g_i	Lower Limit	Upper Limit	Girth Class, C_i	Lower Limit	Upper Limit
	$\leq g_i <$			$\leq C_i <$	
g_1	4' 00"	5' 00"	C_{IV}	4' 00"	5' 00"
g_2	5' 00"	5' 06"	C_{III}	5' 00"	5' 06"
g_3	5' 06"	6' 00"	C_{II}	5' 06"	6' 06"
g_4	6' 00"	6' 06"	C_I	6' 06"	+
g_5	6' 06"	7' 00"			
g_6	7' 00"	7' 06"			
g_7	7' 06"	+			

For the comparative analysis, only 64 compartments with the records of harvesting twice were chosen. Though felling cycle (FC) is prescribed as 30-year under the practice of MSS, various cutting periods was conducted in the study site. Therefore, for the feasibility of analysis for AAC estimation, three types of felling cycles were categorized among those 64 compartments by defining short, medium and long term FC (Table 3.2).

Table 3.2 Categories of felling cycle (FC) in 64 compartments of Pyu Kun RF

Type of FC	Range of Period (yrs.)	Compartments	
		No.	%
A (Short)	$FC \leq 10$	4.00	6.25
B (Medium)	$11 \leq FC \leq 20$	38.00	59.38
C (Long)	$21 \leq FC \leq 30$	22.00	34.38
Total		64.00	100.00

3.2.2 Development of AAC Estimation

For the estimation of AAC, 64 compartments were selected in order to make comparative analysis with the actual cut of those compartments. Here, only the information recorded for trees left was needed for the future yield estimation by Brandi's formula which was presented again as follows.

$$AAC = ARR + [OWS - (\frac{1}{2}FC \times ARR)] / LP \quad (3.1)$$

Where, ARR = annual recruitment rate (No. of trees in C_{II} divided by FC)

FC = Felling Cycle

AAC = Annual Allowable Cut

OWS = original working stock (No. of trees in C_I)

LP = liquidation period

According to Dr. Brandis (1896), all of teak trees within one foot below the exploitable girth limit, C_{II} , are likely to move the next higher class of C_I over some period. That period is assumed as thirty years of felling cycle (FC). Liquidation period of original working stock is usually considered as 60 years. The survival rate (SR) of the trees in C_I and C_{II} during felling cycle is assumed as 95 and 90 percent respectively according to the forest management plan for Taungoo District (2005b). Therefore, the annual recruitment rate was only dependent on number of trees in C_{II} while the original working stock would be the net survival trees in C_I after felling cycle. The respective formulae were defined as follows:

$$ARR = (SR_2 \times N_2) / FC \quad (3.2)$$

$$OWS = SR_1 \times N_1 \quad (3.3)$$

The four classes of girth distribution (Table 3.1b) were applied in formula (3.1) for the calculation of AAC. And then, comparison was made through the three types of felling cycles (A, B, C) over 64 compartments.

3.2.3 Development of Average Growth Rate of Teak

In Myanma natural teak forest, the growing stock of teak is decreasing over time. 64 compartments which would provide information about the growing stock of teak trees before and after harvest were chosen to investigate the disturbance tendency found in natural teak bearing stands.

All of teak trees data either cut or left were supposed to use and original seven girth classes were applied (Table 3.1a). Through the enumeration data, teak trees were rearranged over time series, t_1 , t_2 , t_3 , and t_4 which referred to the measurement time before 1st harvest, just after 1st harvest, before 2nd harvest and just after 2nd harvest, respectively. For the analysis of disturbance occurrence in the growth rate of teak in each girth class, only the trees list at t_2 and t_3 were considered. By using the time interval or felling cycle between t_2 and t_3 , the increment number of trees within the same girth class per year was calculated to estimate growth rate for each girth class. The growth rate, here, only considers the increment of trees within the same girth class.

The growth rate within the same class and average growth rate for 64 compartments were formulated as follows:

$$I = (C_{i, y'} - C_{i, y}) / (y' - y) \quad (3.4)$$

$$G_i = [\sum \sum \{(C_{i, y'} - C_{i, y}) / (y' - y)\}] / N \quad (3.5)$$

Where, y' = the year at t_3 (Before 2nd harvest)
 y = the year at t_2 (After 1st harvest)
 $C_{i, y'}$ = the number of trees in girth class i at t_3
 $C_{i, y}$ = the number of trees in girth class i at t_2
 N = the total number of compartments
 i = girth class (1 to 7)

I and G are the growth and average growth rate for 64 compartments (i.e. number of trees per hectare per year). And then, average growth rates were accumulated through girth class g_7 to g_1 , g_7 to g_2 , g_7 to g_3 , g_7 to g_4 , g_7 to g_5 , and g_7 to g_6 respectively to find out where the disturbance occurs seriously.

3.3 Results and Discussion

3.3.1 AAC Estimation

Before exploring timber productivity, natural distribution of teak in 64 compartments was examined by setting four time series: t_1 , t_2 , t_3 and t_4 . To know the forest conditions before each harvest, the number of trees at t_1 and t_3 were examined. It has been observed that the present girth distribution of teak in natural forests has receded in lower girth classes and this finding is confirmed by the records of enumeration data from some reserved forests in Bago Yoma (Figure 3.1). More than 50% of trees have been lost at the time series of t_3 . Especially, regeneration trees need special attention to recover the growing stock of teak. Moreover, at t_3 , there is not sufficient amount of largest trees on the ground to be harvested. Therefore, at 2nd felling cycle, there might be possibility of decreasing girth limit. Next, we would explore the harvesting intensity from those stands through actual and prescribed cut.

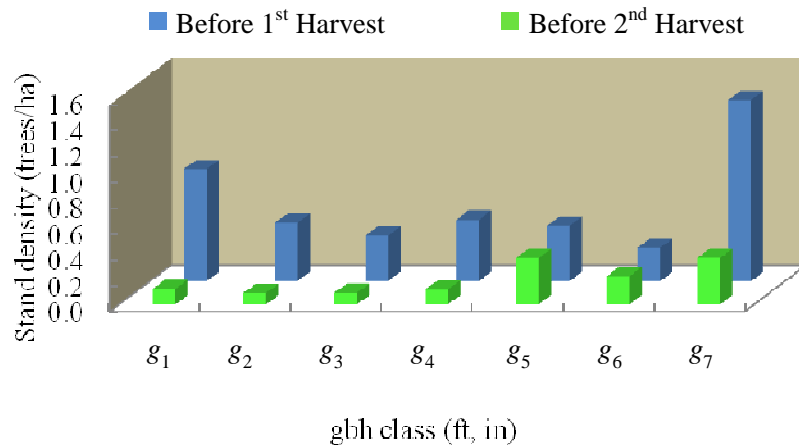


Figure 3.1 Average girth distribution of teak before 1st and 2nd harvest in Pyu Kun RF

Among 64 compartments, only one compartment was noted to follow FC of 30 years, and one was found to be entered 5 years after the first time harvesting. Most of the stands had been harvested about 17 years ago after the first felling

cycle. Generally, three types of felling cycles were found when the second harvesting was conducted in those stands.

Figure (3.2) shows the conditions of estimated annual yield by using Brandis Yield Formula (eq. 3.1) and the actual cut per year in Pyu Kun RF. Here, all of 64 compartments were allocated under three groups of felling cycle (Table 3.2) and then applied the yield model (eq. 3.1) to estimate AAC. It is obvious that, all of the forest stands in (64) compartments had been harvested over the limit of calculated AAC. Especially, the stands under the short felling cycle (A) were heavily over-exploited. This result clarified that harvesting was carelessly done as much as larger trees were found on the ground. Felling intensity under the medium and long FC of B and C types was relatively as not high as that of A- type. However, it is necessary to trace the situation of growing stocks of teak stands after harvest.

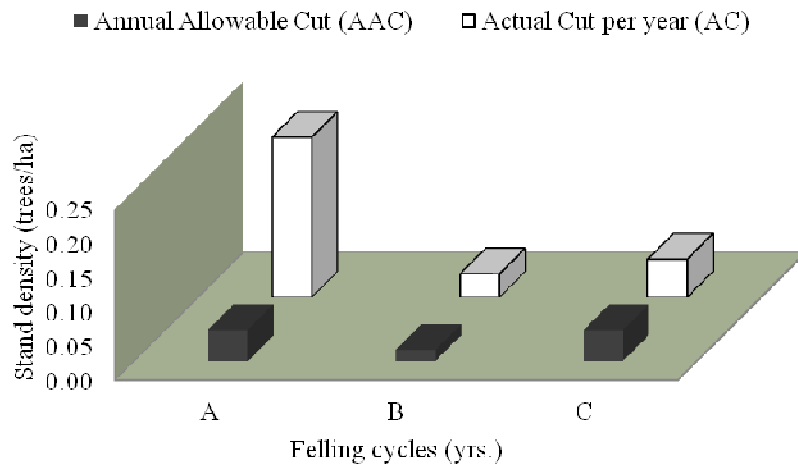


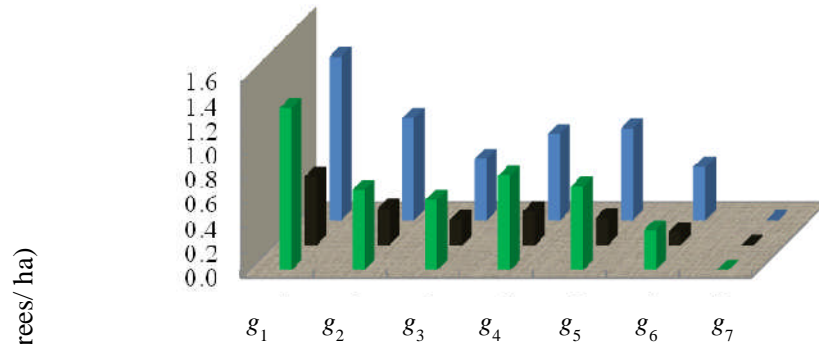
Figure 3.2 Comparisons between calculated AAC and actual cut per year over three types of felling cycles (FC)

Note: A: $FC \leq 10$ yrs.
 B: $11 \leq FC \leq 20$ yrs.
 C: $21 \leq FC \leq 30$ yrs.

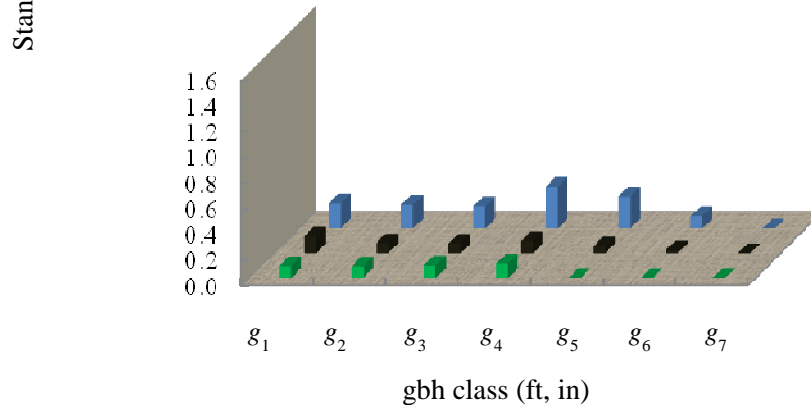
Accordingly, the actual trend of forest conditions after conducting first and second harvest was checked. Figure 3.3 shows the conditions of growing stocks of

teak after harvest in which only left trees were distributed over short, medium and long cutting periods. The growing stock of teak at time series of t_4 was dramatically decreasing in all of girth classes of teak stands, though there was sufficient number of trees left on the ground at t_2 . In those stands falling under A-type of FC, no doubt that the loss of mature trees were due to over-exploitation as shown in figure 3.1. However, the decreasing trend found in stands under C-type was probably due to human disturbance and natural disasters during the long interval for next cutting. As expected before, girth limit for harvestable trees was decreased until g_5 at the time of 2nd harvesting operation (Figure 3.3b).

(a) Measurement Time Series of t_2 (After 1st Harvest)



(b) Measurement Time Series of t_4 (After 2nd Harvest)



■ A (FC ≤ 10yrs) ■ B (11 ≤ FC ≤ 20) ■ C (21 ≤ FC ≤ 30yrs)

Figure 3.3 Conditions of growing stock of teak after 1st and b) 2nd harvest

According to MSS, thirty-year was at least required for the restoration of the largest trees already harvested. However, according to the above results, as there might be unexpected disasters over long period, the trees left for the next felling cycle should be checked in at least twice before the next harvesting time and if necessary, the annual yield should be recalculated. If not, according to observed results in disturbance tendency, the existing mature trees which would soon disappear due to illegal logging and/or natural disturbance such as forests fire. In fact, under the MSS, the stands are chosen for felling if it is due for felling cycle of those stands or if there is available for yield trees even though it is not time yet for harvest. According to the results, yield trees are harvested as much as they are found on the ground without considering any limit of AAC. Consequently, there would be shortage of mature teak from the natural teak forests in the near future. The current situation of teak growing stocks after 2nd harvest showed that average 80% of the stands are decreasing compared with those after 1st harvest. These stands would not be assured for providing sufficient yield at the time of next felling cycle. Therefore, it is necessary to introduce an index to define the sustainability of teak stands.

3.3.2 Disturbance Tendency

The results of girth distribution of teak trees over time series are shown in Figure (3.4). Here, trees enumerated before and after first-second harvest were allotted over four time series of t_1 , t_2 , t_3 , and t_4 respectively. First and second harvesting were conducted at t_2 and t_4 . Therefore, the trees enumerated before first and second harvest (i.e. t_1 and t_3) were composed of all teak trees those are supposed to be either cut or left. On the other hands, the trees measured at t_2 and t_4 were considered only remaining trees as exploitable teak trees had already harvested at those times. It was found that: at the time of both first and second harvesting (t_2 and t_4), all of the largest trees were harvested without leaving any seeding trees for the future generation. However, the girth distributions of teak stands during the first harvest were comparatively better than those after the second operation. At the time of second harvesting (t_4), as there was no mature trees enough to be harvested in the forests, significant loss of trees in gbh class g_5

and g_6 occur. It was probably due to decreasing girth limit at the time of second harvest.

According to MSS, the teak stands in each compartment whenever harvesting was conducted once has to wait at least thirty years for the next felling cycle in order to restore the growing stock of teak. However, according to observed data, various time intervals were found after the first harvest operation. In this analysis, those time intervals or felling cycles occurred between t_2 and t_4 and no legal harvest was conducted at t_3 . Under the condition of no harvest and no disturbance, the number of trees at t_3 must be more than those at t_2 . However, according to the results of enumeration data, disturbance occurs at the time series t_3 , especially in the younger stem during the interval between felling cycles. Apparently, about 80% of younger trees between girth class g_1 and g_4 were lost at the time series of t_3 .

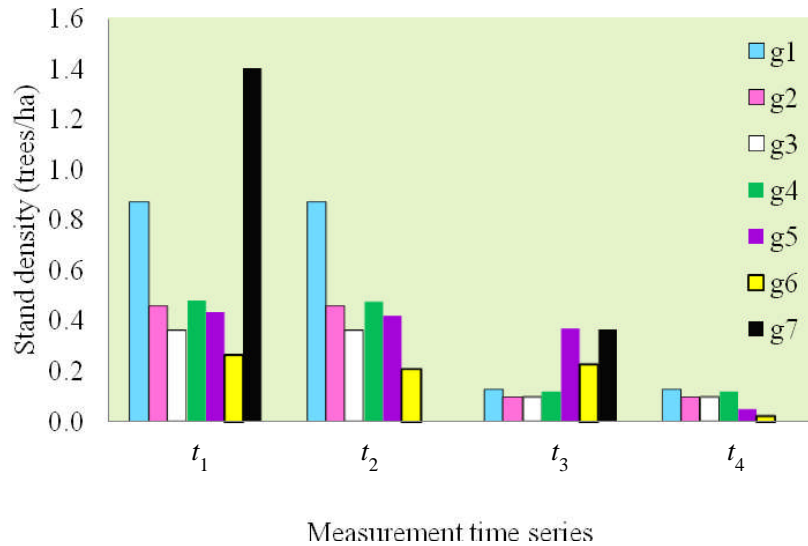


Figure 3.4 Average girth distribution of teak over time series

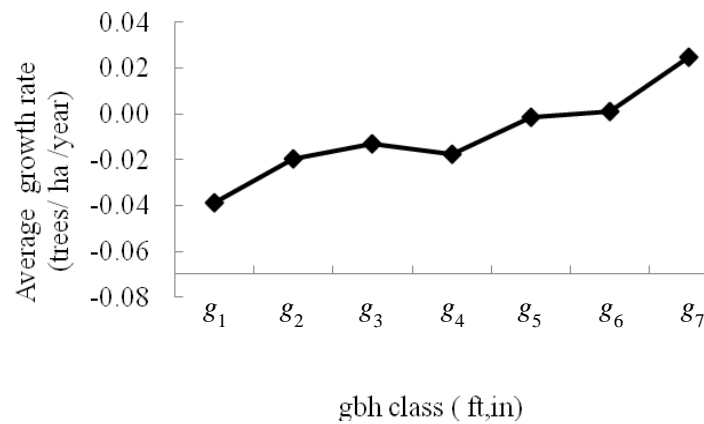
Note: Trees at t_1 and t_3 refer to all the trees cut and left.

Trees at t_2 and t_4 refer to only trees left (remained).

The results of average number of trees increment per hectare per year within the same girth class are demonstrated in figures 3.5a and b. The calculated average growth rates for each class are accumulated through the largest girth class to the next smaller classes to find out in which girth classes are seriously disturbed.

As a result, disturbance was not likely to occur in the mature stands of teak. Obviously, the decrease number of trees increment occurs in the smaller girth classes between class g_1 and g_4 (Figure 3.5b). The loss of younger stands was attributed to illegal logging and fuel wood production by local people as the younger stems are easy to cut and carry with their own cows or buffaloes. It can be concluded that silvicultural operation for younger teak generation is seriously necessary especially maintenance against disturbances likely occurred at the younger stands.

(a)



(b)

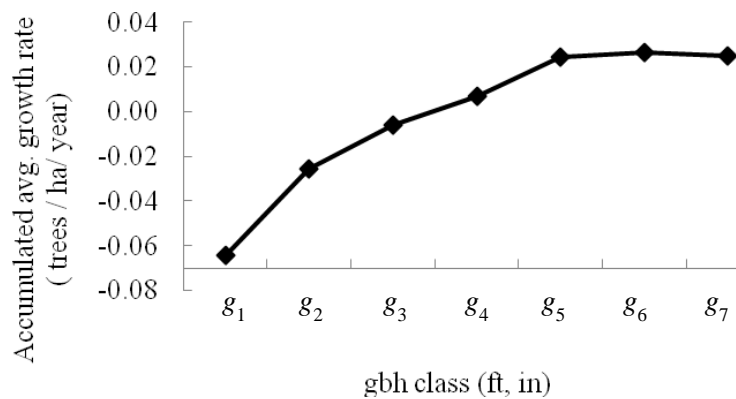


Figure 3.5 a) Average and b) accumulated average growth rate of teak in each girth class

As for conclusion of this chapter, after applying traditional method of yield estimation for future yield, we found that a significant gap between theoretical and practical means of applying under MMS to achieve sustainable basis of teak resources. MMS has once reputation as a sound forest management system to apply in such a complex and multi species natural forests. In fact, there is no way to sustain the forests resources if we continue ignoring the reality of the current forest conditions.

Due to extensive logging in accessible area of forest plots and illegal logging as well, teak quality has been degrading. Consequently, to fulfill the target for teak production, decreasing girth limit and shortening felling cycles are observed in this RF. Most of the mother or mature trees are found to be harvested instead of leaving as seed trees. The planned plots (compartments) are often excluded because of difficult access to the forests.

To keep recognizing the MMS as the most feasible way of managing the natural forests, it is essential to revise the forest management plan regularly as well as to promote forest administrative and inventory. Intensive silvicultural operations, especially in younger teak generation are needed to prevent against loss of trees.

Chapter 4

Developing Alternative Approach for Yield Regulation

4.1 Introduction

Determining the sustainable harvest level from the natural tropical forests is a complex matter and it is difficult to assess the sustainability of a harvest at any point in time (Vanclay, 1996). In the natural forests, after the first harvesting, there would be a major change to species composition and size class that noticeably affect the productive potential of the forests. Zin (2005) stated that sustained yield can only be obtained from a forest with a steady flow of yield and increment and it is hard to install such kind of forest, especially in the natural forests.

In Brandis yield model, a minimum girth limit for harvestable trees was set and only the annual recruitment to harvestable trees were supposed to be cut as the sustained yield. The yield limit was dependent only on the two major girth classes of teak and a stand for harvest was chosen whenever felling cycle was due. However, there is no index to determine whether that stand should be conducted for harvesting operation. According to preliminary analysis on timber productivity, harvesting was intensively carried out without caring the productive capacity of forest stand in long term. By considering those aspects lack in existing model, this chapter aimed to introduce the new model by assuming the utility of maturities as a yield regulation index in the sustainable management of natural teak in stand levels.

Maturity is simply derived from the number of trees in all girth classes. The concept of the maturity is to check whether the trees in each girth class moved to next higher class over years and if moved, the maturity was considered increased. Here, the sustained yield of the stands does not need to regulate equal amount of production. As long as we found the maturity increase across the girth

classes, that stand would be stable and decided to cut. The flow chart for this section is as follows.

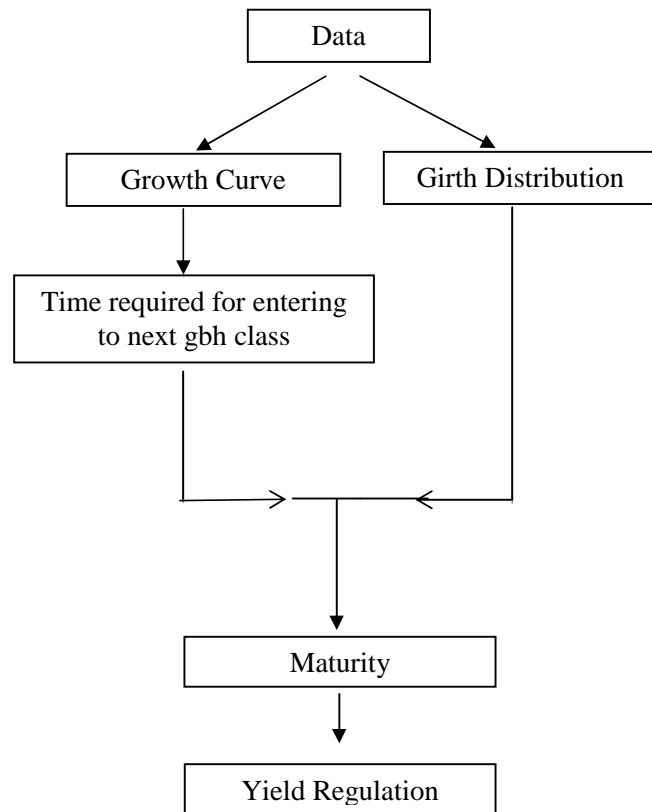


Figure 4.1 Flow chart of construction for a new model

4.2 Material and Method

By using the enumeration data of sixty-four compartments from the Pyu Kun RF, the total girth distributions after and before first-second harvesting were calculated. The seven girth classes were applied for this section (Table 3.1a).

The maturity of a stand was calculated based on the study of (Shiraishi et al., 2006). In this study, the maturity was simply defined as the number of trees in each girth class (i) by years and the formula was as follows.

$$M = \sum_{i=1}^7 N_i Y_i \quad (4.1)$$

Where,

M is the maturity of the target stand

N_i is the number of trees in girth class i per ha.

Y_i is the required year for growing up to girth class i .

i is girth class of $g_1, g_2, g_3, g_4, g_5, g_6$, and g_7

The required years for growing up to lower limit of next girth classes was calculated by the following formula deformed from Mitscherlich equation.

$$Y_i = -\frac{1}{k} \ln \frac{G_i M^{-1} - 1}{-L} \quad (4.2)$$

Where,

M, L and k are parameters

G_i is the lower girth limit in each girth class i .

In the above formula, parameters were estimated (Table 4.1) by applying to the yield table showing the girth of teak (Japan International Forestry Promotion and Cooperation Center, 1996) and then the calculated age requirement for each girth class was shown in Table 4.2. By substituting these estimated ages in the maturity formula (4.1), maturities of stands were calculated at any time series of harvesting at t_1, t_2, t_3 and t_4 .

Table 4.1 Estimated parameters of Mitscherlich equation

M	L	k
206.294	0.971	0.018

Table 4.2 Estimated ages for lower limit of each girth class

Girth Class (i)	Unit		The required year for each gbh class(yrs.)
	ft. & in		
	Lower Limit	Upper Limit	
	$\leq g_i <$		
g_1	4'00"	5'00"	31
g_2	5'00"	5' 06"	45
g_3	5' 06"	6' 00"	53
g_4	6' 00"	6' 06"	64
g_5	6' 06"	7' 00"	77
g_6	7' 00"	7' 06"	95
g_7	7' 06"	+	125

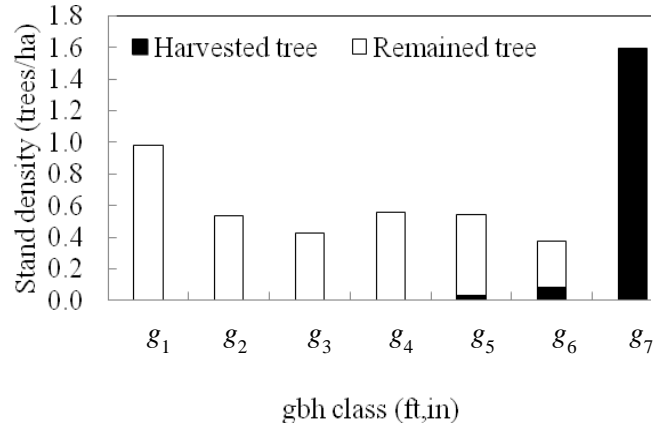
The maturities were then calculated in average girth (gbh) distribution for the whole study site of Pyu Kun RF in Pyu Township. Specified stands (compartments) were also chosen to demonstrate the impacts of harvesting and disturbances through the utility of maturities as an index in sustainable management of stands level. In addition, the impact of disturbances over short, medium and long felling cycles was evaluated in three groups of compartments by applying maturity index.

4.3 Results and Discussion

Figure 4.2a and b shows calculated teak average gbh distributions of first and second harvesting in Pyu Kun Reserved Forest. The first and second harvested trees were distributed in higher girth classes from g_5 and above. The total number of remained trees after first harvesting was observed to have decreased by approximately 50%. According the data sources, no legal harvesting

was conducted between measurement time t_2 and t_3 . Therefore, the difference of maturity between measurement time t_2 and t_3 was derived from illegal logging. This result suggested that the tremendous illegal loggings were conducted after the first harvesting.

(a)



(b)

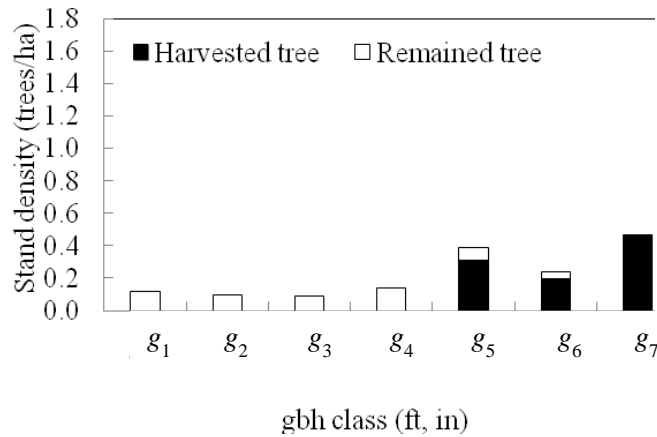


Figure 4.2 Total girth distribution of teak at (a) 1st and (b) 2nd harvest derived from enumeration data of Pyu Kun RF

The calculated maturities of M_1 , M_2 , M_3 and M_4 based on the girth distribution were shown in Figure 4.3. The maturity significantly decreased at t_2 and t_4 was due to legal harvesting operation. However, the maturity was found decreasing during felling cycle between t_2 and t_3 . Therefore, this result suggested

that the maturities were decreased by not only legal but also illegal logging. Further, the use of maturity indices clearly showed the unsustainability of the target teak forest.

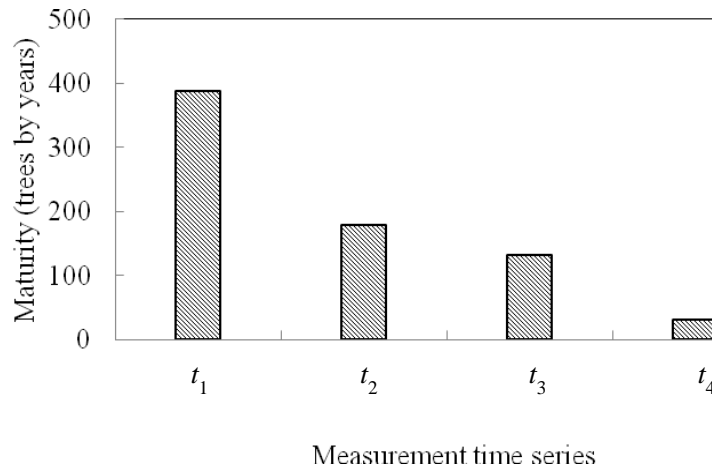


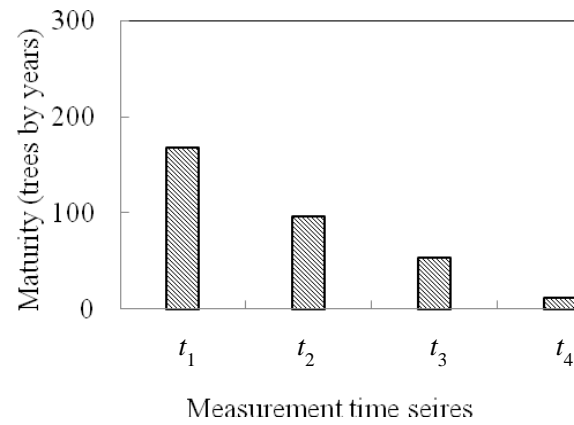
Figure 4.3 Maturity of teak stands in Pyu Kun RF

Note: t_1 , t_2 , t_3 , and t_4 on X-axis refer to measurement time series before first harvesting, just after first harvesting, before second harvesting and just after second harvesting, respectively.

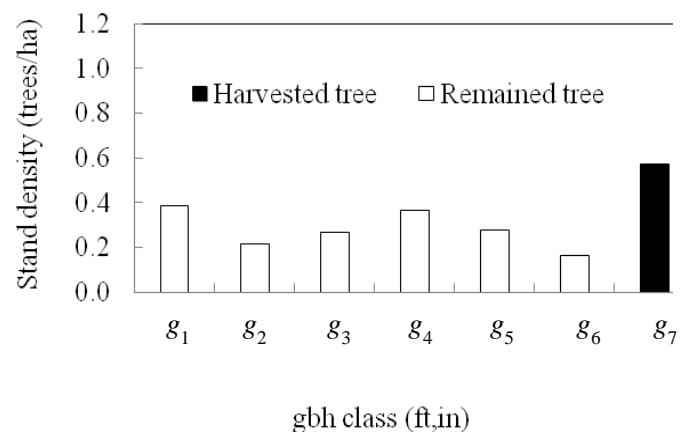
Although these results were calculated by all compartments, the following figures 4.4, 4.5 and 4.6 show three examples of maturities and girth distributions in specific teak stands. Further, we also estimated maturities of all compartments over three felling cycle of short, medium and long.

In figure 4.4a, maturity was simply decreased. As mentioned above, the illegal logging under the small gbh classes has strong negative effect on the maturity in this stand (Figure 4.4b and c).

(a)



(b)



(c)

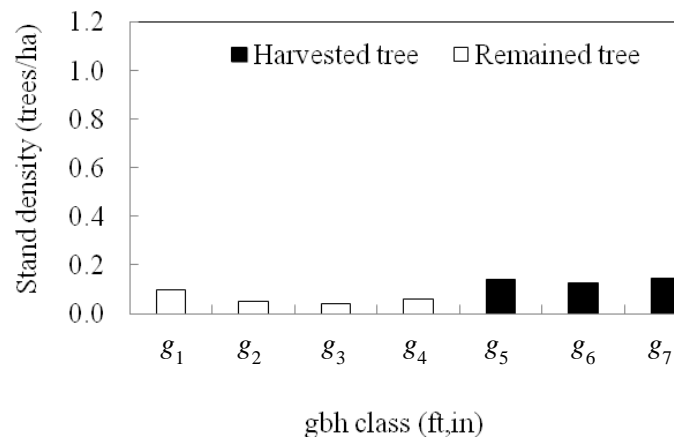
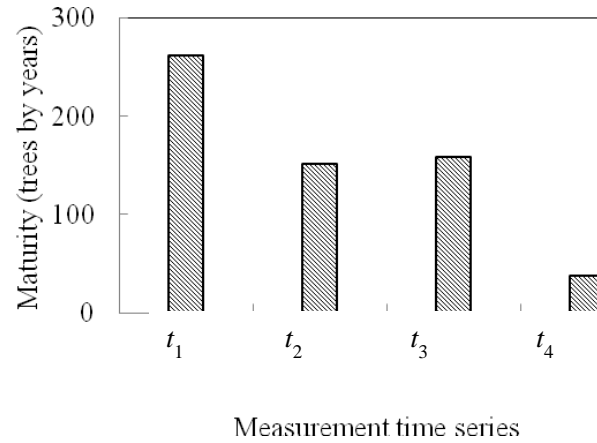


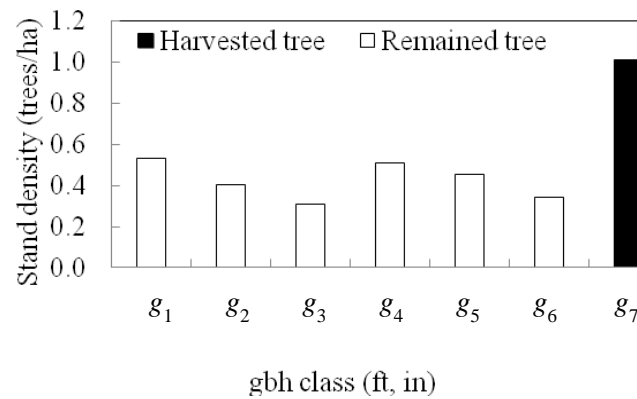
Figure 4.4 First example of (a) the maturities, and girth distribution of (b) 1st and (c) 2nd harvest in specific teak stand (Compartment 27)

As compared with figure 4.4, the difference of maturity between measurement times of t_2 and t_3 in figure 4.5 is relatively small. However, after the second harvesting, the maturity M_4 was dramatically decreased (Figure 4.5a). This result suggested that this second harvesting in figure 4.5a should not be conducted in terms of maintaining maturity of this stands. Instead, it would be better to apply longer felling cycle to get substantial amount of maturity in that stand.

(a)



(b)



(c)

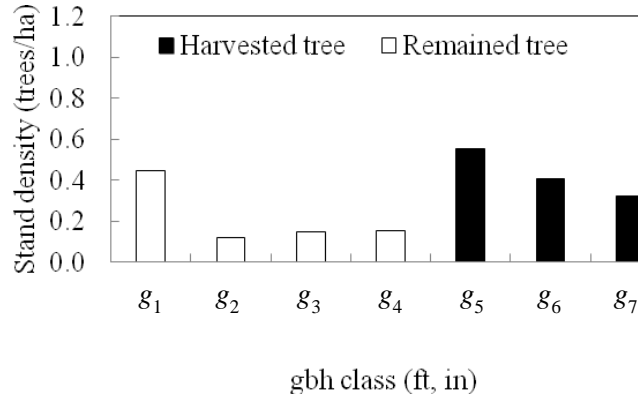
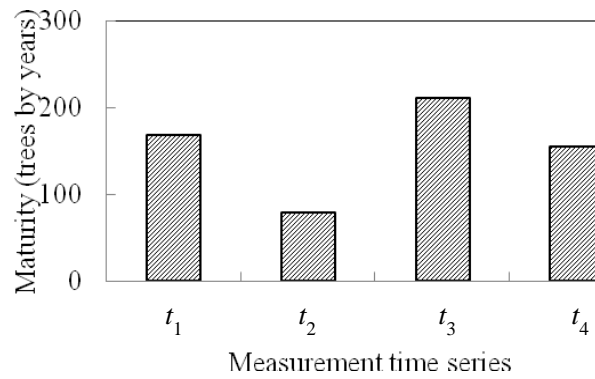


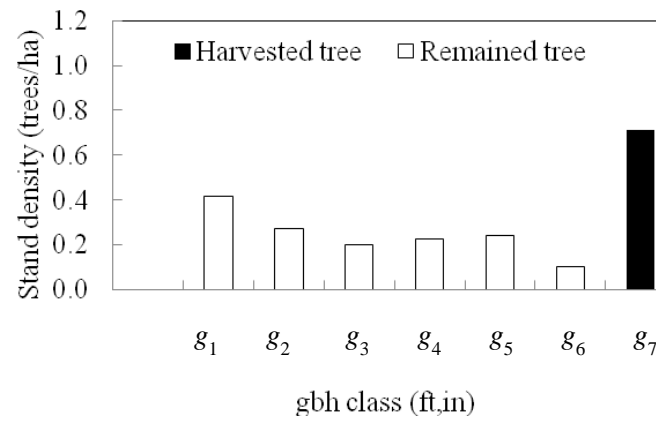
Figure 4.5 Second example of (a) the maturities and girth distribution (b) 1st and (c) 2nd harvest in specific teak stand (Compartment 70)

In figure 4.6a, the maturity (M_3) in measurement time of t_3 was recovered before second harvesting. These maturities of measurement times, t_3 and t_4 are higher than those of t_1 and t_2 , respectively. Therefore, it can be concluded that the sustainability of this teak stands would be relatively higher compared to other two previous examples (Figure 4.4 and 4.5).

(a)



(b)



(c)

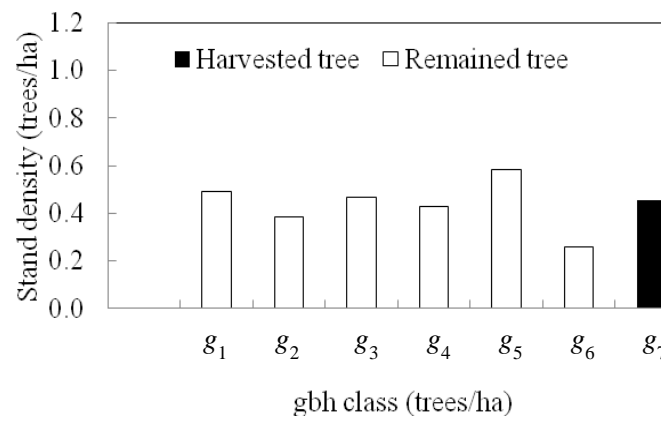


Figure 4.6 Third example of (a) the maturities and girth distribution of (b) 1st and (c) 2nd harvest in specific teak stand (Compartment 8)

We also estimated the maturities over three felling cycle in this study site as shown in figures 4.7a, b and c.

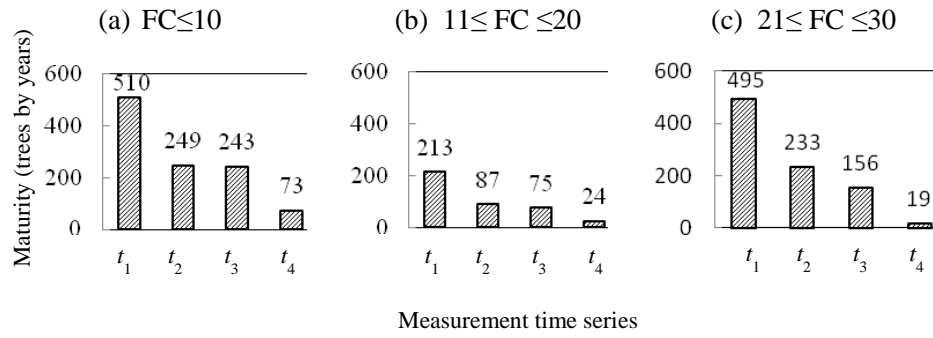


Figure 4.7 Maturities of compartments under three felling cycles in Pyu Kun RF

The results show that the maturity indices under the longest felling cycle (Figure 4.7c) were apparently decreasing compared with figures 4.7a and b. Therefore, this result stated that tendency of disturbance was likely to occur in those compartments with long felling cycle. Through the utility of maturity, about 70%, 68% and 87% of the total trees with the girth of 4 feet and above at the measurement time, t_3 are found harvested in the compartments over short, medium and long felling cycles respectively. It implied that harvesting operation was conducted as much as mature trees are found on the ground without considering for the future supply of teak trees.

Chapter 5

Discussion and Conclusion

5.1 Discussion

5.1.1 Current Conditions of Natural Teak Forests

The natural teak forests in Myanmar were found seriously affected by disturbances, especially in smaller stemmed trees. As transportation of harvestable trees are carried out by elephants that could only own by government, the loss of these trees was suggested mainly due to illegal logging by relatively poor local people for their daily need such as firewood, charcoal making and housing. Even though the MSS is only the feasible system to apply in the complex natural forests and believed it as the sustainable management, it was observed that the current harvesting activities led the system in the unsustainable condition.

5.1.2 Inapplicability of Current Yield Model

The un-sustainable way of teak production from the natural forests in Myanmar is the main driving force to evaluate the currently applied Brandis yield model for AAC. There are two issues to point out inapplicability of current yield estimation model. The first issue is the theory itself. In the concept of existing yield model, the largest trees above minimum girth limit are selected to be harvested from the stands whenever the felling cycle is in due for those stands. Allowable cut was mainly dependent on two largest classes which led the shortage of mature trees on long term. To apply Brandis's method, there must be sufficient amount of larger trees on the ground. It was also stated that Brandis Yield Regulation model is limited to apply the forests with the sufficient amount of mature teaks in the original working stock (Osmaston, 1984). However, gbh distribution of teak in the current natural forests was found very scattered. Moreover, even though the model was claimed as ensuring sustained yield (i.e.,

non-declining even flow of timber), it was just simply taking out the recruitment from C_{II} to C_I over the felling cycle of thirty-year.

Second is operational issue of applying Brandi's method under the MSS. Under the system of MSS, it was believed that the future consistent supply of teak would be ensured by following AAC. However, Chapter (3) of this study addressed that no forest stands had been harvested within the boundary of AAC. In the process of forest management, there are generally two main departments to undertake forestry activities. For harvesting operation, Forest Department, FD is responsible for setting AAC according to Brandis Yield Model while Myanma Timber Enterprise, MTE is responsible for harvesting in accordance with instruction by FD. In practice, harvesting has been carried out by determining its own cutting cycle and harvesting volume, and deciding plot which is more accessible. In fact, this yield regulation model was developed over centuries for the sustainable teak productivity of the virgin natural forests which were almost untouched by disturbances. At the time of the first felling cycle of teak stands, it was found that girth distribution of teak in most of teak stands was reverse J-shape which is typical for the normal forest of uneven-aged. Those forests still provided enough mature trees for the second felling cycle. However, during the time interval of next felling cycle, the trees left were seriously loss. As a result, at the time of second felling cycle, as the mature trees between minimum girth limit became scare, prescription of girth limit was decreased and consequently, there was not possible to leave some mature trees as seed-bearers for the next generation. For the coming third felling cycle of those forests, more than thirty years of felling cycle must be applied to recover those deforested teak-forests. By considering those findings in chapter (3), the current AAC is no longer applicable in the forests with the scarcity of mature teak.

5.1.3 Merits of New Approach (Maturity Index)

To resolve the drawbacks of existing yield model, the new approach was developed by considering the utility of maturities as an index to assess the impacts of harvesting and disturbances occurred in natural teak forests. The maturity is simply defined as the number of trees multiplied by years required for growing up to each girth class. As teak trees are growing very scattered together with other

hardwood species in the natural forests, taking consideration of number of trees instead of volume would be the best way to apply in the maturity index. This simplicity is one of the facts that makes applicable with the current forest management system in which enumeration data is readily carried out from every stand to be chosen for harvest.

Through the number of trees and estimated age in each girth class, we could easily assess the maturity of a stand at any time series of t_1 , t_2 , t_3 and t_4 . Therefore, we can estimate the increment of maturity during felling cycle between t_2 and t_3 . However, there might be any disturbance included in this maturity increment between M_2 and M_3 and this maturity increment may be composed of not only recruitment of trees above girth 4 feet but also recruitment of those below 4 feet. Assuming disturbance to be negligible, it would be possible to predict the future maturity of stand. Therefore, we could adjust the length of felling cycle to control the maturity index of the stand.

Unlike the Brandis's method which was only focus on increment between two largest class trees, the new model assumed all of increment through each girth class. The concept of the maturity is to check whether the trees in each girth class moved to next higher class over years and if moved, the maturity was considered increase. As long as we found the maturity of a stand increase across the girth classes, that stand could be consider stable and harvesting operation could be conducted in that stand. This decision factor of possibility of harvest for next felling cycle through maturity index is another merit that has ignored in Brandis's method in which forest stand was chosen whenever felling cycle is due.

Through maturity index, we could simply control the desirable amount of mother trees to be left on the ground. In this study, 125 of maturity referred to one largest tree with girth class of g_7 . Through the value of maturity, harvesting amount also could be estimated if the stand is in good condition. However, while the maturity is a simple score, it has lost the vector information of number of trees in each girth class. While Brandis' method was applicable only for the forests with the excess amount of mature trees, the new one would be feasible to apply in the current situation of natural forests which has been facing the problems of degradation and overexploitation of timber in Myanmar.

5.2 Conclusion and Recommendations

This study revealed that MSS is too perfect to apply in practice as both representative departments are lack of monitoring the conditions of forests before harvest, during harvest and after harvest. According to MSS, AAC for selected stand was estimated before 30 years ago and some trees might die or be stolen during the lag time. The girth distribution of teak found at the time of before second harvesting proved unsatisfactory action of silvicultural management for tending of natural teak bearing forests. Therefore, maintenance against disturbances is seriously needed. Periodic monitoring and security of remaining trees on the ground should do twice, especially longer felling cycle is needed to apply. During harvest, it was revealed that harvesting has been carried out independently of AAC setting. Therefore, even if we proposed some new ideas or models for maintaining current forest condition under the sustainable way, it would be in-vain if there are weaknesses in the operational issues.

The study revealed that the current harvesting activities were unsustainable as almost all of the largest trees were found cut. It was demonstrated by using the enumeration data of selected reserved forest. Even in natural dense forests where teak occurs scattered in mixtures with other hardwood species, teak was found with the amount of 7 or 12 trees per hectare. According to current enumeration data of study site, only one tree to three per hectare occurs in most of compartments. In that situation, exciting model for the estimation of future yield of teak was not applicable and that was demonstrated through comparative analysis on actual and prescribed cut.

This study also addressed that disturbance tendency strongly affected on the younger stands of teak, which could be suggested that disturbance was derived from illegal loggings and damage at the time of felling selected trees.

In conclusion, this study would provide the alert for the long-standing practice of yield estimation model and lack of silvicultural operations of MSS, and finally proposed a reliable yield regulation model for the sustainable productivity of teak as an alternative to existing one. The study demonstrated the potential use of maturity as a yield regulation index for the sustainable management of natural teak forests. While Brandis' yield model was applicable only for the forests with

the excess amount of mature trees, the author proposed that the new one would be feasible to apply in the current situation of natural teak forests which has been facing the problems of degradation and over-exploitation of timber. Although this study was mainly focus on teak trees in natural forests, the model would be applicable in other hardwood species as long as we could make research on growth rate of other species because the list of trees for those species was readily handy in the process of enumeration.

Further study may enhance the proposed method if there was data available on growth rate and number of trees of teak in all girth classes because this study was carried out by using enumeration data which had information about only the number of trees above 4 feet in girth. The actual growth rate for all girth classes in natural teak forests may improve the accuracy of applying maturity index. It is recommended that research forests should be installed in the accessible areas of natural forests for the availability and accuracy of data set to study teak as well as other hardwood species.

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Annexes

Annex 1. Historical Review of Myanmar Forest Management

Timelines	Year	Activities
Pre-colonial Period (1752—1884)	1752---	<ul style="list-style-type: none"> ✓ Declared Teak as Royal Property by Myanmar King ✓ Formulated a complex regulatory system to max. revenue and control
	1824	<ul style="list-style-type: none"> ✓ Extracted Teak through Girdling Method
	1829----	<ul style="list-style-type: none"> ✓ Ended Teak Monopoly System after 1st Anglo-Myanmar War
	1852	<ul style="list-style-type: none"> ✓ Depletion of Taninthayi`s Teak Forests due to private firms
	1856----	<ul style="list-style-type: none"> ✓ Declared Teak as State Property by the British Government. ✓ Initiated scientific forest management by Dr. Dietrich Brandis ✓ Established Burmese Forest Department ✓ Prepared the first forest management plan(working plan)
Colonial Period (1885—1947)	1885----	<ul style="list-style-type: none"> ✓ Declared all of Myanmar Forests as State Property ✓ Created reserved forests in accordance with the Burma Forest Act(1881)
	1890—	<ul style="list-style-type: none"> ✓ Formulated working plans
	1931	<ul style="list-style-type: none"> ✓ Opened private enterprises in the lower part of Myanmar
	1907	<ul style="list-style-type: none"> ✓ Modified Brandis Selection System into Myanmar Selection System-MSS
	1920 1923---	<ul style="list-style-type: none"> ✓ Established Ministry of Forestry, Controlled the timber extraction by private
Independence To Date (1948--Present)	1948----	<ul style="list-style-type: none"> ✓ Established the State Timber Board(STB) ✓ Timber Cooperation(TC) as the sole government agency (Nowadays called Myanmar Timber Enterprise-MTE)
	1997	<ul style="list-style-type: none"> ✓ Established the Dry Zone Greening Department
	1980---	<ul style="list-style-type: none"> ✓ Started Green Teak Extraction
	2005---	<ul style="list-style-type: none"> ✓ Stopped the Girdling Method ✓ 62 forest working plans are drawn up

Annex 2. Silvicultural Operations of MSS (Modified Brandis Selection System)

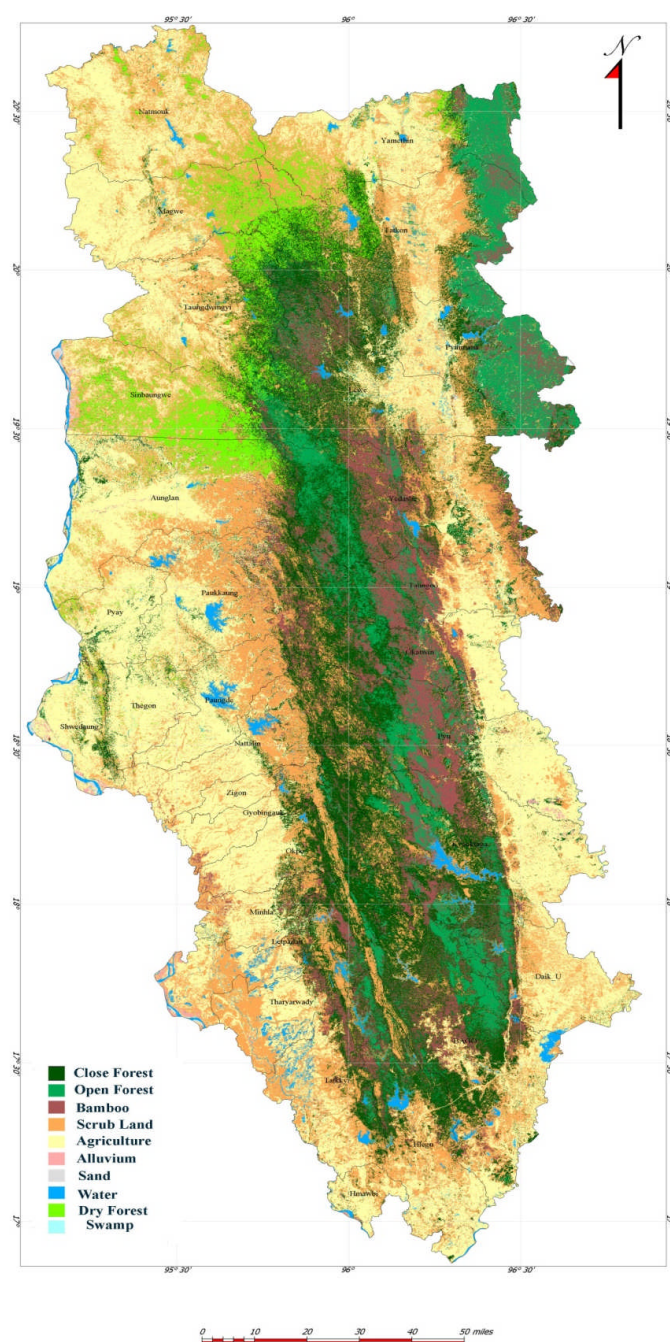
Year	Operations	Activities and Explanation
Y-3	1) Girdling of Teak trees (Dry teak) 2) Enumeration of residual teak trees 3) Improvement Felling (O Felling) 4) Thinning and cleaning	-Girdling ¹ ; a technique of killing marketable trees by cutting through the bark and sapwood and letting those die as standing for 3 years. -Enumeration of all teak trees ≥ 4.5 feet gbh for estimating future yield -Climber cutting -Felling of Ficus-bound teak trees -Removing useless species in favor of Teak within groups of crowded young teak trees -Removal of undesirable mature trees and bamboos overtopping with the main tree
Y-1	1) Selection-Felling Marking of species including teak for green felling (Green Teak) 2) Enumeration of Marketable residual Species	-Commercial trees are marked for extraction according to AAC and prescribed minimum gbh limit -All commercial trees below 10cm of exploitable gbh are enumerated and recorded
Y	Extraction	-Felling of girdled teak and marked commercial species -Removal of inferior trees suppressing teak -Cutting of dead and moribund trees
Y+1	1) Improvement Felling (Y Felling) 2) Line Enrichment and Gap planting	-Improvement felling of seedlings and saplings of undesirable tree species -Opening up of patches for the established advanced growth of teak - Supplement of teak and improve proportion of valuable spp.,
Y+1 to Y+5	Fire Protection	-Weeding and cleaning of undergrowth and controlled burning -Construction of fire lines in dry season

Source: En Route towards Sustainable Development of Myanmar Natural Teak Forests, Nyi Nyi Kyaw (2004)

Note:

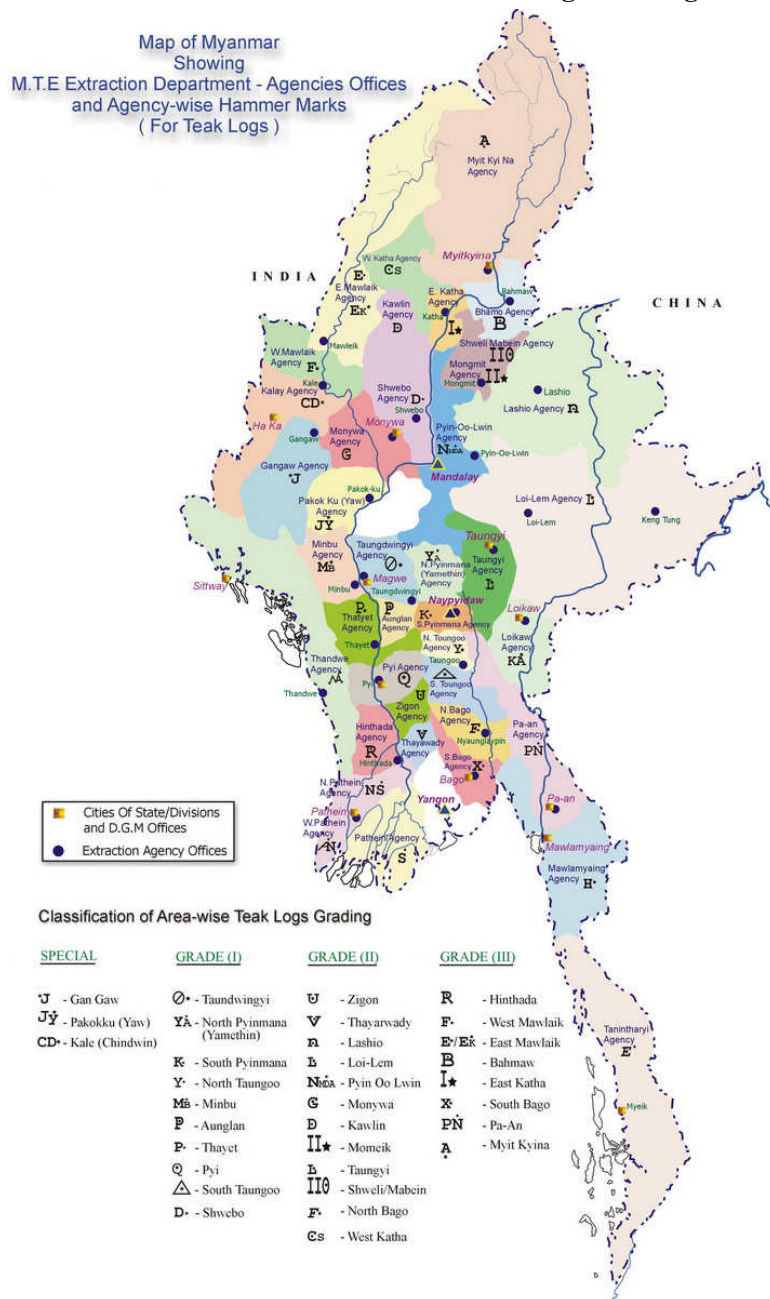
- ✓ *(Y) Stands for the year of timber extraction.*
- ✓ *(Y-1) stands for one year before timber extraction*
- ✓ *(Y-3) stands for three years before timber extraction (in case of girdling operation)*
- ✓ *(Y+1) and (Y+5) stand for one year and five years after timber extraction respectively.*
- ✓ *(gbh) stands for girth at breast height; girth is common unit in Myanmar, instead of diameter.*

Annex 3. Land Cover of Bago Yoma Region



Source: Settlements and Land Records Department, Ministry of Agriculture and Irrigation

Annex 4. Classification of Area-wise Teak Logs Grading

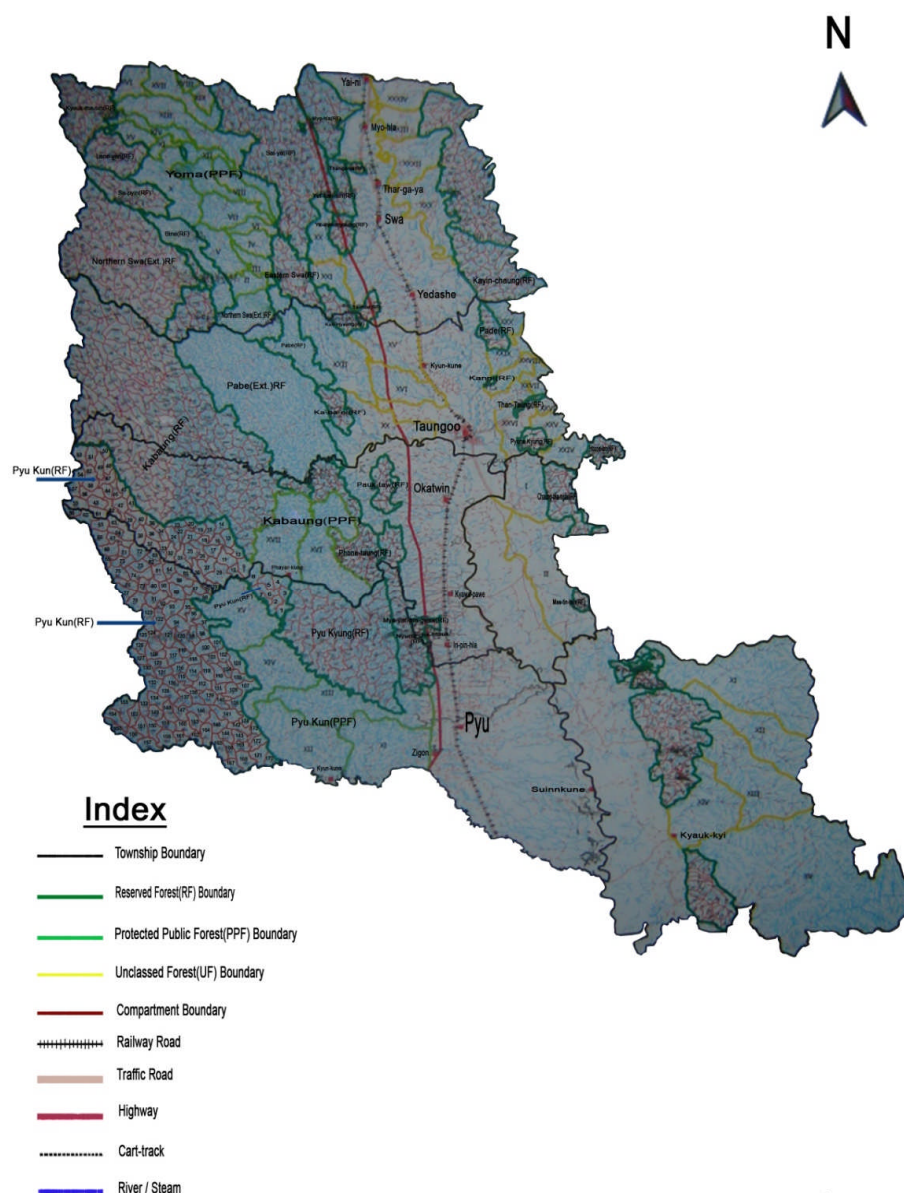


Source: Planning and Statistics Department, Forest Department

Note:

- ✓ Except Shwebo, Grade (I) teak comes from townships under Bago Yoma
- ✓ Region, especially Bago (East) Division.
- ✓ The Study site (Pyu Kun RF) was located in South Taungoo District, Bago (East) Division where Grade (I) teaks produce.

Annex 5. Map showing Boundaries of RF and PPF in Eastern Bago Yoma



Source: Settlements and Land Records Department, Ministry of Agriculture and Irrigation

Annex 6. RF and its Compartments under Taungoo District, Bago (East) Division

Location (Townships)	Name of RF	Name of Compartments	Area (ha)	%of Total Area
Pyu	1. Pyu Kyung	1-59	28542.38	7.68
	2. Myayarpingyaw(Part)	11(part),12-36, 37(part), 38(part), 39-57	8827.38	2.38
	3. Ka-nyunt-kwin	1-13	0.00	0.00
	4. Pyu Kun(Part)	1-8, 29(part), 59,60, 63-174	64397.03	17.33
Okatwin	Pyu Kun(Rest)	9-28, 29(rest), 30-58,61,62 59-59,58-103, 107-112,	23600.57	6.35
	Kabaung(Rest)	189-190,194-218	31042.44	8.35
	5. kabaung(Ext.)	219-221	844.43	0.23
	6. PhoneTaung	1-56	9748.35	2.62
	7. Pauk-taw	1-16	652.46	0.18
	8. NyungChe	23(rest),24(rest), 25-27, 30-32,33(rest)	820.13	0.22
	Myayarpingyaw(Rest)	1-10, 11(rest),12,37(rest), 38(rest)	1598.94	0.43
Taungoo	9. Kun-myaung (Part)	26-30	1261.98	0.34
	10. Samoe (Part)	5(part),6(part)	252.72	0.07
	11. Pade	1-11	2332.40	0.63
	12. Kanni	1	113.40	0.03
	13. Pyone-Kyung	1-8	1507.82	0.41
	14. Htone-bo	1-10	1940.76	0.52
	15. Than-taung(Rest)*	1,2(rest)	349.92	0.09
	16. Pabe(Part)	-	5702.40	1.53
	17. Kabaung(Part)	1-44,49(part),57,106, 113-188,191-193	46353.87	12.48
Yedashe	18. Ka-ba-ni	1-9	2558.39	0.69
	19. Lone-yan	1-12	5584.55	1.50
	20. Sa-pyin	1-18	5154.03	1.39
	21. Nothern Swa(Ext.)	1-107	33915.92	9.13
	22. Sai-ya	3-7,24-97	24781.14	6.67
	23. Myo-hla	1-17	7374.24	1.98
	24. Yet-kan-sin	18-25	2869.43	0.77
	25. Ye-aye-myaung	26-35	2074.01	0.56
	26. Eastren Swa	1-19	5396.63	1.45
	Kun-myaung (Rest)	20-25	1658.07	0.45
	27. Myo-hla	1-7	698.63	0.19
	28. Thar-ga-ya	1-6	443.07	0.12
	29. Swa	6-8	0.00	0.00
	Samoe(Rest)	1-4	1050.98	0.28
	30. Gwe-the	1-70	17753.58	4.78
	31. Kayin-chaung	1-38	10265.94	2.76
	32. Kyauk-ma-sin	11-14,18-41	7182.68	1.93
	33. Bine	-	11599.20	3.12
	Pabe(Rest)	-	1296.00	0.35
Total Areas of 33 RF			371545.79	100.00

Source: Forest Department

Note:

- ✓ *(Part) means forest area in one compartment or one reserved forest extending over another township which may be either under the same division/state or under the different one.*
- ✓ *(Rest) means the rest area of that compartment or that RF. If that compartment /RF extend over another township of the same division/state, its name will be counted only one time.*
- ✓ *(Ext.) means extension of compartments in one compartment.*
- ✓ *Some were cancelled from RF for various reasons.*

Annex 7. Original Set of Enumeration Data of Pyu Kun Reserved Forest

Compartments		Girdled/Marked			Trees girdled/ marked						Total Yield Trees	Trees Left						Total trees left	
Number	Area(ha)	Year	time interval	Area (ha)	4' 00"	5' 00"	6' 00"			7' 00"		4' 00"	5' 00"	5' 06"			6' 06"		≥ 7' 00"
					4' 11" interval of 12"	5' 11"	6' 05"	6' 06"	6' 11" interval of 6"	7' 05"				5' 11"	6' 05"	6' 11"			
1	491.67	1982	14	491.67	0	0	0	0	0	0	298	298	469	185	97	159	197	43	
		1996		491.67	0	0	0	0	1	229	230	30	30	19	65	57	8	1105	
2	476.69	1982	14	476.69	0	0	0	0	0	0	68	68	101	27	15	20	13	14	
		1996		476.69	0	0	0	0	0	234	234	74	72	34	75	64	1	320	
3	377.87	1982	14	377.87	0	0	0	0	0	0	0	0	9	7	7	11	8	13	
		1996		377.87	0	0	1	2	0	61	64	19	14	15	10	22	7	87	
4	543.11	1982	17	425.25	0	0	0	0	0	3	60	63	94	42	11	8	0	155	
		1999		425.25	0	0	0	0	0	87	87	33	13	12	17	24	23	122	
5	444.29	1982	22	444.29	0	0	0	0	0	3	56	59	28	29	17	16	19	5	
		2004		444.29	0	0	0	30	21	23	74	13	2	8	12	0	0	35	
6	558.50	1982	11	558.50	0	0	0	0	1	0	172	173	212	115	81	110	77	46	
		1993		558.50	0	0	0	0	0	101	101	92	22	18	29	19	189		
7	483.98	1982	14	483.98	0	0	0	0	8	0	1142	1150	785	341	120	185	101	12	
		1996		483.98	0	0	0	0	2	309	311	59	53	57	132	83	2	386	
8	646.38	1982	14	646.38	0	0	0	0	0	0	459	459	268	177	130	147	157	64	
		1996		646.38	0	0	0	0	0	295	295	317	248	302	278	378	166	1689	
9	142.56	1982	9	142.56	0	0	0	0	0	0	483	483	468	284	119	209	242	108	
		1991		142.56	0	0	0	0	0	302	302	77	61	61	115	91	24	429	
10	383.13	1976	9	383.13	0	0	1	0	0	131	146	278	576	157	176	183	87	82	
		1976		383.13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11	531.36	1976	26	531.36	0	0	0	0	8	257	251	516	460	189	160	224	202	93	
		2002		531.36	0	0	0	78	83	139	300	4	2	12	26	0	44		
12	523.26	1976	29	523.26	0	8	13	14	442	625	1102	1474	636	732	516	480	335	4173	
		2005		523.26	0	0	0	233	165	173	571	0	2	13	49	0	64		
13	616.41	1976	29	616.41	0	0	0	2	1	417	796	1216	1639	409	412	488	607	436	
		2005		616.41	0	0	0	329	249	193	771	4	15	15	50	0	84		
14	449.15	1977	24	441.05	0	1	3	7	8	930	949	169	126	107	226	236	74		
		2001		344.25	0	0	0	476	221	240	937	121	38	40	113	0	312		
15	585.23	1977	25	585.23	0	0	0	0	0	0	1166	1166	189	152	103	228	198	35	
		2002		455.63	0	0	0	0	298	186	216	700	4	3	20	24	0	51	
16	519.21	1976	26	519.21	0	0	0	0	4	306	494	804	769	377	218	383	304	234	
		2002		445.50	0	0	0	112	79	159	350	46	38	15	11	0	110		
17	500.58	1977	26	500.58	0	0	0	0	0	0	1226	1226	158	251	169	298	205	90	
		2003		500.58	0	0	0	0	499	265	136	900	98	80	37	98	0	313	

Source: District Forest Office (2010)

Note:

- ✓ *Only part of the spread sheet is mentioned.*
- ✓ *Here, the actual names of compartments are neglected and the numbers of compartments are arranged numerically.*
- ✓ *In the original data, areas of compartments are mentioned as acre and converted into hectare for this study.*