Introduction

In managing a forest designated primarily for timber production, one of the basic prerequisites for planning is an inventory of timber resources. Such an inventory is designed mainly to assess commercial timber stocking and the regeneration status of commercial trees. The information generated from the inventory then forms the basis for management decisions over the length of the planning period (usually 10-20 years), especially with regard to yield regulation and timber stand improvement. For Deramakot and Tangkulap, linear sampling methods were adapted for a compartment level inventory, focusing only on the essentials of forest management for timber production.

The Silvicultural and Management Inventory

Defining inventory objectives

A fundamental requirement in designing a system for forest assessment is to first define the purpose of the assessment, what information is useful in decision-making, how best to collect that information, and how best to present it to the decision-maker or forest manager. An inventory to be used for managing an area for long-term timber production has to provide information that is useful for making decisions related to timber management. In designing the Silvicultural and Management Inventory **(SMI)** for Deramakot and Tangkulap, information of interest for timber management includes:

1) *Timber stocking*—How much harvestable timber is available, both in terms of tree numbers and volume, and what is their spatial distribution? What is the species composition of the timber crop?
2) *Status of commercial regeneration*—What are the number, size, and quality of individuals? What is the spatial distribution of commercial regeneration?

3) *Silvicultural treatment required*— What, if anything, is impeding regeneration and where? What are the opportunities for yield enhancement, both in terms of quality and volume?

4) *Estimates the cutting cycle and potential productivity*— What is the level of sustainable harvest? A problem of considerable practical significance involves the use of inventory data in predicting the timing of future harvests and determining timber yield.

Inventory planning at the compartment level

Like any other forest operation, office-based planning is necessary before field work can commence. The use of aerial photographs is essential in this process. The recommended scale of aerial photographs is 1:12,500 to 20,000, a convenient scale to work with, and large enough to enable the visual stratification of the forest into stands of homogeneous canopy texture or crown size. Forest stratification is done if more than one forest stratum is apparent from the aerial photograph. As a rule of thumb, a forest stratum should be a more or less contiguous area of at least 10 *ha*. The different strata are then inventoried separately.

Figure 1 is an aerial photograph showing how inventory lines were planned for Compartment 69 in Deramakot. A map including features such as compartment boundary, inventory lines, roads, rivers, and ponds, was also produced from the aerial photograph to be kept as a permanent compartment record (Figure 2). Inventory lines were planned is such a way that they are representative of the area to be sampled. The starting points for inventory lines were also planned from the aerial photograph such that they can be easily located on the ground. This would enable the future re-enumeration of the inventory line for the long-term monitoring of growth and development of the growing stock (i.e. continuous forest inventories). The distance between inventory lines were set at 200 *m* interval.

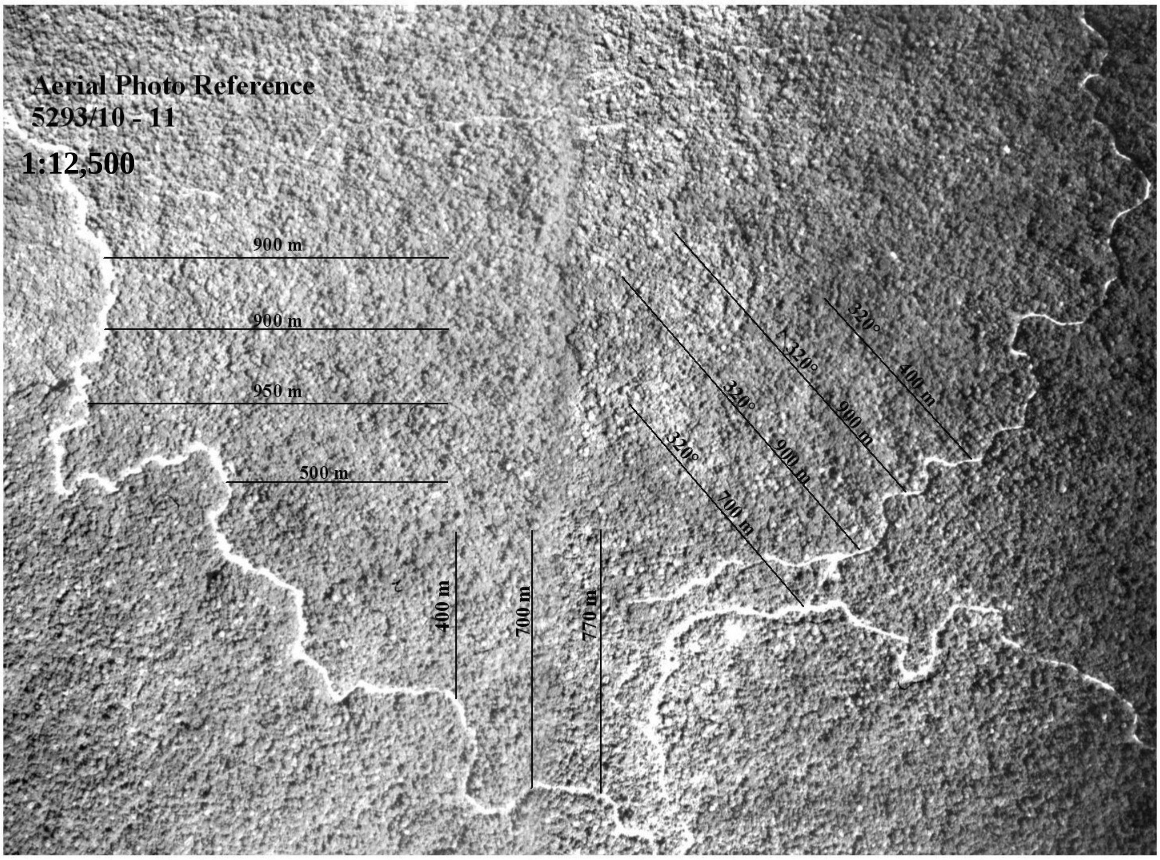

Figure 1: An aerial photograph of Compartment 69 showing how inventory lines were planned before the actual field inventory was carried out.

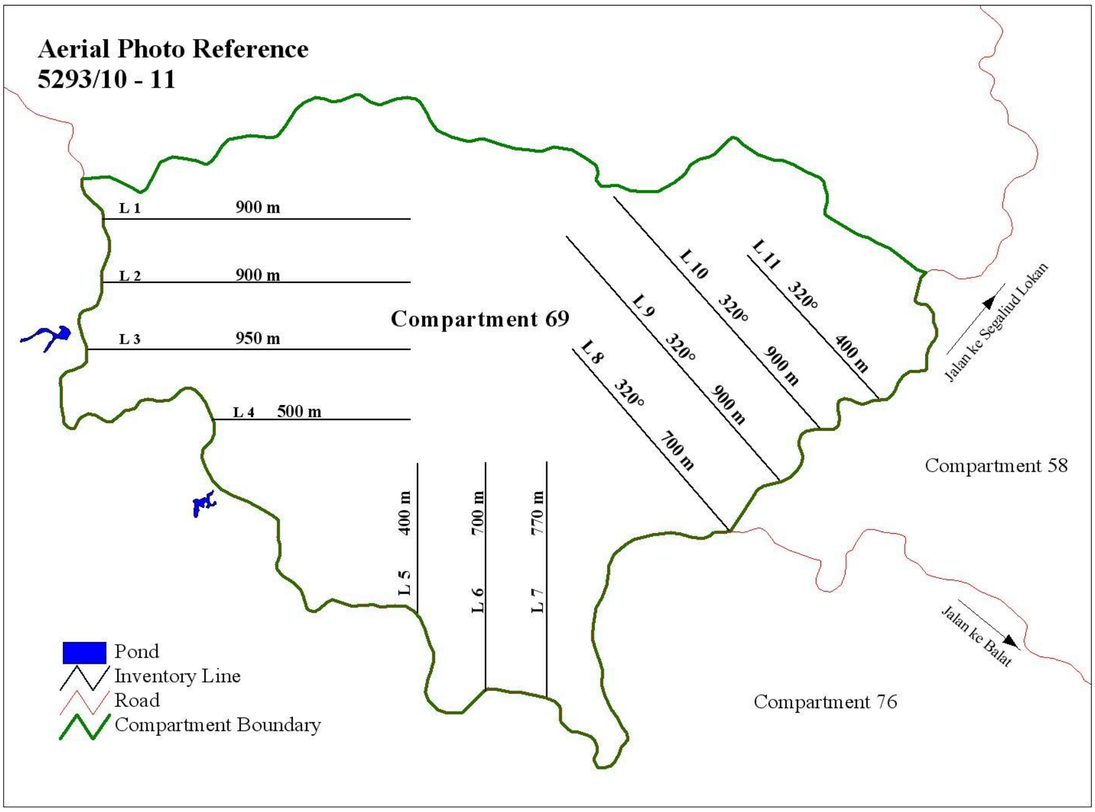

Figure 2: A map of Compartment 69 that is kept for permanent record.

Data recording in the field

The inventory is carried out along strips, divided into continuous 10 x 10 *m* and 10 x 20 *m* sections or plots (Figure 3.3). Data recording can be divided into 3 parts. The first part records all trees ≥ 30 *cm* DBH within a 10 x 20 *m* plot, the second part records potential crop trees 5-30 *cm* DBH within a 10 x 10 *m* plot, and the third part records other silvicultural information within the same 10 x 10 *m* plot. All data are recorded onto the inventory data sheet (Table 1) according to the following guidelines:

1) **10 x 20 m plot**—All trees > 30 cm DBH regardless of species are recorded. Trees are identified by species as far as possible and their quality classified as either 'sound' or 'defective' according to a set criteria.

2) **10 x 10 m plot**— PCTs are selected based on the following criteria:

- It should be 5–30 cm DBH in size and listed as either 'preferred' or 'acceptable' in the list of commercial species (Appendix A);
- It should be the best among the commercially desirable trees in the plot. This is often the tallest and largest in diameter. A smaller tree should only be chosen if the largest tree is defective or belongs to a species of considerably lower value;
- It should have a single trunk, sound, well-formed, free of serious defects;
- It should have a healthy and vigorous crown;
- It should be a stable tree, without a pronounced lean.

Up to two PCTs may be recorded in a plot. However, the minimum distance between two PCTs is set at 5 *m*. Therefore, the maximum stocking of PCTs is 200 more or less evenly-spaced PCTs per hectare. If only one tree in the plot meets the above criteria, then only one PCT is recorded. If no PCTs meet the above criteria can be found, then the column is left blank.

3) **Other silvicultural information—**Within the 10 x 10 *m* plot, the occurrence of woody vines, climbing bamboo, pioneer trees, and young commercial regeneration are recorded as shown in Table 2. If more than 50 % of a plot falls in a gap, stream, tractor path, or swampy area, this is indicated in the 'remarks' column. Such information may be used to estimate the proportion of a compartment that is not suitable for timber production.

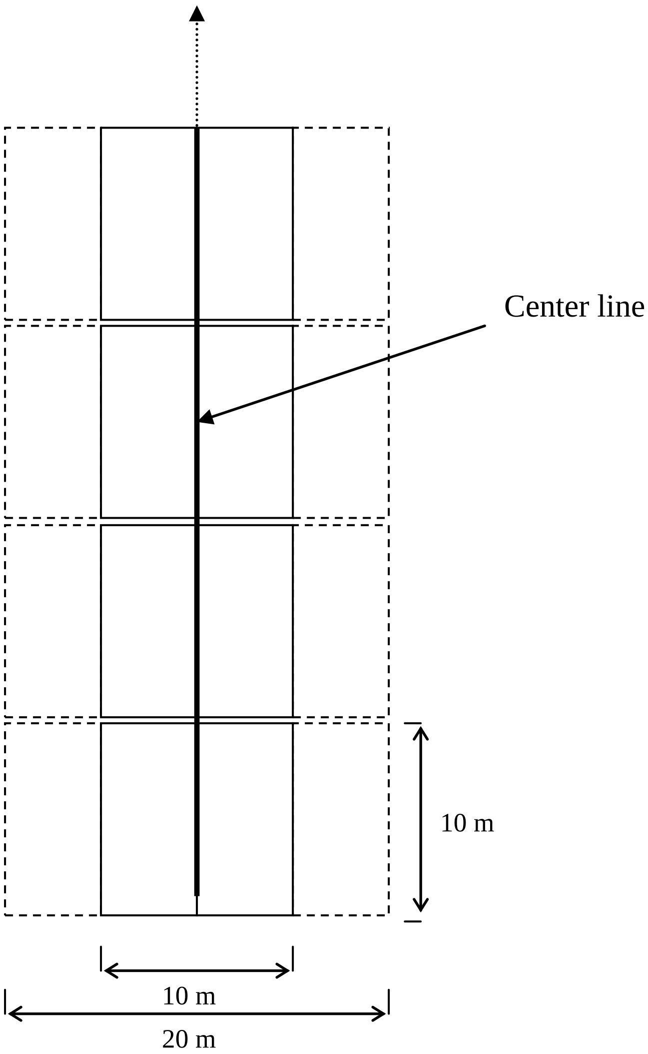

Figure 3: Layout of inventory strip.

Table 2 : Data recording sheet for the Silvicultural and Management Inventory

SILVICULTURAL & MANAGEMENT INVENTORY

FMU: ________________ Compartment: __________________
Line number/bearing/distance:_______/_______/_______
GPS reading at starting point:______________________________
Team Leader:_______________________ Date: __________________

Distance (m)	All species > 30cm DBH (10 x 20 m plot)				Only PCTs 5–30 cm DBH (10 x 10 m plot)		Other silvicultural information (10 x 10 *m* plot)				
	species	DBH (cm)	tree quality	defect	species	DBH (cm)	Regen	CB	WV	pioneers	remarks

Tree quality: **1** (sound) **2** (defective)
Regeneration: Count only commercial species 50 *cm* height to 5 *cm* DBH.
CB (Climbing bamboo): Count number of clumps
WV (Woody vines): Count only vines > 2.5 *cm* DBH.
Pioneers: Count only number of stems ≥ 10 cm DBH.
Pioneers refer to all Macaranga species (e.g. Sedaman and Kubin), Ludai, and Bawing.
Remarks: **Sm** (stream) **G** (gap) **TP** (tractor path) **Sw** (swampy or water-logged)

Analysis and interpretation of the SMI results

Data for the SMI is processed using a specially developed computer program. The output for each compartment is presented in a series of tables that are designed for quick and easy interpretation. Tables 4 and 5 are the results of the actual SMI carried out for Compartment 69 and 20 of the Deramakot FMU, and are presented here for the purpose of discussion.. The key silvicultural questions to answer in evaluating these compartments are:

- What are the prospects for harvesting?
- Is the compartment sufficiently regenerated?
- What sort of timber stand improvement treatments are required?

Trees ≥ 30 *cm* DBH (10 x 20 *m* plot)

The main purpose for recording large trees along the 20 *m* strip is to evaluate the prospects for harvesting. For the purpose of illustration, the SMI results for all trees greater than 30 *cm* DBH for Compartments 20 and 69 are provided in Tables 4 and 5. This information is reported according to general species groups and their size class distribution. At 17.8 trees ≥ 60 cm DBH per hectare, Table.4 clearly shows that Compartment 69 is ripe for harvest. On the other hand, it will take years for Compartment 20 (Table 5) to produce a mature crop of trees. The time required for Compartment 20 to mature can be estimated by a simple stand table projection. This is where trees below the minimum cutting limit (≤ 60 cm DBH) become relevant, since they are expected to form the future crop; and the time interval to the next harvest may be determined by the projection of their diameter growth. The database used for growth projections would be the same as that of the inventory data. Assumptions on growth rates may be derived from permanent sampling plots or existing data. In order to monitor the reliability of projections, a certain portion of the inventory lines may be set aside for repeated inventories (continuous forest inventory) so that actual growth may be compared against projected growth.

Table 4: Results of the SMI for PCTs and sound quality commercial trees ≥ 30 *cm* DBH for Compartment 69, classified largely as ‘ moderate forest’ in terms of merchantable timber stock.

Number of trees ≥ 30 *cm* DBH ha^{-1} (10 x 20 m plot)				
Species group	**30–60 *cm***	**60–80 *cm***	**80–120 *cm***	**> 120 *cm***
Dipterocarp				
- light hardwood	12.1	7.6	1.6	0.3
- medium hardwood	2.3	2.0	0.8	0.1
- heavy hardwood	0.9	1.3	0.4	
Commercial non-dipterocarp	6.5	2.9	0.8	
Total	**21.8**	**13.8**	**3.6**	**0.4**
Number of PCTs 5–40 *cm* DBH ha^{-1} (10 x 10 m plot)				
Species group	**5–10 *cm***	**10–20 *cm***	**20–30 *cm***	**30–40 *cm***
Dipterocarp				
- light hardwood	2.5	7.5	7.1	6.0
- medium hardwood	0.3	1.2	0.9	0.8
- heavy hardwood	0.3	0.6	0.5	0.4
Non-dipterocarp	0.2	0.8	0.9	0.5
Total	**3.3**	**10.1**	**9.4**	**7.7**

Table 5: Results of the SMI for PCTs and sound quality commercial trees ≥ 40 cm DBH for Compartment 20, classified largely as *poor forest* in terms of merchantable timber stock.

Number of trees ≥ 30 *cm* DBH ha^{-1} (10 x 20 m plot)				
Species group	**30–60 *cm***	**60–80 *cm***	**80–120 *cm***	**> 120 *cm***
Dipterocarp				
- light hardwood	4.5	1.9	0.1	
- medium hardwood	0.6	0.8	0.2	
- heavy hardwood	0.4	1.1	0.1	
Commercial non-dipterocarp	0.6	-	-	
Number of PCTs 5–40 *cm* DBH ha^{-1} (10 x 10 m plot)				
Species group	**5–10 *cm***	**10–20 *cm***	**20–30 *cm***	**30–40 *cm***
Dipterocarp				
- light hardwood	4.2	12.8	7.6	3.5
- medium hardwood	4.7	6.6	0.8	0.5
- heavy hardwood	0.5	1.8	1.3	1.0
Non-dipterocarp	1.0	2.7	3.0	1.1
Total	**6.4**	**20.9**	**11.7**	**6.4**

Potential crop trees (10 x 10 *m* plot)

If there is insufficient number of harvestable trees to justify a harvest, then information on trees below the diameter cutting limit becomes more critical. The idea of recording these poles and advanced growths is basically to evaluate the regeneration status of the compartment to see if it is sufficiently stocked with PCTs to produce a future crop within a certain time frame, usually one cutting cycle. In order to have an objective means of evaluating stocking there must be some minimum standards against which stocking is evaluated. If 15 trees between 60─80 *cm* DBH per hectare is assumed to be the minimum economic cut, then working backwards, one could establish the equivalent minimum standards for the lower diameter classes by simply assuming certain growth and mortality rates. This has been roughly established in broad diameter classes for Deramakot and Tangkulap as shown in Table 7 below. The figures in the table are interpreted as such: If there are no commercial trees ≥ 60 *cm*, then an equivalent of 18 PCTs are needed in the 40─60 *cm* DBH class, and if there are no PCTs ≥ 40 *cm* DBH, then 21 PCTs are needed in the next lower size class, and so forth. The fewer PCTs there are in the larger size classes, the more PCTs are required in the lower size classes, and vice versa.

Table.7: Minimum standards for PCT stocking used for silvicultural planning in Deramakot

Size class	Minimum number of trees ha^{-1}
≥ 60 cm	15
40─60 cm	18
20─40 cm	21
5─20 cm	28

With 17.4 trees ha^{-1} ≥ 60 *cm* DBH, it is obvious that Compartment 69 satisfies the minimum stocking standards (Table 3.4). However for Compartment 20 this is less obvious. Table 7 is used here to discuss the evaluation of Compartment 20. The compartment should be evaluated from the largest size class downward. The stand has no trees ≥ 60 *cm* , therefore an equivalent of 18 trees are needed in the 40─60 cm size class. There is only 0.6 trees ha^{-1} in this class, short of the minimum standard by 17.4. This 17.4 deficit in tree numbers is equivalent to a requirement of about 20.3 trees in the next lower class. Compared against the actual stocking of 18.1 PCTs, there is again a deficit of 2.2 PCTs in the 20─40 *cm* size class, and this is equivalent to 2.9 PCTs in the lowest size class. In the final analysis, there are 24.4 trees more than the minimum standard, and it can be concluded that the compartment is sufficiently regenerated for

timber production. Should the results be otherwise, then one will have to look closely at seedling regeneration, those trees < 5 cm DBH.

Table 8: PCT stocking evaluation for Compartment 20 following protocols set under the SMI.

Size class	Min. no. of trees ha^{-1}	Actual stocking	Equivalent no. of PCTs required	No. of PCTs +/- the minimum standard	Equivalent no. of PCTs in the next lower class
≥ 60 cm	15	-	15	-15	18
40─60 cm	18	0.6	18	-17.4	20.3[1]
20─40 cm	21	18.1	20.3	-2.2	2.9[2]
5─20 cm	28	27.3	2.9	+24.4	-

[1]Calculated as 17.4 x (21/18) = 20.3, meaning one tree in the 40─60 cm class is equal to 21/18 trees in the 20─40 cm class.
[2]Calculated as 2.2 x (28/21) = 2.9

Other silvicultural information (10 x 10 m plot)

Seedling regeneration—The presence of seedling regeneration becomes important where the number of PCTs ≥ 5 *cm* DBH is low. If the number of PCTs is below the established minimum standards then seedling regeneration should be looked at critically. Information on regeneration provides a basis for predicting the potential of the stand for natural regeneration. In the interpretation of the SMI, only plots with 3 seedlings or more are considered stocked. Table 8 shows that 68.7 % of Compartment 69 is stocked with commercial seedlings. If in the instance that the PCT stocking is insufficient and the proportion of stocked plots falls below 50 % then the compartment is considered poorly regenerated and some form of enrichment and seedling release treatment may be necessary.

Climbing bamboo and woody vines—The incidence of climbing bamboo and woody vines is usually high in logged over forests. Like climbing bamboo, woody vines also have an adverse impact regeneration establishment and tree growth. Recording the incidence of both these silvicultural weeds has never been practiced in conventional forest inventories or diagnostic sampling, but with very little extra effort, such information gives the forest manager an idea of the extent and intensity of the problem. As a rule of thumb, it is suggested that if the incidence of climbing bamboo or woody vines exceeds 40 %, then one may consider prescribing their control by cutting as a blanket treatment. Knowledge of the intensity level of climbing bamboo infestation may also be used to determine the contract rate for their removal.

Pioneer trees—The presence of pioneer trees is yet another indication of past forest disturbance and the stage of forest recovery. Pioneer trees normally invade open areas of bare soil. The higher the proportion of plots containing pioneer trees, the more intensive was the past damage inflicted on the forest. The percentage of pioneer tree cover has to be considered in relation to seedling regeneration and PCT stocking. If either or both seedling regeneration and PCT stocking is sufficient, then a high percentage of pioneer tree cover will likely mean greater opportunities for liberation by their removal. If regeneration stocking is poor, then the advantage of removing pioneer trees may be minimal. Under such a condition, the manager may consider enrichment planting in gaps created be the group-felling of macaranga trees. In the case of Compartment 69, pioneer tree cover is considered low at 17 %.

Prescriptions for silvicultural treatment

The information generated from the SMI serves as an aid to guide silvicultural decision-making, and is not intended to provide answers to management planning problems. The information generated for each compartment helps the forest manager establish operational priorities for the duration of the planning period. In establishing these priorities the

Table 8: Other information relevant to silvicultural decision-making as recorde on 10 x 10 *m* plots.

Silvicultural & Management Inventory **Compartment : 69** **Inventory date: June 1998** **Size: 333 ha** **Total number of plots: 802**	
1. Regeneration of commercial seedlings **(50 *cm* height to 5 *cm* DBH)**	
Frequency class	**Proportion of plots (%)**
0–2 stems	31.3
3–5 stems	60.1
> 5 stems	8.6
2. Climbing bamboo	
Frequency class	**Proportion of plots (%)**
none	35.1
1–3 clumps	48.8
≥ 4 clumps	16.1
3. Woody vines **(≥ 2.5 cm DBH)**	
Frequency class	**Proportion of plots (%)**
none	18.6

1–3 stems	77.6
≥ 4 stems	3.8
1. Pioneer trees (≥ 10 cm DBH)	
Frequency class	**Proportion of plots (%)**
none	83
1–3 stems	14
≥ 4 stems	3
5. Other information	
	Proportion of plots (%)
gap	
stream	
tractor path	

manager will have to take into account resource constraints such as funding and manpower, and decide on how to allocate available resources in the most efficient manner. On the other hand, the necessary resources may be requested based on the planned activities. There are basically 5 silvicultural options in dealing with individual compartments:

1. ***Harvest—***If the compartment is found to be sufficiently stocked, the forest manager may schedule a harvest at any time within the planning period.
2. ***Cut climbing bamboo and woody vines—***The cutting of climbing bamboo and woody vines is normally prescribed together in a single operation and as a blanket treatment. Where a large proportion of PCTs are below 20 cm DBH or seedling regeneration is abundant, cutting climbing bamboo and woody vines would be beneficial. However, because vine cutting is prescribed as a blanket treatment, one has to trust thereby on the incidental improvement in the illumination of seedlings or saplings on the ground.
3. ***Carry out selective liberation of PCTs—***This operation entails the selection of PCTs and their deliberate liberation by the removal of trees of lesser value that are impeding their growth. Like vine cutting, selective liberation is beneficial where many PCTs in the 5 to 20 cm DBH range are present. But unlike vine cutting, the problem with selective liberation is that it requires skillful workers for effective implementation.
4. ***Regenerate by artificial means—***Artificial regeneration refers to either enrichment planting or the establishment of tree plantations. These options may have to be considered

if the compartment is found to be insufficiently stocked and the prospects for natural regeneration is poor as indicated by the paucity of seed bearers.

5. ***Do nothing*—**There may be several reasons for this course of action. Perhaps the compartment is not ready for a harvest and present stocking conditions do not warrant any timber stand improvement. Therefore treatment is not a priority within the present planning period, and is deferred to the following planning period.

Continuous Forest Inventory

As a routine management activity, regardless of whatever inventory system is used, it is extremely important that the inventory be supplemented by a permanent monitoring and control system in the form of repeated forest inventories in order to check for discrepancies between projections and reality. In the case of Deramakot and Tangkulap, this practice of *continuous forest inventory* serves to check the actual growth and development of the growing stock against what was projected in order to avoid discords between what was planned and what can actually be achieved. If large discrepancies are found between actual and projected growing stock then adjustments will have to be made with regard to harvest scheduling.

For the SMI, monitoring of the growing stock can be done by re-sampling former inventory lines. Since the starting point of linear sampling strips are placed along roads, they can be easily located on the ground from information drawn onto compartment maps. A GPS reference is also recorded for all starting points to facilitate their re-establishment on the ground. Therefore, there is no need to permanently mark, demarcate and maintain any plot boundary because strips can easily be reestablished by knowing only the starting point, the inventory line bearing, and the strip length, all of which can simply be noted on the compartment map.

It is suggested that 3 inventory lines (or 2500−3500 m of inventory lines) per compartment be maintained for permanent monitoring. These lines should be re-enumerated every 5 years.