Tropical Forest Management Planning

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Contents

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Abstract

The section Introduction on tropical forest management (TFM) provides an insight of the present areas under sustainable forest management where systematic management planning is applied. Furthermore comparative inventory and silviculture data on different tropical forest ecosystems are provided. These are convincing enough to draw conclusions that only details in the local application of forest management planning are different. The subject TFM is dealt in three sections: Multifunctional forest management planning sets the logic how productive areas should be identified and mapped. In the section of yield regulation, the respective approach for Malaysian conditions is explained. It is suggested that the Malaysian yield regulation could be applied, considering the specific differences, in any other tropical high forest of the similar ecotype and structure. Finally a generic forest management plan preparation is presented based on international experience.

Keywords

Forest management planning • Forest function mapping • Forest management zoning, yield regulation • Annual allowable cut • Increment • Management plan preparation

Acronyms and Abbreviations

AAC	Annual allowable cut
AACa	AAC calculated with area control formula
AACd	AAC calculated based on DIPSIM
AACfinal	Finally determined AAC
AACh	AAC calculated with Heyer formula
AACph	AAC calculated with Paulsen-Hundeshagen
AACprel	Preliminary AAC
AACTP1	AAC for TP1 timber production areas
AACTP2	AAC for TP2 timber production areas
AC	Allowable cut (for the whole planning period)
Ca	Annual coupe
Ct	Total coupe for the whole planning period
Ct-prel	Preliminary total coupe for the whole planning period
DFO	District forest officer
DIPSIM	Dipterocarp Forest Growth Simulator Model
fd	Damage factor
fdTP1	Damage factor for TP1 areas (ground-based logging)

fdTP2	Damage factor for TP2 areas (soil-conserving harvesting systems)
fi	Felling intensity factor (accounts for losses at harvesting)
fi1	Felling intensity factor in relation to harvestable volume
fi2	Felling intensity factor in relation to total volume
FMIS	Forest Management Information System
FMPG	Forest Management Planning Guidelines
FMU	Forest management unit
hc	Harvesting cycle
Ic	Mean annual increment at current stocking
It	Mean annual increment at target stocking
m^3	Cubic meters
MIDAP	Management Inventory Data Analysis Program
NPA	Net production area
NPAannual	Annual net production area
NPAharv	Harvestable net production area
NPAtot	Total net production area
NPATP1	Net production area in TP1 timber production zone post-F post felling inventory
NPATP2	Net production area in TP2 timber production zone
tad	Adjustment period
TP1	Timber Production Zone 1 (ground-based skidding systems permitted)
TP2	Timber Production Zone 2 (only soil-conserving harvesting systems permitted)
Vc	Current standing stock of commercial species
Vharv	Harvestable standing stock (above cutting limit)
Vt	Target standing stock of commercial species
Vharvvir	Harvestable standing stock of virgin forest
Vtresh	Maximum harvestable volume = 85 cbm/ha

Introduction

Forest management planning was and is still the core element of forestry engineering sciences. In its simplest way it applies “cut and wait” management, but in a planned way. Forest management employs intelligently biometrics, growth and yield sciences, silviculture, and of course enterprise management. Therefore, the task of this chapter within the Tropical Forestry Handbook is no minor then to outline where and how these elements play together and in what context. Besides, the subjects of multifunctional planning and yield regulation are of special importance for the subject and will be dealt with accordingly. But to tune in into the global context of forest management, we think it is appropriate to start with ITTO’s survey on forest management from 2011.

(ITTO 2012) The estimated size of the natural tropical permanent forest estate (PFE) is 761 million hectares, comprising 403 million hectares of production forest and 358 million hectares of protection forest. Between 2005 and 2010, the area of natural forest under management plans in ITTO producer countries increased by 69 million hectares to 183 million hectares, which is 24 % of the PFE:

– The area of certified forest in ITTO producer countries grew from 10.5 million hectares in 2005 to 17.0 million hectares in 2010. The forest area certified in Africa more than tripled to 4.63 million hectares.
– The area of PFE considered to be under management consistent with sustainability requirements increased from 36.4 million hectares to 53.3 million hectares, comprising 30.6 million hectares of production PFE (compared with 25.2 million hectares in 2005) and 22.7 million hectares of protection PFE (compared with 11.2 million hectares in 2005).
– New international measures to combat trade in illegal timber have been introduced. In many countries there is increased transparency in forest operations, increased participation of stakeholders, and increased interest in forest conservation and SFM at the community level.
– International assistance is required urgently to help ITTO producer countries undertake detailed inventories of their PFEs. This is particularly important given the requirements of REDD+ for reference-level data on forest extent and quality.
– Countries that made notable progress toward SFM during the period include Brazil, Gabon, Guyana, Malaysia, and Peru.

To put the validity of any generalized approach in perspective stand, data from the three tropical continents from IPCC (2003) are listed in Tables 1 and 2.

Forestry management in the tropics is affected by a whole array of factors which have direct implications to their implementation. Any planning has to be aware about this and consider it in its design and development. ITTO (2012) gives a comprehensive overview of these factors and trends which affect directly the management of natural tropical forests since 1990:

– Increased social demands and expectations on forests and environmental and social awareness about tropical forests
– Increased recognition of the role of tropical forests in delivering “global” ecosystem services, including those related to biodiversity, carbon, soils, and water
– Increased recognition of the rights of indigenous peoples and forest communities over forests and forest use and the need to safeguard those rights
– Increased decentralization of control over forests
– Emergence of forest certification as an important driver of SFM
– Increased awareness of illegality and corruption as major impediments of SFM
– Increased role of the informal sector and its lack of visibility in national statistics and development plans
– Increased role of nongovernmental organizations (NGOs) in forest management and forest policy development

Table 1 Aboveground biomass stock in naturally regenerated forest by broad category (tonnes dry matter/ha) IPCC (2003)

Tropical forests						
	Wet	Moist with short dry season	Moist with long dry season	Dry	Montane moist	Montane dry
Africa						
	310 (131–513)	260 (159–433)	123 (120–130)	72 (16–195)	191	40
Asia and Oceania						
Continental	275 (123–683)	182 (10–562)	127 (100–155)	60	222 (81–310)	50
Insular	348 (280–520)	290	160	70	362 (330–505)	50
America						
	347 (118–860)	217 (212–278)	212 (202–406)	78 (45–90)	234 (48–348)	60

The ecological conditions which characterize these main vegetation cover classes are *wet*, evergreen dense forests which receive more than 2,000 mm per year rainfall evenly throughout the year; *moist with short dry season*, deciduous forests, characterized by a short dry season (<4–5 months), and rainfall 1,000–2,000 mm per year; *moist with long dry season*, woodlands and open forests, characterized by a long dry period (>5 months), and rainfall 1,000–2,000 mm per year; *dry*, woodlands and tree savannas which receive less than 1,000 mm per year of rainfall, very seasonally distributed; and *montane moist and dry*, main features of this zone are altitude above 1,000 m and rainfall above and below 1,000 mm per year, respectively

– Loss of silvicultural knowledge and practice and a lack of research, leading to overoptimistic cutting cycles and a lack of silvicultural management
– Increased vulnerability of tropical forests to abiotic and biotic threats attributed to climate change and climate variability
– Development of REDD+ as part of a global climate change agenda, which has raised the visibility of tropical forests to the highest political level
– Increased demand for wood and wood products, even as the international market for tropical timber diminishes
– Increased role of planted forests in meeting demand for wood products
– Increased demand for renewable energy, including forest-based energy

Multifunctional Zoning

Introduction

Multifunctional zoning is a critically important step in defining and locating the net production area for timber production.[1] Besides, it is a major prerequisite for certification along different schemes, e.g., Forest Stewardship Council (FSC). The multifunctional zoning could be applied either in one step resulting from forest

[1]Adapted from Haase and Schindele 2005a

Table 2 Average annual increment in aboveground biomass in natural regeneration by broad categories (tonnes dry matter/ha/year) IPCC (2003)

Age class	Wet	Moist with short dry season	Moist with long dry season	Dry	Montane moist	Montane dry
	R > 2,000	2,000 > R > 1,000		R < 1,000	R > 1,000	R < 10,00
Africa						
≤20 years	10.0	5.3	2.4 (2.3–2.5)	1.2 (0.8–1.5)	5.0	2.0 (1.0–3.0)
>20 years	3.1 (2.3–3.8)	1.3	1.8 (0.6–3.0)	0.9 (0.2–1.6)	1.0	1.5 (0.5–4.5)
Asia and Oceania						
Continental						
≤20 years	7.0 (3.0–11.0)	9.0	6.0	5.0	5.0	1.0
>20 years	2.2. (1.3–3.0)	2.0	1.5	1.3 (1.0–2.2)	1.0	0.5
Insular						
≤20 years	13.0	11.0	7.0	2.0	12.0	3.0
>20 years	3.4	3.0	2.0	1.0	3.0	1.0
America						
≤20 years	10.0	7.0	4.0	4.0	5.0	1.8
>20 years	1.9 (1.2–2.6)	2.0	1.0	1.0	1.4 (1.0–2.0)	0.4

R, annual rainfall in mm/year

function mapping for the whole management unit, which is a general practice, e.g., in China, Vietnam, and Colombia, or it could be developed in a two-step approach where in a first step all functions are identified for the whole planning unit which depend on legal or topographical features and in a second step functions are identified which require field investigation. The second step is linked with harvesting planning on compartment level. The latter is observed in the tropics in concession systems such as Malaysia and Indonesia but also in Central Africa. The term utilized for this subject varies between countries. For example, in Central Africa the terms macro- and micro-zoning are utilized which correspond to forest function mapping and management zoning.

Definitions:

– *Multifunctional zoning* is the entire process comprising both function mapping and forest zoning.
– *Forest function mapping* is a process to classify forest areas according to defined functions based on spatial, topographical, floral, and faunal information.

However, only those functions need to be mapped which require restrictions in forest management activities.

– *Forest management zoning* is the classification of an area into productive, restrictive, and protective zones based on previously determined forest functions.

Forest Function Mapping

Forest function mapping can serve to identify the various forest functions in relation particularly to wood production. Some functions are easily identifiable such as the topographical features, while others require extensive surveying (e.g., wildlife habitats, rare ecosystems). Some functions can be protected if the areas are large enough (e.g., water catchment), while others can be protected by small patches (e.g., cultural sites). Functions can depend on variable factors, such as societal needs, and on invariable factors such as topography. Some functions cannot be mapped (medicinal plants or others). Forest function mapping is a process to classify forest areas according to defined functions based on spatial, topographical, floral, and faunal information. However, only those functions need to be mapped, which restrict forest management activities. Specific management restrictions are defined for each function, and the silvicultural system to be applied depends on the level of these restrictions.

Forest functions are generally defined in national legislations and commonly include the following three main clusters: productive functions, conservation functions, and socioeconomic functions (Table 3). Each one includes a number of subfunctions, which are distinguished by the purpose of the function and/or its degree of management restrictions. For the identification and mapping of forest functions, the following working steps and relevant information for each step are required: analysis of existing forest management plans (if available); satellite image interpretation (tree species composition and forest condition, stand- and/or forest-type boundaries); analysis of existing maps, e.g., geological, soil, vegetation maps; GIS analysis of topography (slope classification, cultural sites, riparian buffers and catchment areas, roads and infrastructure, settlements, national border), biodiversity surveys (wildlife, endangered species, flora, and fauna), and socioeconomic surveys (social functions, use of forestry products in local markets, sources for local water supply); and review of contacts with relevant institutions.

Apart from these forest functions, additional forest functions could be considered and identified during forest management planning. Whenever a given forest area has to fulfill protective or conservation functions, any planned management operations have to be geared toward the maintenance or even enhancement of these functions. In most cases this will restrict or even exclude timber production in these areas. In the following the process for identification of forest functions and zones is described. Forest functions may overlap or exclude each other. In general all forest functions of strictly protective nature are not compatible with timber production,

Table 3 Main forest functions relevant to tropical forest management (Inspired by Schindele and Eberherr 2013)

Forest functions		
Main functions	Subfunctions	Specific functional targets
Productive functions		Production of NTFP
		Wood production
		Wood production (restricted)
Conservation function	Soil conservation	Soil protection
		Coastal protection
	Water conservation	Riparian buffer protection
		Water recharge area protection
	Nature conservation	Wildlife habitat conservation
		Biodiversity conservation
		Endangered species ecotype protection
		Connectivity protection
	Protection sites against natural hazards	
Socioeconomic functions		Cultural sites protection
		Recreational area protection
		Traditional medicine plant area protection
Others		National border protection
		Infrastructure protection
		Research site protection

while they are fully compatible with each other. Functions of restrictive nature are partly compatible with timber production. If functions overlap, the more restrictive management prescriptions should be applied.

Forest function maps are updated annually with incoming information from short-term planning. For each compartment due for harvesting, it is recommended to prepare a forest function map during the course of preharvest assessment.

Forest Management Zoning

Once the forest functions are identified, they are grouped according to their compatibility with timber production. Two groups of functions are distinguished: (1) functions that preclude logging and (2) functions that allow logging but with some restriction on silvicultural and harvesting technology. This process is called forest zoning, and the result is presented in the forest zoning map:

Step 1: For the forest management planning, forest functions are identified as described under section "Forest Function Mapping." This process provides an estimate of the net production area and a preliminary forest function map.

Step 2: Verification and identification of forest management zones and corrections of the forest function mapping could be still added during field surveys. This step is carried out for those compartments that are selected for harvesting during the process of preharvest planning. This step identifies the actual net production area and defines management prescriptions in line with the designated zones. Step 2 also completes multifunctional zoning for a given forest area.

The forest zoning map should be updated every 10 years during the course of medium-term management planning.

Multifunctional Zoning

Multifunctional zoning is an essential prerequisite and tool for sustainable multiple-use forest management planning. It aims to analyze and delimitate ecological, environmental, social, and other functions for all the forest areas managed by a forest management unit (FMU) with a view of balancing the existing different objectives of wood production, nature conservation, and socioeconomic needs. Once the wood production areas have been identified, the net wood production area can be calculated, which is pivotal to sustainable yield regulation.

When the forest functions are identified, they are grouped into four different forest management zones based on the level of restrictions they impose on commercial wood production. All those areas, which do not fall under a specific function, belong to management zone WP "Wood Production." Individual functions may overlap, but forest management zones do not (Fig. 1, Table 3). The forest function map and the forest management zones should be agreed among all the stakeholders concerned including the communities within the FMU. It should receive official approval in order to become legally binding for the planning period. The preparation of a multifunctional zoning report has to provide the justification for the identification of the various functions, i.e., the process of identification, the methods applied, the stakeholders involved, and the sources of information used. Two maps should be resulting from the GIS analysis: a forest function map and a forest management zone map. Therefore, the objectives of multifunctional zoning are as follows:

– Identify and delineate the various functions (productive, conservation, socio-economic) of a given forest area.
– Balance the maintenance and enhancement of these functions with the objective of *sustainable timber production* by defining management prescriptions for the identified zones.
– Establish a reliable estimate of the net production area.

As mentioned above under forest management zoning, the different forest functions are grouped into four zones according to the need for restrictions on the harvesting system (see also Fig. 1):

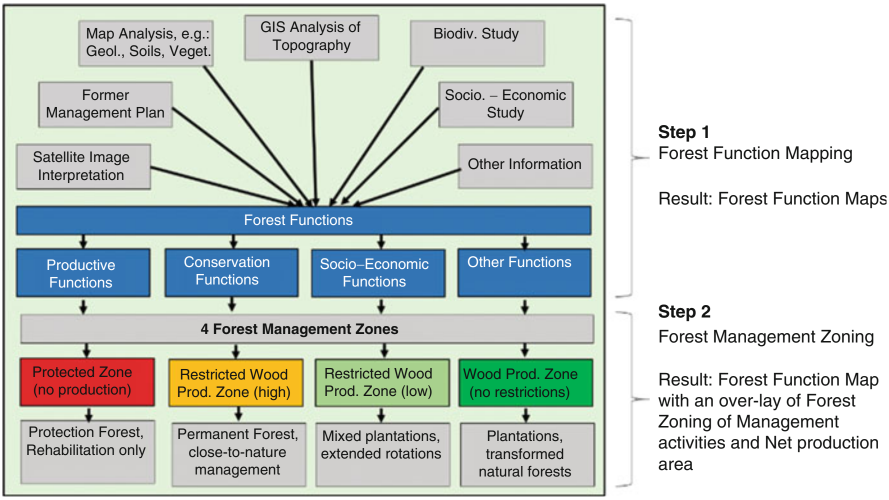

Fig. 1 Process of multifunctional zoning (Adapted from Schindele and Eberherr 2013)

PF: Production forest, no restriction (industrial plantations, transformed natural forests).

RTP1: Restricted (low) timber production, mixed plantations with extended rotation.

RTP2: Restricted (high) timber production (permanent forest, close to nature forest management only).

P: Protection zone. These areas have significant environmental or social values. The maintenance or enhancement of these functions is the major management objective of these areas. It is not compatible with timber production, and harvesting is therefore not permitted in this zone.

Map Preparation

The first step toward the generation of forest function maps is the preparation of a *base map* at a scale of 1:50,000. The map should include the following information:

– Forest reserves (FR) classified for sustainable timber production
– Compartment boundaries
– Urbanizations, settlements
– Rivers and other water bodies
– Infrastructure: permanent roads, railway lines, permanent log landings
– 20 m contour lines (or 10 m)
– Slope classes

To arrive at the *forest function map* and thereafter at the *forest management zoning map*, the following information layers are added to the base map:

– Forest functions and non-forest area. The resulting forest function map indicates already the net production areas and is used, as mentioned above, for forestry management planning.
– Forest zones and non-forest area. The forest management zoning map contains an overlay of management zones in the prepared forest function map.

All functions are shown on one map layer, using the standard legend of the base map. The map should contain statistics in tabular form indicating the area of each individual function. At the end of the mapping process, a report should be prepared with the following content: area statistics and net production area.

Example of Map Preparation

In the following the procedures of the forest function mapping and forest management zoning are described using the example generated for Honduras and developed by GIZ (Jimenez 2015): Municipality of Guata within the Department of Hualancho. The starting prerequisites included:

– A wall to wall coverage with RapidEye high-resolution (5 m) satellite images from 2012
– ARC-GIS 10.1 GIS software

The initial information layers to start the mapping procedures included:

– Infrastructure: road networks of different categories
– Urbanized areas
– Waterways and water recharge areas
– Elevations (m.a.s.l.)
– Slope inclination categories (1–15 %, 15–30 %, 30–60 %, >60 %)
– Forest types: broad-leaved tropical forest, tropical dry forest, tropical pine forest (dense, overutilized) (Figs. 2 and 3, Table 4)

Yield Regulation with Special Reference to Malaysia

Introduction

The hereafter presented yield regulations have been tested for Malaysian conditions.[2] Nevertheless we are convinced that the procedures have general validity for forest formations all over the tropics, provided that specific inputs are developed for

[2] Adapted from Haase and Schindele 2005b

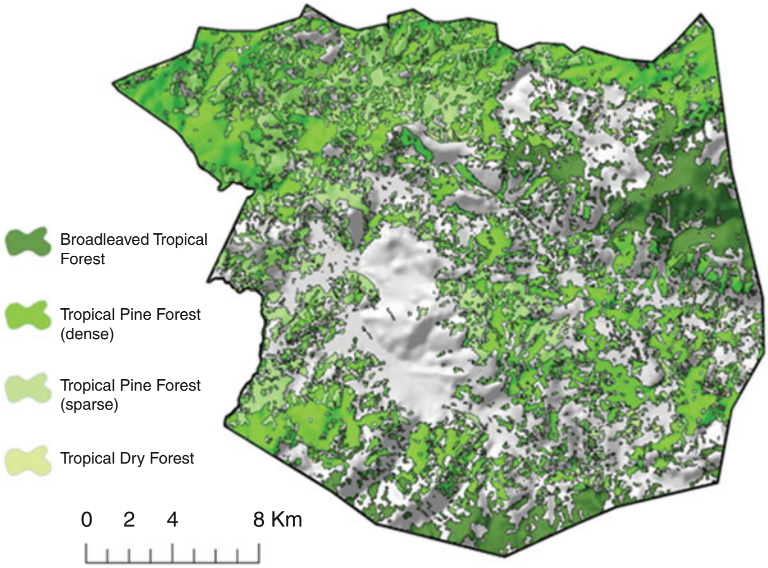

Fig. 2 Forest type map (map prepared by Jimenez 2015). First, the forest areas have been separated from non-forest areas, and four forest classes have been identified: broad-leaved tropical forests 2,973 ha (15 % of total forest area), tropical dry forest 544 ha (3 % of total forest area), tropical pine forest (dense) 9,759 ha (51 % of total forest area), and tropical pine forest (sparse) 5,929 ha (31 % of total forest area). The total forest area is 19,204 ha

the subjects of standing volumes, increment, and damage figures on concrete research results.

The objective of yield regulation is to calculate the amount of timber that may be harvested annually, or periodically, from a specified forest area over a stated period of time in accordance with the principle of sustained yield and other management objectives. It includes the calculation and its formal written expression of the *annual allowable cut* (*AAC*) and its allocation to the localities to be harvested.

The determination of the AAC is one of the most important tasks of forest management planning. It provides a basis for deriving to a log harvest which is in balance with forest increment, thus ensuring the continuous supply of timber in perpetuity.

The AAC is calculated for the entire forest management unit (FMU). The total allowable cut (AC) for the planning period is calculated as AAC × 10 years. It forms the upper ceiling for harvesting, and it should by no means be exceeded; it may, however, be underutilized. The actual annual cut may vary from year to year within the planning period depending on the forest condition of the harvested areas or on management considerations (e.g., demand of wood processing industry).

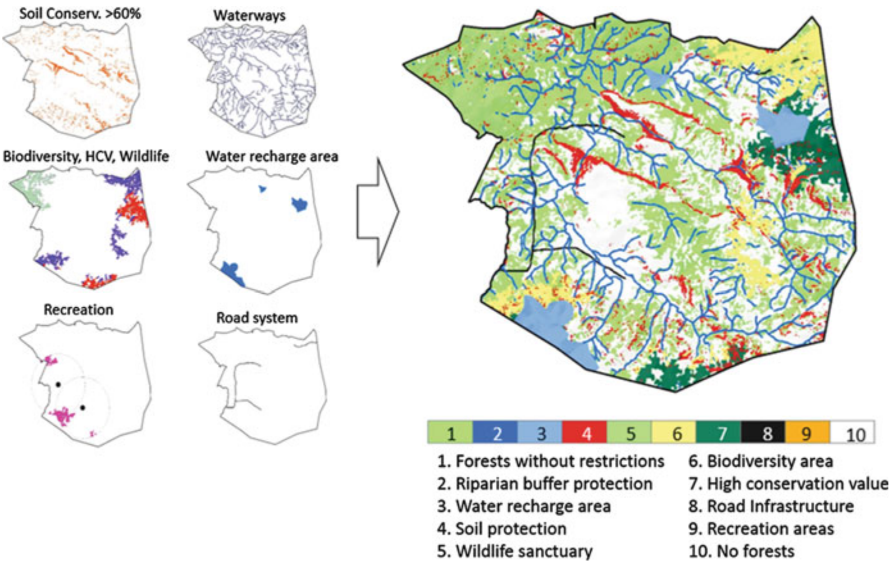

Fig. 3 Forest function mapping (map prepared by Jimenez 2015). In a first step the areas with complete protection are mapped: This includes soil conservation areas, riparian buffer protection areas, and roads (50 m protection area on each side); thereafter areas of timber production with high restrictions are mapped (high conservation value areas, wildlife sanctuaries); finally timber production areas with low restrictions are mapped (in this example this refers to biodiversity and recreation areas). The result is a map where forest functions are clearly identified

Definition of Terms

Yield in this context is defined as the standing volume of commercial timber.[3] This is the clear bole standing volume of commercial species in m3 above the cutting limit.

Yield determination: The calculation, by volume or by area (or a combination of both), of the amount of forest produce that may be harvested annually, or periodically, from a specific area of forest over a stated period, in accordance with the objects of management.

Yield planning: The allocation over time of land units within a productive forest for harvesting in a manner calculated to yield sustainable amounts of logs and other products, while ensuring the maintenance and regeneration of the forest's productive capacity which may be required to support that production.

Sustainable yield means the continuous production of commercial timber with the aim of achieving an approximate balance between net growth of the forest and the harvest.

[3]From SAF (1971)

Table 4 Example of forest management zoning data based on map above

PF	**Production forest**	**10,327 ha**
	Broad-leaved tropical forest	618 ha
	Tropical dry forest	382 ha
	Tropical pine forest (dense)	4,568 ha
	Tropical pine forest (sparse)	4,759 ha
RTP1	**Restricted (low) timber production**	**3,801 ha**
	Broad-leaved tropical forest	252 ha
	Tropical dry forest	17 ha
	Tropical pine forest (dense)	3,342 ha
	Tropical pine forest (sparse)	191 ha
RTP2	**Restricted (high) timber production**	**2,098 ha**
	Broad-leaved tropical forest	1,730 ha
	Tropical fry forest	3 ha
	Tropical pine forest (dense)	284 ha
	Tropical pine forest (sparse)	80 ha
P	**Protection forest**	**2,979 ha**
	Broad-leaved tropical forest	373 ha
	Tropical fry forest	142 ha
	Tropical pine forest (dense)	1,564 ha
	Tropical pine forest (sparse)	899 ha
Total forest area		19,204

The *allowable cut* (AC) is the commercial timber volume that may be extracted from a forest management unit (FMU) or defined parts thereof during the 10-year planning period.

The *annual allowable cut* (AAC) is the AC expressed on an annual basis.

The total *coupe* (C) or *cutting area* is the area of production forest that may be cut during the 10-year planning period. Both terms are used synonymously. The annual coupe (Ca) is the average forest area that may be harvested during 1 year.

Felling cycle: 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. The term is synonymous with cutting cycle.

Rotation: The planned number of years between the establishment of a crop (by planting or regeneration) and final felling. The term is applied where forest is managed under a monocyclic silvicultural system.

The Process of Yield Regulation

Working Circles

Yield regulation is generally carried out for different major natural forest types. Yield is regulated separately for each of the identified working circles. The total

AAC of a FMU is the sum of the AACs of all working circles which occur in a given FMU.

Data Requirements

Yield regulation has to be based on up-to-date forest resource information. The following information is required for every working circle:

– *Net production area* (NPA): An estimate for the NPA is obtained from the forest zoning process.
– *Stocking levels*: The combined forest inventory generates information on mean commercial volumes by logging status and type of production zone (RTP1, RTP2, and TP).
– *Increment data* is derived from the analysis of growth and yield plots. Data from the continuous forest inventories will constitute an additional source of incremental data.
– *Target volume*: Commercial volume of stands at which growth is maximal.
– *Correction factors*: The damage factor and the felling intensity factor provide allowances for damage to a residual stand during logging and for trees that cannot be harvested despite meeting some of the formal requirements (commercial species, dbh above minimum diameter threshold).

Steps for Yield Regulation

Yield regulation comprises the following steps in Malaysia:

1. Compilation of required information and data.
2. Calculation of different AAC indicators and formula methods, i.e., Paulsen-Hundeshagen modified, Heyer modified, area control, and AAC determination by growth modeling. Depending on the overall forest condition (predominantly pristine or previously utilized), the AAC calculated by means of the different indicators is weighted. This results in the preliminary AAC.
3. Calculation of the available net production area of harvestable forests (i.e., forest reserves and forests logged over more than 30 years ago). If the harvestable forest area is less than the required coupe (Step 3), the allowable cut needs to be reduced accordingly.
4. Distribution of the allowable cut to the different forest districts and forest concessions within the district, based on the distribution of the harvestable forest area and other criteria.
5. Selection of compartments to be harvested during the planning period for each forest district. The selection is based on the following criteria: years elapsed after logging, distribution of timber production zones, spatial distribution, and accessibility of compartments.
6. Adjustment of AAC according to the different forest zones.
7. Yield regulation ends with the justification of the AAC, i.e., the decision-making process has to be made transparent.

Table 5 Area-related information

Variable		Description
Total net production area	NPAtot	Calculated as total FR area minus area of protection zones minus non-forested area
Total harvestable net production area	^{NPA}harv	Equals the net production area of harvestable forests. A forest is considered as harvestable if it is either pristine or if more than 30 years (in case of Malaysia) have elapsed after the last logging

Yield Regulation for Lowland Tropical Forest

Yield for lowland tropical forest is preferably regulated by volume. For AAC determination a number of different AAC indicators are calculated. AAC indicators to be used are the formulas “modified Paulsen-Hundeshagen,” “modified Heyer,” and “area control” and results obtained from application of different growth simulators such as the Dipterocarp Forest Growth Simulator (DIPSIM).

Collection of Information and Compilation of Data

For AAC calculation a number of different information and data are required which are described in the following.

Area-Related Information

One of the most important factors for *AAC* calculation is the net production area (*NPA*). An estimate for this is a direct output of multifunctional zoning by subtracting the protection zones and non-forested areas from the total forest area. Area-related information should be compiled by a GIS unit and should be directly retrieved from a compartment register (CR), the forest management zoning map, or the forest resources map (Table 5).

Standing Stock

Information on standing stock is directly derived from the results of the combined forest inventory on FMU or concession level as calculated (Malaysia) by the Management Inventory Data Analysis Program (MIDAP). All volume-related data refer to standing clear bole volume in m^3/ha of commercial species (Table 6).

Increment

Background

Procedures to develop and compute data on increment are presented below from Alder (1999) and Armitage (1998), which are helpful to understand the complexity of the subject:

Table 6 Standing-stock-related information

Variable/unit		Description
Current standing stock (m^3/ha)	*Vc*	This is the weighted average standing stock of all commercial species per ha for the dry inland production forest strata as assessed during an inventory
Target standing stock (m^3/ha)	*Vt*	Level of growing stock at which the (current) annual increment culminates. Based on analysis of growth plots and growth and yield plots, this is at about 70 % of the standing stock of an undisturbed pristine forest. Vt can be derived from the results of the respective inventory (Note: Vt refers to *undisturbed pristine* forest
Harvestable standing stock (m^3/ha)	$^{V}harv$	The harvestable standing stock *Vharv* is the average total standing stock of all commercial species per ha above the cutting limit
Harvestable standing stock of virgin forest (m^3/ha)	$^{V}harvvir$	This is the average harvestable standing stock as applied to pristine forest strata
Harvestable standing stock of forest logged >30 years ago (m^3/ha)	$^{V}harv30+$	This is the average harvestable standing stock for a certain dipterocarp forest stratum (logged over more than 30 years ago)
Average harvesting threshold	$^{V}thresh$	The harvesting threshold *Vthresh* is defined as the maximum amount of timber to be extracted per ha. In the case of dipterocarps (Malaysia), it is set at 85 m^3/ha. This threshold has no direct effect on the allowable cut, but on the working area required, to realize it. As this threshold is an upper limit, which cannot be exceeded, the average removable volume will be less

Box 1 Increment According to Alder (1999)

Alder (1999) proposes that the following has to be considered in measuring increment (adapted and shortened). Volume increment of the whole stand can be calculated in at least three ways:

- *Gross periodic annual increment without recruitment* (*GPAI*). This is the volume increment of live standing trees measured over a relatively short period, usually less than 5 years, and averaged to an annual value.
- *Gross periodic increment including recruitment*. This is the volume increment of live standing trees, together with the additional volume of recruit trees entering the lowest measured size class, again measured periodically and averaged to an annual figure.

(continued)

- *Net periodic annual increment* (NPAI) is the total change in volume over a short period including growth and recruitment, and also deducting losses from mortality, averaged as an annual value. The NPAI is the most simply calculated value from direct observation, requiring only a measurement of volume at the start and end of a period (say V_1 and V_2 over T years), giving

$$NPAI = (V_2 - V_1)$$

In natural forests, the spatial and size class distribution of the stock is very variable, especially with regard to the commercial species. Further, the losses that occur during and after harvesting from damage and mortality reduce the residual stock substantially. In classical theory we have

$$Residual\ stock = Growing\ stock - Harvest$$

In natural forest management we have rather

$$Residual\ stock = Growing\ stock - Harvest - felling\ damage$$

Figure 4 illustrates these points for a typical natural forest logging and recovery. Following a logging of some 30 $m^3\ ha^{-1}$ (the yield), the growing stock is actually reduced by 50 $m^3\ ha^{-1}$, from 100 to 50 $m^3\ ha^{-1}$. From this point, in year 4 on the graph, MAI and NPAI can be calculated, as shown by the thin solid and dotted lines. Initially, net growth is slightly negative or static for some 10 years after logging, for two reasons:

– Regeneration, although stimulated by logging, has not yet reached the measurement limit for recruitment.
– Trees damaged or disturbed by logging, especially larger trees, show a higher mortality for a period, declining over about 10 years back to typical levels.

During this period, MAI drops from zero at the time of felling (the base time for calculation) to a negative value (−2 $m^3\ ha^{-1}\ year^{-1}$) and then gradually starts to recover. NPAI is also negative and fluctuates markedly from year to year. As recruitment starts to occur, and the mortality of larger trees declines, then there is a more rapid phase of stand development, with NPAI of the order of 2 $m^3\ ha^{-1}$ over a 10–20-year period. This drops away after some decades as the recruitment diminishes and growth of the trees is inhibited by competition. This is a typical pattern, but many variations are possible, depending on the species mix and their response to logging and the status of advance growth and saplings at the time of logging (Fig. 5).

(continued)

In practical terms, *AAC* should be about 50–70 % of the estimated commercial MAI, depending on observed levels of logging damage. This refers purely to volumes calculated as standing volumes and does not consider an allowance for within tree wastage and degrade. The latter is necessary if AAC is monitored and controlled in terms of extracted volumes and is likely to be an additional 50–70 % reduction factor. Thus, Dawkins' (1964) pan-tropical mean estimate of commercial MAI of 1 m^3 ha^{-1} $year^{-1}$ amounts in practice to pan-tropical AACs of around 0.25–0.5 m^3 ha − $year^{-1}$ measured as logs at the landing or roadside.

Box 2 Mean Annual Increment (MAI)

Armitage (1998) includes in his presentation of increment measurements the different reduction estimates due to damages as follows: Periodic and regular assessment of a forest is the most reliable method for determination of increment. Accurate mapping and CFI are able to provide reliable data on forest resources at the beginning and end of a planning period for which the MAI is to be derived. The total volume of removals (including logging waste losses) are derived from accurate records of volumes cut each year, supplemented with an estimate of waste determined through logging waste studies. In equation form the relationship is

$$MAI = \frac{V(t+n) + Vp - Vt}{n}$$

where

MAI = mean annual increment in m^3/year for a forest management unit during a planning period of not less than 15 years in length

Vt and $V(t+n)$ = total standing forest volume in m^3 determined from CFI at the beginning (Vt) and at the end ($V(t+n)$), respectively, of the planning period

Vp = total wood volume in m^3 harvested during the planning period, including a logging waste estimate for the period

n = length of the planning period, in years

Application

Haase and Schindele (2005b): The increment data used for yield regulation is derived from the analysis of growth and yield plots and from growth plots. The increment is expressed in m^3 commercial volume/ha/year (Table 7).

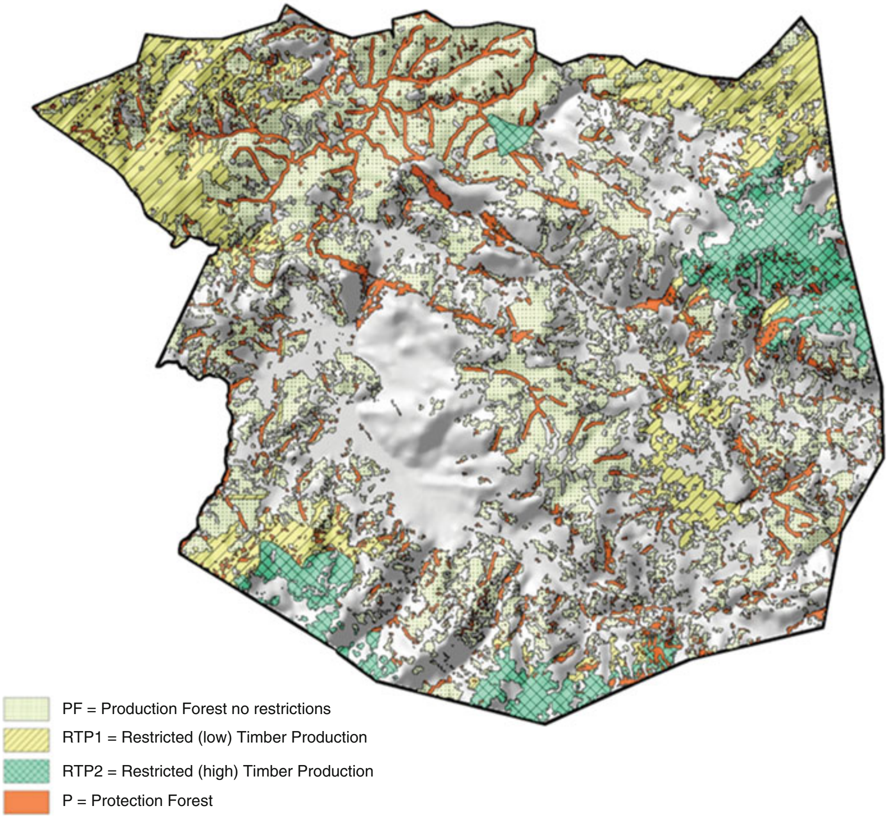

Fig. 4 Forest management zoning map (map prepared by Jimenez 2015). Based on the forest function map (Fig. 3), the forest management zones are overlaid using the three production criteria: low restriction in timber production, high restrictions, and no restrictions in timber production. The resulting zones allow the projection where and to what intensity forest operations could be included into the forest management plan. This procedure allows furthermore to overlay the forest type information with the forest zones which results in a map forest management intensities per forest types. The information so far generated will allow the forest manager to allocate to each forestry production unit (in this case 3 + protection forest) the standing volume per ha and the increment in m3 per ha per year. This is a crucial base for calculation of the allowable cut and the projection of harvesting activities. Further subdivisions of the production area according to specific stand characteristics derived from forest inventories (stand densities, species composition) may contribute to an additionally precision of the data set for management decisions (see Table 4)

Other Factors

Apart from standing stock and increment, some more parameters need to be considered when the allowable cut is calculated. These factors are described in Table 8.

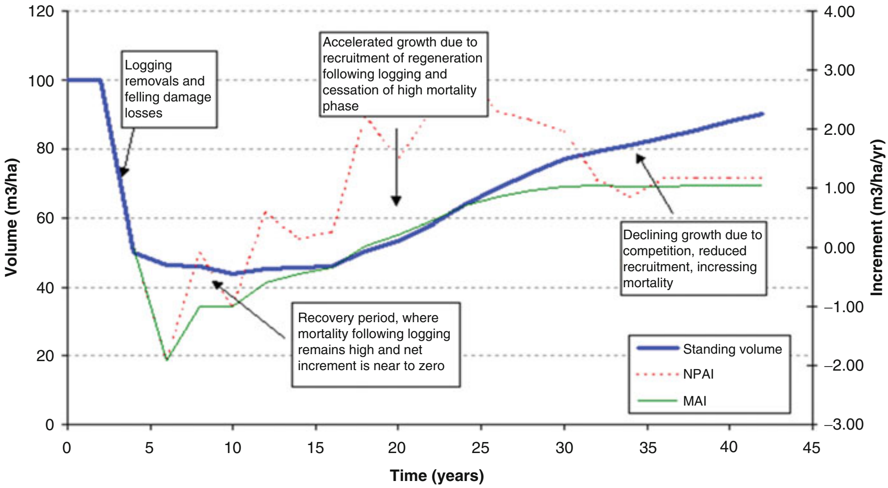

Fig. 5 Volume, current, and mean annual increment in logged natural tropical forest

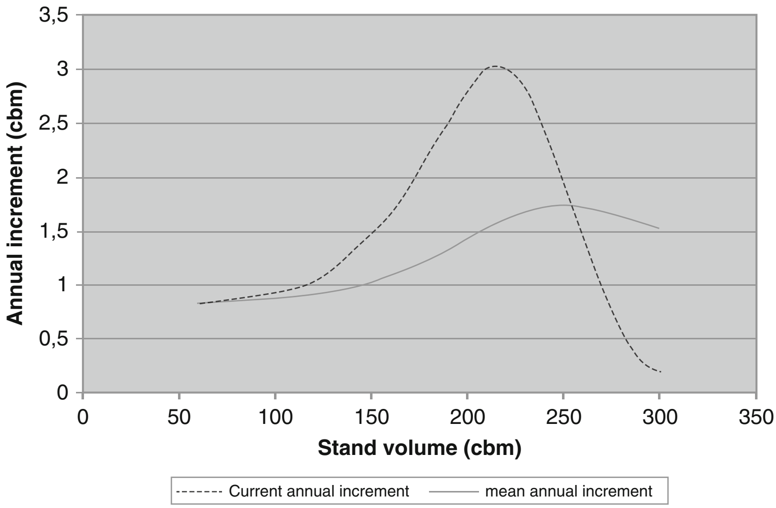

Fig. 6 Mean and current annual increment over stand volume (example)

AAC Calculation

Data Compilation

Before AAC calculation starts all required data shall be compiled by filling the table below. Shaded cells contain standard values for Malaysia (Table 9).

Table 7 Mean annual increment

Variable		Description
Mean annual increment at *target stocking*	It	This is the mean annual increment of commercial species at target standing stock. Based on the analysis of growth plots in Africa, Asia, and Latin America, it ranges between 0.5 and 3.0 (Grulke et al. 2015) m^3/ha. In our example in Peninsular Malaysia, it is estimated to reach for dry inland forest 1.6 m^3/ha/year (see Fig. 5)
Current annual increment at *present stocking*	Ic	This is the annual increment at the average standing stock Vc. It can be derived from the graph in Fig. 6.

Table 8 Other parameters required for yield regulation

Factors		Description
Harvesting cycle	*hc*	Time period after which a logged forest can be harvested again. It is set for tropical lowland forests between 20 and 40 years; in the case of Malaysian lowland forests, it is 35 years. It should be adjusted to reflect the share of MUS-treated forest area
Adjustment period	*tad*	Time span after which the targeted stocking levels should be reached (i.e., Vc = Vt). It depends on many criteria such as the existing stocking levels, the estimated harvesting cycle, the management objectives, the economic situation (timber market), etc. In general, the larger the difference between Vt and Vc, the longer the tad should be
Damage factor	*fd*	The damage factor fd captures the reduction of the residual standing stock and its volume increment due to damage inflicted to the residual stand. This factor depends largely on the harvesting system applied and on the degree of compliance with harvesting standards
	fdtp1	For ground-based skidding this factor is set at 0.75
	fdtp2	For soil-conserving harvesting systems this factor is increased to 0.85, as the damage caused by ground-based skidding is eliminated
Felling intensity factor	*fi1*	The factor *fi* expresses the proportion of the harvestable standing stock, which is actually felled (excludes mother trees, protected trees, and unusable trees). It is set at 0.7 in relation to the harvestable volume *Vharv* (i.e., for AAC formula 3)
	fi2	In relation to the total volume, it should be set at 0.85 (i.e., for AAC formulas 1 and 2)

Calculation of AAC Based on Formula Methods

According to the Forest Management Plan-Rules of Malaysia, the AAC is calculated by applying the following formulas:

Paulsen-Hundeshagen, modified:

$$AAC_{ph} = I_t * \frac{V_c}{V_t} * fd * fi_2 * NPA_{tot}$$

Note: *It* is the *mean annual increment* at a target standing stock.

Table 9 Data compilation for AAC calculation

Variable	Value	Unit
NPAtot		ha
NPAharv		ha
Vc		m^3/ha
Vt		m^3/ha
Vharv		m^3/ha
Vharvvir		m^3/ha
It	1.6	m^3/ha/year
Ic		m^3/ha/year
hc		Years
tad		Years
fd = fdtp1	0.75	
fi1	0.70	
fi2	0.85	

This formula is suitable for all stocking conditions.

1. Heyer, modified:

$$AAC_h = \left(IC + \frac{V_c - V_t}{t_{ad}}\right) * f_i * fi_2 * NPA_{tot}$$

Note: *Ic* is the *annual increment* at a current average standing stock.

This formula is a good *AAC* indicator for logged-over forests. However, for heavily degraded forests this formula is not as suitable (rule of thumb: the actual standing stock *Va* should be at least 170 m^3/ha). The result depends on the selected adjustment period and can, in contrast to the other formulas, be influenced by the management planner. The shorter the adjustment period, the sooner the target standing stock is reached.

In situations where the actual standing stock is below the target standing stock ($Vc < Vt$), it may be helpful to calculate the time required until the forest resource would reach the target standing stock without harvesting. This is done as follows:

$$t_{ad} = \frac{V_t - V_c}{I_c}$$

This should be the starting point for simulation.

2. Area control:

$$AAC_a = V_{harvvir} * f_i 1 * \left(\frac{NPA_{tot}}{h_c}\right)$$

This formula depends largely on the harvesting cycle, which is set at 35 years. The area control formula should only be used for FMUs which have a high proportion of pristine forests and where only virgin forests will be logged within the planning period.

Table 10 Example of suitability matrix for different *AAC* indicators in relation to the proportion of logged forests in Malaysia

AAC calculation method		Proportion of logged forests in %		
		>80 %	10–80 %	<10 %
(1) Paulsen-Hundeshagen	AACph	3	3	2
(2) Heyer modified	AACh	2	3	2
(3) Area control	AACa	0	1	3
(4) DIPSIM	AACd	3	3	3
Total suitability scores		8	10	10

0, not suitable; 1, suitable with restriction; 2, suitable; 3, very suitable
(2) Modified Heyer should not be used for heavily degraded forests

AAC Based on DIPSIM Harvesting Simulation

Dipterocarp Forest Growth Simulation Model (DIPSIM) Version Sarawak is a growth and harvesting simulator, which has been developed for logged-over dipterocarp forests. It is a very good tool for AAC calculation, as it simulates the growth of the forest under different harvesting scenarios. Today a wide set of commercial software for forest management planning are available with application possibilities in a wide range of forest types.

Determination of Preliminary AAC

The *AAC* derived from the different formulas may vary considerably. The suitability of the different formulas depends largely on the ratio of logged-over forest to pristine forest. Table 6 presents a suitability rating of the different *AAC* indicators in relation to the proportion of logged forests (Table 10).

The AAC can be determined as a weighted mean of the different indicators according to Table 6. For example, in case the proportion of logged forests is 35 %, then the AAC could be derived as follows:

$$AAC_{prel} = \frac{3 * AAC_{ph} + 3 * AAC_h + AAC_a + 3 * AAC_d}{10}$$

However, apart from this purely mathematical approach, other criteria should also be taken into account – such as market requirements, processing capacity and demand of the timber industry, and certification-related aspects. Considering these factors, the AAC_{prel} as calculated according to the above formula may be increased or decreased, but only within the range provided by the various individual indicators. For any deviation of more than 10 % from the calculated AAC_{prel}, a detailed justification is necessary.

Verification and Allocation of the AAC

Before the AAC is finally determined, it needs to be verified, whether it can be actually realized, i.e., whether there are enough forest areas, which

Table 11 Harvestable forest area

Forest strata	Net production area NPA	Average harvestable volume Vharv/ha	Total harvestable volume (2) (3) fd fi1
(1)	(2)	(3)	(4)
Pristine forest (good to superior)			
Pristine forest (moderate to poor)			
Logged over (30+ years)			
Total/weighted average			

Explanation: Column (4) of Table 7 provides an estimate of the total harvestable volume. The total harvestable volume has to be compared with the preliminary allowable cut (*ACprel*), which is calculated by multiplying the *AACprel* with ten (10 years planning period). If the total harvestable volume as computed in Table 7 is below the *ACprel*, the latter has to be reduced accordingly. Note: Since the removal threshold in the Malaysian example is set at 85 m^3, it needs to be checked whether the average harvestable volume of a given stratum is in line with this. Due to uneven distribution of harvestable trees, it is expected that the average harvestable volume will be less than 85 m^3. Therefore, a correction factor has to be applied. Until a proper correction factor is calculated from field tests, the factor is set at 0.9. Hence, the average removal of standing volume to be applied in column 3 shall not exceed 77 m^3

are harvestable. If this is not the case, the AAC needs to be adjusted accordingly as described below:

- **Verification of the AAC and allocation to harvestable areas**
  The first step of AAC verification is to identify the area of harvestable forest. A forest is considered as harvestable if it is a pristine forest or a forest that was logged more than 30 years ago. For this purpose the table below needs to be completed. Data can be derived from the forest resources map and the forest inventory (Table 11).
- **Selection of compartments to be harvested**
  The next step is to select the compartments which shall be logged within the planning period. A compartment is considered as harvestable if it comprises of pristine forest or of forests, which have been logged more than 35 years ago. As the planning period is 10 years, all compartments that have been logged more than 30 years ago at the beginning of the planning period are theoretically harvestable.

  To allow management flexibility, the total harvestable area of selected compartments should exceed the area which is required to realize the *AC* by about 30 %. The final decision which compartments will be actually harvested is subject of the road plan. The compartments earmarked for harvesting shall be indicated on the forest management map.

In the sample case from Malaysia, the final *AC* for every district is determined based on the distribution of the timber production zones. So far, the *AC* was calculated based on the damage factor $fdTP1 = 0.75$ for ground-based logging

Table 12 Determination of yield (example)

Yield parameter		TP1 zone	TP2 zone	Total (TP1 + TP2)	Unit
Total allowable cut	AC	500,000	280,000	780,000	m^3
Annual allowable cut	AAC	50,000	28,000	78,000	m^3/year
Total coupe	Ct	6,500	3,200	9,700	ha
Annual coupe	Ca	650	320	970	ha/year

AC = ACfinal as calculated above AAC = ACfinal/10
Ct = forest area required to realize ACfinal
Ca = Ct/10

systems. However, for the *TP2* zone, a different damage factor is applicable due to reduced damage (*fdTP2* = 0.85). Therefore, the following calculation is made to take account of that:

TP1% = share of TP1 zone (e.g., 0.31 if 31 % of the selected compartments belong to the TP1 zone)
TP2% = share of TP2 zone (e.g., 0.69 if 69 % of the selected compartments belong to the TP2 zone)

Note: The area percentage of *TP1* and *TP2* zones for every district can be calculated from Table 9 (rows "Distribution of *NPA* (%)").

$$AC_{TP1} = AC * \%\, TP1$$

$$AC_{TP2} = AC * \%\, TP2 * \frac{f_{dTP2}}{f_{dTP1}}$$

$$AC_{final} = AC_{TP1} + AC_{TP2}$$

The resultant final AC will be inserted in the District Forest Working Plan (DFWP). The AC for the state is then the sum of the ACs for all district and forest concession ACs.

By filling in Table 7, the yield is finally determined for the planning period. Table 12 has to be filled in for both the FMU and the higher hierarchical level.

Scheduling of the AC

The total *AC* forms the upper threshold, which shall, by no means, be exceeded. The scheduling of the coupe area and the *AAC* within the planning period is carried out by using the table format below (Table 13).

AAC Justification

The final *AAC* needs to be briefly explained and justified. If, besides the *AAC* indicators (formulas), other criteria were applied, they have to be clearly pointed out and justified. It also needs to be discussed how the *AAC* will influence the

Table 13 Scenario for realization of the allowable cut (example)

	TP1 zone		TP2 zone		Total (TP1 + TP2)	
Year	Coupe area (ha)	Expected *AAC* (m^3)	Coupe area (ha)	Expected *AAC* (m^3)	Coupe area (ha)	Expected *AAC* (m^3)
1	1,200	92,000			1,200	92,000
2	1,000	77,000	100	9,000	1,100	86,000
3	900	69,000	150	13,000	1,050	82,000
4	750	58,000	200	18,000	950	76,000
5	600	46,000	300	26,000	900	72,000
6	550	42,000	350	31,000	900	73,000
7	500	39,000	400	35,000	900	74,000
8	400	31,000	500	44,000	900	75,000
9	300	23,000	600	52,000	900	75,000
10	300	23,000	600	52,000	900	75,000
Total	6,500	500,000	3,200	280,000	9,700	780,000

This may serve as an example for a situation where it is necessary to gradually downsize the timber processing industry on one hand and to introduce soil-conserving harvesting technology on the other. The figures for the expected AAC are rounded values

overall stocking (i.e., whether the *AAC* is below the *final* mean annual increment or above). In case the working areas are not equally distributed throughout the planning period (refer to scenario above), this must be justified in detail.

Basis for Yield Regulation in Vietnam: An Example (Schindele 2008)

In Vietnam yield regulation starts with the calculation of a sustainable annual allowable cut (*AAC*) based on two different AAC formulas:

1. Vietnamese standard
2. Area control

The result of both calculations will be compared with the estimated annual growth, and if it is below, it will be preliminarily fixed taking into consideration the pro and cons of each formula.

Based on the preliminary *AAC*, the required annual cutting area (*AC*) will be estimated taking into account harvesting thresholds and management zones.

The *AAC* is then validated by comparing it with the total area of the harvestable forests. If it can be realized, then the *AC* will be fixed on the proposed level; if not, it will be adjusted.

Finally the *AAC* will be allocated per year taking into account the current quota, the current production capacity, and the time required to set up the necessary infrastructure such as roads, harvesting equipment, etc.

The *AAC* is expressed in terms of log volume on forest road and excludes broken or damaged logs and unusable trees. It is fixed on the volume, while the annual cutting area *AC* is variable. It is controlled at the log landing. The *AC* may vary from year to year depending on the management zone, the average log volume of harvestable trees above cutting limit, and harvesting thresholds imposed.

Calculation of the Annual Allowable Cut (AAC)

This formula considers only the harvestable areas which comprises of the net production area of the rich and medium forest. The AAC is calculated as follows:

$$AAC\,(1) = Vh\,Z\,R\,Ah\,K$$

where

- *Vh*: **Total log volume of harvestable forest**
  The total log volume *V* of harvestable forest (i.e., rich and medium forests) is 264 m^3/ha. The total volume is corrected with the standard error of 8 % to be on the lower confidence level. Furthermore, trees of log quality "A" and "B," which – according to the inventory results – have a proportion of 84 %, are considered as usable. Thus, the total log volume of harvestable forest after correct shall be

$$Vh = 264\;0,84(1 - 0,08) = 204\text{ cbm/ha}$$

- *Z*: **Growth percent**
  According to government regulation 792/CV-LN-SDR, the growth percent shall range between 1 % and 2 % depending on the forest type. Moreover, the growth percent also depends on specific forest status and type, whereas specific growth percentage for each SFE has not been available. Therefore, the growth rate for Dak To SFE forest is set at 1.7 % which is considered fairly low.
- *R*: **Utilization factor**
  This factor expresses how much of the log volume is actually converted into logs at the log landing. It takes into account unusable logs, broken or damaged logs, cull trees, etc. It is set at 0.8.
- *Ah*: **Net production area of harvestable forests**
  This is the area of rich and medium forests which are located within the timber production zone (TP + RTP). Their net production area is 6,663 ha.
- *K*: **Accessibility coefficient**
  This factor takes into account that not all of the area is accessible or operable. As during forest function mapping all steep slopes and riparian buffers have already been considered, this factor is set at 0.75, which means that only 75 % of the log volume per ha is accessible for harvesting. The annual allowable cut AAC (1) is then calculated as follows:

$$AAC(1) = 204\;0.015\;0.8\;6,663\;0.75 = 12,233\text{ cbm/year}$$

Formula (2): Area Control

This formula considers the total net production area (rich and medium forest) of the natural forests of the SFE as sustainable unit. It is a simple formula which just

Table 14 Log volume above cutting limit (Schindele 2008)

Timber group	Cutting limit (cm)	V log (cbm/ha)
1	50+	0.2
2	50+	0.4
3	45+	0
4	45+	26.6
5	45+	58.2
6	45+	29.2
7	40+	14.7
8	40+	4.5
Total		133.8

This volume is again corrected with the standard error of the harvestable forest stratum which is 10 %. This reduces the harvestable volume to 133.8 0.9 = 120.42 cbm/ha

divides the total exploitable log volume of the natural production forest by a harvesting cycle. It is a good formula for areas with a high proportion of harvestable forests.

$$AAC(2) = (\boldsymbol{A\ K\ V\ R\ fi})/\boldsymbol{Hc}$$

A: **Total net production area of natural forest**

The total net production area of the natural forest is 6,663 ha. This area is corrected with the same accessibility coefficient K of 0.75 as for formula (1).

V: **Average harvestable log volume above the cutting limit**

The cutting limit for different timber tax groups is regulated in Decision 40/2005/QD-BNN. The cutting limits and the harvestable volume above the cutting limit are shown in the table below (Table 14).

As not all of the harvestable volume can be removed, it must be multiplied with the factor $fi(\Phi)$ for the felling intensity.

fi: **Felling intensity**

The factor *fi* expresses the proportion of the harvestable standing stock, which is actually felled. It excludes mother trees, protected trees, bad formed and cull trees, and trees which cannot be felled out of any other reason. It is set at 0.75.

Finally the harvestable log volume has to be corrected with the utilization factor R as applied for formula 1.

hc: **Harvesting circle**

The harvesting circle is conservatively set at 45 years (normally the cutting circle is 35 years in Vietnam).

The annual allowable cut *AAC* (*2*) is then calculated as follows:

$$AAC(2) = (6,663\ 0.80\ 120.42\ 0.75\ 0.75)/45 = 8,024\text{cbm/year}$$

***AAC* indicators**

AAC calculated by two formulas results in different outputs in which Vietnamese formula results in higher output than that of the other area control formula.

Table 15 Estimated annual exploitable log volume increment

Forest status	Annual volume increment	Average log volume	Net production area	Total annual increment	Corrected with utilization factor R	Corrected with accessibility coefficient K	Exploitable annual increment
	%	cbm/ha	Ha	cbm	cbm	cbm	cbm/ha
	−1	−2	−3	(4) = (1) (2) (3)	(5) = (4) 0,8	(6) = (5) 0,75	(7) = (6)/(3)
Rich forest	2.43	270	2,724	17,872	14,298	10,724	3.937
Medium forest	2.71	240	3,936	25,600	20,480	15,360	3.902
Total			6,663	43,472	34,778	26,084	3.915

The preliminary annual exploitation rate of 1.204 m^3/ha is considerably lower than the estimated annual exploitable increment per ha of 3.915 m^3/ha. As such the *AAC* is estimated extremely cautious and is well below the annual increment

To ensure the sustainability, it is decided to use area control for AAC calculation:

$$AAC(2) = (6,663\ 0.80\ 120.42\ 0.75\ 0.75)/45 = 8,024\ \text{m}^3/\text{year}$$

The average log exploitation rate per ha net production area of the natural forest is

$$Exploitation\ rate = 8,024/6,663 = 1,204\text{m}^3/\text{ha}/\text{year}$$

The current increment is calculated based on volume increment percent specified by FIPI for the broad-leaved evergreen eco-zone “central highlands” (Table 15).

Forest Management Software (Köhl 2015)

For Tropical Forests

– **Software for helping forest management – TF suite**, developed by CIRAD: http://ur-bsef.cirad.fr/en/main-projects/software-for-helping-forest-management-tfsuite
The software includes five modules especially developed to help forest managers. Easy to use, these modules were developed by a multidisciplinary team in collaboration with practical experience projects.
Modules:
- Data input: Help for data input and the clearance of forest inventory data
- Analysis: Statistical treatment of forest inventories
- Space: Spatial analysis of inventories and help for cutting of the forest in homogeneous blocks

  - Growth: Prediction of the evolution and recovery of forest resources according to management options
  - Optimization-decision support: Optimization of practical exploitation and the forest industry
- **DIPSIM Sarawak** (**Dipterocarp Forest Growth Simulation Model Version Sarawak**): available for download from the Forest CHM, http://forest-chm.aseansec.org//refop/php/doc/doc_detail.php?id=DOC-000689
- **SILVIA**: **for integrated forest management** by CATIE http://www.ipef.br/publicacoes/stecnica/nr35/cap10.pdf

  Modules: plantation, equations, maps, simulation, inventory, financial

For Other Forests

- **SILVACOM forest management system**: https://www.silvacom.com/software-solutions/forest-management-system

  Modules: harvest planner, silviculture planner, spatial viewer, harvest tracker, SHS manager, maps online, file exchange, spatial data exchange
- **PhoenixPro** from British Columbia: http://www.drsystemsinc.com/software_products.php?SID=1

  Features: harvest planning, silviculture management, roads management, automated map creation, contractor management, customizable, easy to use querying tools, government submissions

  PDA applications cover roads, surveys, activities, and harvest obligations and observations. Optional add-on modules create a customizable system for every size of operation. These modules assist with planning, budgeting, and streamlining data entry and provide a flexible and scalable approach to satisfy current and future business needs.

  PhoenixPro is designed to work seamlessly with MapIT!, a web-based geographic information viewer.
- **UVIO Forest Management and Information System** (mainly for plantation management): http://www.uviocorp.com

  UVIO provides a comprehensive, consistent company-wide view of your forests, the management inputs they require, and the wood flows and cash flows arising.

  Features: improved planning and plantation management, improved productivity and lower costs, consistent implementation and efficiency in resource allocation, improved budgeting and control, superior capture of key data during operations

  Improved data security, quality and corporate governance by compiling, cross-referencing, and managing key data sets from across the company
- **CENGEA forest management**: http://www.cengea.com/industry-solutions/forestry/planner.htm

The software identifies which actions need to happen on which locations. What follows are highly practical activity scheduling, budgeting, and resource allocation. Maps and related spatial data are combined with the plans to provide a thorough perspective on land-based activities and costs. Additional features include:

- Scheduling of harvest activities, including detailed volumetric breakdowns and product analysis
- Management of planned and actual costs which can be rolled up at various levels to provide detailed financial analyses
- Planning of silviculture activities including seedling requirements and chemical application details
- Interaction with growth and yield models, ability to export, import, and store multiple sets of projection data

When your plans are approved for action, the forest management module seamlessly links the plans to the field operations, allowing your company to analyze options, determine priorities, efficiently allocate resources, track progress, and roll the information up to a management level for the entire land base. We provide you with the capability to track, manage, and report on:

- Road construction and maintenance
- Silviculture performance
- Operational cruising, including generation of plot grids
- Harvest tracking, particularly planned vs. actual removals
- Field data, handheld collected and tabulated
- Stand rotation, with splitting and merging of tabular and spatial data
- Compliance and regulatory reporting

Content of a Forest Management Plan

Introduction

The forestry management plan as presented here is a framework plan which describes the forest development policy, defines the management objectives, and regulates yield on a sustainable basis. It includes an analysis of the forest sector relevant to the forestry management unit; furthermore it gives a general orientation of implementation principles of the forest management plans. Guiding principles for the implementation of forest management are listed in Table 16.

To start with, forest management plans have sequences which are common to most of the forest management systems; an overview is given in Table 17.

Table 16 Guiding principles for the implementation of forest management plans (Adapted from ITTO 2012)

1	Conduct preliminary FMU management studies	Carry out preliminary studies in the FMU on socioeconomic, environmental, and biodiversity aspects for the elaboration of the management plan
		Create a GIS database to keep the information from the preliminary studies, which can be used to prepare forest zoning maps
		Based on air photographs or satellite imagery, identify and map different vegetation types of plant formations covering the FMU
2	Conduct a multi-resource forest management inventory	Conduct a multi-resource forest inventory in order to collect statistical data on timber and NTFPs, natural regeneration, fauna, flora, soil, hydrology, human activities, areas with high biodiversity, scientific or historical value, etc.
		Integrate forest resource inventory and forest zoning by forest functions, taking into account traditional rights
		Incorporate wildlife conservation areas in FMU mapping as an integral part of sustainable forest management
		Carry out an analysis of management scenarios in accordance with the national legislation/policies, strategies, and plans based on inventory data
		Develop a clear understanding of values and goals and establish clear long-term and medium-term management objectives taking into account the trade-offs needed
3	Define management objectives for individual resources (timber, NTFPs, biodiversity, environmental services, etc.)	Forest management objectives and the means of achieving them should be defined in a forest management plan or equivalent document
		Involve as far as possible all stakeholders through a participatory process in the definition of management objectives
		In selecting management objectives, consider all potential range of goods and services from the FMU
4	Use a reliable method for regulating and controlling yield to ensure the sustainable production of timber and other forest products and services in the FMU	Determine the minimum cutting diameter per species or species group and the cutting cycle
		Carry out sustainable yield analysis, with spatial allocation of yield based on the variation of the forest mosaic and taking into account multiple-use constraints, buffer zones, species, and minimum cutting diameter limits
		Determine the AAC based on the minimum cutting diameter for each species or species group
		Division of the FMU into blocks or compartments and definition of annual cutting areas and volumes are essential for the practical control of the harvest level
		Close off the block or compartment after harvesting until the next felling cycle
		Maintain records of production levels of wood and non-wood forest products for each block or compartment harvested

(*continued*)

Table 16 (continued)

5	Carry out preharvest inventory	Undertake systematic preharvest inventory of the timber
6	Plan harvest to enable good technical control, minimize costs, and reduce environmental impacts	
7	Put the FMU under a management plan	Write, implement, and keep up-to-date forest management plan appropriate to the scale and intensity of the operations
8	Select the silvicultural systems to be applied	
9	Provide specific prescriptions for silvicultural interventions in the FMU's management plan	
10	Incorporate wildlife concerns into FMPs	
12	Take into account in the FMP the potential for generating income from the ecosystem services provided by the FMU	
13	Develop FMU working plan revised every 5 years to implement the FMP	Write a working plan to address activities during specific periods of 5 years in greater detail than in the management plan, including the specification of silvicultural system to be applied, the road network and other infrastructures, the extraction methods and equipment, fire control, hunting, monitoring and control measures, and description of data management and reporting. Working Plan
14	Plan harvesting to enable good technical control, minimize harvesting costs, and reduce environmental impacts	
15	Include in the working plan guidance for postharvest assessment and measures	
16	Prepare each year an annual operational plans (AOP) scheduling and specifying all activities and resources required	
17	Monitor the implementation of the management plan	

Generic Structure of a Forest Management Plan

According to Armitage (1998) a forest management plan should consist of four major parts, which are:

i. *Basic information*: Basic geographic, ecological, resources, social, industry, and environmental information having direct relevance to issues concerning future forest management. It is helpful to identify the managerial implications of specific features of each feature of basic information that are presented.
ii. *Management goal and specific objectives*: One goal and several specific objectives, preferably not more than five, with the primary objective being related to wood production.

Table 17 The tiered forest management planning system (Armitage 1998)

Management level		Time frame	Key elements of forest management
Strategic issues	National	>10 years	Conservation-driven forest policies
	Subnational	>10 years	Forest sector development plans
Operational issues	Forest management unit	10 years	1. **Management function – planning**
			Integrated forest resources inventory
			Environmental impact assessment
			Forest zoning by forest functions
			Forest protection
			Integration of customary land rights
			Yield regulation
	Compartment	Annual	2. **Management function – implementation**
			Low-impact forest resources management
			Yield allocation according to stand maturity
			3. Management function – control
			Forest resources accounting
			Periodic revision of management plans

iii. *Management proposals*: Prescriptions should be directly related to objectives and include forest protection arrangements, the yield and how it will be controlled, silviculture, monitoring, and reporting arrangements.
iv. *Records of forest history*: Information on all forest operations, recorded in compartment history records and measured annually.

The design of an appropriate forest management plan has to consider framework conditions which vary from country and locality. Nevertheless there are common features which are valid all over the tropics. In the following the major parts and principal contents of a forest management plan are presented.

As the Forest Stewardship Council (FSC) is doubtlessly the most important certification body worldwide, including the tropics, it is necessary that forest managers are aware of the certification requirements which correspond to the principal parts of a forestry management plan. Having this overview at hand will allow the forest practitioner/manager to decide which path to take or whether to invest from the beginning in a certified forest management or not. The FSC certification criteria are not simple planning schemes; moreover they imply the implementation of actions to create conditions for certification (Table 18).

Table 18 Generic structure of a forest management plan for tropical forests with corresponding certification requirements stipulated by FSC

Basic forest management plan (Adapted from Armitage 1998)	FSC certification criteria
Part 1 basic information	
Authority, period of operations, and policies	Principle 1: comply with all laws, regulations, treaties, conventions, and agreements, together with all FSC principles and criteria
Location, area, and legal description of forest lands	1.2: *Organization* (*forest administration*) shall demonstrate that the *legal status* of the *management unit*, including *tenure* and *use rights* and its boundaries, are clearly defined
Climate, hydrology	
Rainfall, humidity, and winds (only if relevant); temperature and sunshine, water balance	
Geology, soils and land use	
Topography; rock types and erosion (only if relevant); managerial implications of geology	
Soil types; land uses; land use capability classification (only if relevant); managerial implications of soil types and land use capability classifications	
Forest resources	
Vegetation types, summary of forest type and land use classes, managerial implications of forest ecology issues, summary of forest resources data (tables)	
General forest inventory data: species, volume, and tree size data. General non-wood forest resources. Overall forest resources summary	
Silvicultural system(s) – type(s), strengths, and limitations; forest growth and yield data (tables); assessment of the potential for sustainable wood production	
Log harvesting and transport issues	
Harvest plan; logging methods and machinery, log transport methods (roads, railways, barging)	
Forest industry issues	Principle 5: the *organization* (forest administration) shall efficiently manage the range of multiple products and services of the management unit to maintain or enhance long-term economic viability and the range of environmental and social benefits
Summary of existing forest industry; wood industry development potential (preferred and underutilized species, resources, log sizes)	

(*continued*)

Table 18 (continued)

Basic forest management plan (Adapted from Armitage 1998)	FSC certification criteria
Social issues *Characteristics of community groups: ethnic origin(s), populations, distribution and size of villages; social dependency patterns on the natural forests; social conflicts or potential conflicts with forests; implications of social issues with forests*	3.1 *The organization* (*forest administration*) shall identify the *indigenous peoples* that exist within the *management unit* or are affected by management activities. The organization shall then, through *engagement* with these indigenous peoples, identify their rights of *tenure*, their rights of access to and use of forest resources and *ecosystem services,* and their *customary rights* and legal rights and obligations that apply within the management unit. The organization shall also identify areas where these rights are contested
Wildlife resources The forest "landscape" as habitat for wildlife, wildlife resources, biological diversity, implications of wildlife relationships with natural forests	6.4 *The organization* (*forest administration*) shall protect *rare species and threatened species and* their *habitats in* the *management unit through conservation zones*, *protection areas*, *connectivity and*/or (where necessary) other direct measures for their survival, and viability
	6.6 *The organization* shall effectively maintain the continued existence of naturally occurring native species and genotypes and prevent losses of *biological diversity*, especially through habitat management in the *management unit*. The organization shall demonstrate that effective measures are in place to manage and control hunting, fishing, trapping, and collecting
Environmental issues *Environmental issues influenced by wood production management, for example, soil and water conservation, biodiversity and wildlife conservation, ecotourism*	Principle 6: environmental values and impacts. *The organization* shall maintain, conserve, and/or restore *ecosystem services* and *environmental values* of the *management unit* and shall avoid repair or mitigate negative environmental impacts
	6.3 *The organization* shall identify and assess the *scale*, *intensity*, *and risk* of potential impacts of management activities on the identified *environmental values*
	6.7 *The organization* shall protect or restore natural water courses, water bodies, riparian zones, and their connectivity. The organization shall avoid negative impacts on water quality and quantity and mitigate and remedy those that occur

(*continued*)

Table 18 (continued)

Basic forest management plan (Adapted from Armitage 1998)	FSC certification criteria
Forest protection and security	
Issues and data concerning protection of a forest management unit from fire, trespass, shifting cultivation, and other potential threats; implications of forest protection and security issues	
Part 2 goals and objectives	
Goal, objectives	6.5 *The organization* (*forest administration*) shall identify and protect representative sample areas of native ecosystems and/or restore them to more natural conditions. Where representative sample areas do not exist or are insufficient, the organization shall restore a proportion of the *management unit to* more natural conditions
Forest protection; wood production; non-wood production; other objectives, such as social development, reforestation, afforestation, research, environmental conservation, and business development	7.1 *The organization* shall proportionate to *scale*, *intensity*, *and risk* of its management activities and set policies (visions and values) and *objectives* for management, which are environmentally sound, socially beneficial, and economically viable. Summaries of these policies and objectives shall be incorporated into the *management plan* and publicized
Part 3 management prescriptions (primary objective is wood production)	Principle 7: management planning
Forest function and forest management zoning, Inc. demarcation and mapping of protection forest on steep slopes, natural regeneration, water sources, fragile soils and swamps, endangered species, etc.	*The organization* (*forest administration*) shall have a *management plan* consistent with its policies and *objectives* and proportionate to *scale*, *intensity*, *and risks* of its management activities. The management plan shall be implemented and kept up to date based on monitoring information in order to promote *adaptive management*. The associated planning and procedural documentation shall be sufficient to guide staff, inform affected *stakeholders* and interested *stakeholders*, and justify management decisions
	6.9 *The organization* shall not convert natural *forest* to *plantations* nor natural forests or plantations on sites directly converted from natural forest to non-forest land use, except when the conversion:
	(a) Affects a very limited portion of the area of the *management unit*

(*continued*)

Table 18 (continued)

Basic forest management plan (Adapted from Armitage 1998)	FSC certification criteria
	(b) Will produce clear, substantial, additional, secure long-term conservation benefits in the management unit
	(c) Does not damage or threaten *high conservation values* nor any sites or resources necessary to maintain or enhance those high conservation values
	9.3 *The organization* shall implement strategies and actions that maintain and/or enhance the identified *high conservation values*. These strategies and actions shall implement the *precautionary approach* and be proportionate to the *scale*, *intensity*, *and risk of* management activities
Preharvest wood inventory for annual yield planning	
Continuous forest inventory for determination of forest growth and derivation of yields	
Specification of a periodic (5 years) or annual cut	
Harvest planning, Inc, wood harvesting and log transport arrangements	
Forest protection and security arrangements	
Diagnostic sampling	
Specification of appropriate silvicultural system(s)	
Specification of silvicultural operations	
Specification of environmental prescriptions on issues influenced by production management	
Accountability prescriptions to ensure that progress in plan implementation can be regularly and reliably monitored and subsequently reported	
Specification of the action that should be taken before a plan terminates for its review and for preparation of a new plan	
Part 4 monitoring and evaluation	Principle 8: monitoring and assessment
Monitoring and evaluation system with specification of responsibilities, monitoring contents, and monitoring deadlines throughout the year and during production cycles	*The organization* (*forest administration*) shall demonstrate that progress toward achieving the *management objectives*, the impacts of management activities, and the condition of the *management unit* is monitored and evaluated proportionate to the *scale*, *intensity*, *and risk* of management activities, in order to implement *adaptive management*

(*continued*)

Table 18 (continued)

Basic forest management plan (Adapted from Armitage 1998)	FSC certification criteria
	8.5 *The organization* shall have and implement a tracking and tracing system proportionate to *scale*, *intensity*, *and risk* of its management activities, for demonstrating the source and volume in proportion to projected output for each year, of all products from the *management unit* that are marketed as FSC certified
Part 5 annexes, records	
Maps, including remote sensing imagery	
Technical details of topics expressed in part I	
Records	
Comprehensive compartment records of forest operations. Where practicable records should be made using a computer database system and should include GIS	

High conservation values
HCV 1 – Species diversity. Concentrations of *biological diversity including* endemic species and rare, threatened, or *endangered species* that are significant at global, regional, or national levels
HCV 2 – Landscape-level ecosystems and mosaics. Intact forest landscapes and large landscape-level *ecosystems and* ecosystem mosaics that are significant at global, regional, or national levels and that contain viable populations of the great majority of the naturally occurring species in natural patterns of distribution and abundance
HCV 3 – Ecosystems and habitats. Rare, threatened, or endangered ecosystems, *habitats*, *or refugee*
HCV 4 – Critical ecosystem services. Basic *ecosystem services in* critical situations, including protection of water catchments and control of erosion of vulnerable soils and slopes
HCV 5 – Community needs. Sites and resources fundamental for satisfying the basic necessities of *local communities or indigenous peoples* (for livelihoods, health, nutrition, water, etc.), identified through engagement with these communities or indigenous peoples
HCV 6 – Cultural values. Sites, resources, habitats, and *landscapes of* global or national cultural, archaeological, or historical significance and/or of critical cultural, ecological, economic, or religious/sacred importance for the traditional cultures of local communities or indigenous peoples, identified through engagement with these local communities or indigenous peoples

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