Estimating Growing Stock and Allowable Cut in Lao PDR using Data from Land Use Maps and the National Forest Inventory (NFI)

Bounpone Sengthong

Arbetsrapport 48 1998/
Working Paper No 48 1998

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Master thesis in forest resource management
Supervisor: Ulf Söderberg, Swedish University of Agricultural Sciences

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Abstract

Since 1989, the Lao government is implementing a policy on better use of forest resources. In order to get more accurate data for strategic decisions and planning of a sustainable forest management, the government is conducting a national forest inventory (NFI) and a nationwide mapping of land use and forest cover. Both activities provide important information but any of the two sources is not sufficient for calculating growing stock for production forest areas which is an important base for estimating allowable cut.

The objective of this study is to investigate the possibility of combining two different types of data, firstly sampling data from the NFI and secondly land use maps based on SPOT satellite imagery, for estimating growing stock in small areas (production areas) and estimating allowable cut on province level.

In the study an approach (CNL) has been developed. The CNL approach provides the opportunity of combining the different types of data and it is also tested and evaluated in two production forest areas. In the study, management inventory data has been used as a reference, and government guide-lines for determining, in which area logging can take place.

For each area, the CNL provided such information as the average volume per hectare for different land use groups and forest types and the average number of trees per hectare. For current forest the information on crown density and stand structure has been used to improve the estimates. The precision of the estimates has also been calculated.

The CNL approach gave slightly higher figures than the reference data (average volume per hectare of Natural High Forest), but the differences can be explained by the time factor (different year of survey) and classification standards.

It is concluded that the CNL is feasible for estimating growing stock for areas similar to the two study areas. The areas were about 10,000 hectares each and located in accessible areas (covered by NFI sample plots).

Through the CNL approach, it is possible to make use of NFI and map data in combination to calculate the growing stock for areas defined by the data user. This information is one important piece of information needed for estimating the Annual Allowable Cut on, for example, province level.

Acknowledgments

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Bounpone Sengthong
Umeå, Sweden
October, 1998

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Chapter I

Introduction

1. 1. Background and Significance of the problem

The Lao People's Democratic Republic (Lao PDR) is a mountainous country situated in the South-East Asia, which share the borders with China, Vietnam, Cambodia, Thailand and Myanmar. The total area of the country is 236,800 square kilometers. The major topographic feature is the southward-flowing Mekong River and its flat, low-lying plain, which mainly lies below 200 meters. Through the North of the country and in the Annamite Mountain, there are steep, rugged hills. The total population is about 4.6 million people, the majority of the population live in rural areas. The average annual growth rate of the population is estimated at 2.4% (1985-1995) and population density is 19 persons per square kilometers. The Gross Domestic Product (GDP) per capita in 1994 was 335 USD (NSC, 1995).

The Forests

Lao PDR experiences a seasonal monsoon climate, with two to five cool and dry months between November and April. Total forest cover in Lao PDR in 1989 was 11.2 million hectares or about 47% of the land area, the rate of forest cover is lowest in the northern Region (36%) and highest in the South (58%). The distribution on different land use classes and vegetation types show that the Mixed Deciduous Forest was the predominant forest types in all the three region of the country at that time and that about 1/3 of the land was Unstocked forest areas (including fallow land) or Bamboo (Manivong, K. and Sandewall, M., 1992)

Forests play an important role in the survival and development of socio-economic life in Lao PDR. They have a marked effect on the environment such as preventing erosion, conserving soil, controlling water runoff and improving of the climate. Besides, they also contribute to the national income and employment of the people. With the political and economical reforms of the Lao Government during the late 1980's, the demand to exploit natural resources has increased. Forty percent of the population is estimated to be directly reliant upon the forest. The use of forest land for food production is extensive all over the country, especially in the uplands. The national economy is also heavily

dependent on forest products. The export of timber and wood products provides about 40% of the total value of exports (SUAN-EAPI-MAF, 1991).

The rate and extent of commercial logging in Lao PDR has been quite high in the past. It has been concentrated to the most accessible areas. Felling has been selective (based on species and diameter guidelines), but in practice, it has been poorly controlled and operated without adequate forest management plans (Young, V. and Hyde, M.J.1988).

Deforestation

Shifting cultivation (upland cultivation) and attendant uncontrolled fires has for long time been the major cause of deforestation in Lao PDR. Other factors such as mining, dams and roads have had relatively minor effects on forest areas in the past. However, the improvement of the national road network, due for completion in the 1990s, will provide access to areas hitherto untouched, which is likely to increase exploitation and lead to forest destruction by migrant agricultural settlers.

Laos is still comparatively rich in forest, but the forests areas decline almost every year. The total forest cover in Lao PDR in 1982 was 11.6 million ha. The area represents 49% of the area of the Country. By 1989, the forest cover of Lao PDR is estimated at 11.2 million ha or approximately 47% of the area of the Country. Thus, the net loss of forest during the period is estimated at 67 000 ha per annum. In total, the forest cover has decreased by 470 000 ha corresponding to 2% of the land area (or 4% of the area of Current Forest) during the 7 years (Manivong, K. and Sandewall, M., 1992).

Coupled with such a high rate of deforestation which cause decreases in forest products, there is another problem as far as bio-diversity is concerned, with respect to florist composition in the remaining forests. Selective use of certain species and improper management practices, has caused extensive forest degradation.

Attention of Government

To handle these environmental problems and achieve a more sustainable use of the forest resources, the Lao Government aims at regulating the use of the forest through legislation and management planning. So far the system is not functioning perfectly. Many different users, illegal practices and difficulties to estimate the actual cut and potential cut are some reasons.

The first National Forest Conference in 1989 was the starting point for the Government policy on better use of forest resources. In order to get more accurate information for planning and sustainable forest management, several activities were started under the National Office of Forest Inventory and Planning (NOFIP), a section under the Department of Forestry (DoF). The most important activities were: The Nationwide Reconnaissance Survey (NRS), providing data about forest cover, land use and the changing of forest cover, the National Forest Inventory (NFI) providing data on growing stock at province level (some provinces) and the Forest type and Land Use mapping of the whole country area.

With reference to the problem above, research and development has an on-going role in assisting progress towards sustainable forest management. Traditionally, research and development has provided the underpinning for management prescriptions that had the objective of maintaining productive capacity of the forest whilst also protecting the environment. Sustainable forest management will continue to have an important role in building an improved understanding of the long-term impacts of alternative management strategies on ecological processes and forest productivity. This information can provide more confidence in currently used practices, and provide improved management options where necessary.

1. 2. Research question:

Both the NFI and the Land Use and Forest Type maps provide a lot of important information but any of the two sources is not sufficient for calculating growing stock for production forest areas.

1.The NFI sampling inventory shows the total area and the growing stock in different forest types for the whole province area. But this method is unable to indicate the

location of the individual forest types. Where is the location of Evergreen forests for example?

2. The Land Use and Forest Type map derived from SPOT satellite image interpretation shows the location and boundary of individual compartments of different land use and forest type. But this method can not indicate some important information such as total growing stock for particular areas, which defined in the map, the average volume per hectare for different forest types?

3. Could the two data sources be combined? Can this technique be used to estimate growing stock for small areas within a province and not any province means? Is it possible to estimate potential or allowable cut with the help of this method or not?

1. 3. Objectives of the study

The Study aims at exploring the possibility of using the Lao National Forest Inventory Data in combination with other data sources for estimating growing stock for any particular areas according to desire, for example production forest areas and project areas.

The main objective is to investigate the possibility of combining two different types of data, sampling (NFI) and Land use map data (SPOT) for estimating:

- Growing stock in small areas defined on the map
- Allowable cut on province level

1. 4. The study area

The Author has selected Savannakhet Province as a study area for estimating growing stock and allowable cut. The study will be based on the NFI data together with land use map data (SPOT) and the result will be compared with the management inventory data from two production forest areas Dongkapho and Dongsithouane.

1. 5. Expected outcomes

The following main outcomes are expected from this study:

1. The study would provide a technique for estimating growing stock etc. for small areas by use of available NFI data and Land use map data.

2. The study would explore the possibility and constraints of using the above technique when trying to estimate the Annual Allowable Cut (AAC) on province level.

3. The study would be beneficial to the Province of Agriculture and Forestry Office (PAFO) as a base for future forest management plan and strategic decisions on use of the timber resource.

Chapter II

Available data sources and existing guide-lines for estimating growing stock and allowable cut

2. 1. The different data sources

Several sources provide data that could be used for estimating growing stock and allowable cut.

A Nationwide Reconnaissance Survey of Land Use and Forest Cover (NRS) has been conducted in Lao PDR by it's Department of Forestry (DOF), National Office of Forest Inventory and Planning (NOFIP) with the support of the Swedish International Development Cooperation Agency (Sida). The survey was initiated in 1987 and completed in 1991.

The main objective of the NRS was to develop a feasible inventory method, provide information on the status and change of the forest cover and to update and develop the capacity of the Department of Forestry to carry out inventory work. The NRS was based on remote sensing and designed as a photo sample plot inventory. Field checks were carried out by the photo interpreters in accessible areas on various occasions throughout the time of the survey. The NRS results were presented for three regions (North, Central and South) and as totals for the whole country. Some results of land use and forest cover 1982 and 1989, were also presented province wise.

As a second step, to obtain more detailed information on the forest stand, environmental changes etc, a full scale test for a National Forest Inventory (NFI) was carried out in Saravan Province, in 1990/91. Since then NFI field work has been conducted in many provinces of the country. The complete results are available for some of them and data processing is ongoing for the other.

A Land Use map covering the whole country has been produced by the staff of the photo interpretation section, NOFIP. The objective of the land use mapping is to present some important information on the map such the distribution of land use and forest types, road, river, stream (etc).

There are also Forest Management Inventories which are prepared for all production forest areas as a frame for forest management planning.

The Government guide lines for making the forest and forest land a sustainable source for livelihood of the population, includes laws, decrees, prescriptions and standards. The land use classification system and standard for logging and forest production are some examples.

2. 2. The National Forest Inventory (NFI)

The objective of the NFI is to provide certain information, in particular about standing volume, but as far as possible also about cutting and site conditions, that would improve the estimates of the NRS. Another purpose is to collect data for elaboration of volume functions and to compile ground truth for soil, vegetation and land use map.

The NFI field work is carried out province by province. The second year field work was carried out in Savannakhet Province (the field season 1991/92).

2. 2. 1. Inventory design

The design of NFI has been made and described (Manivong, K. and Eriksson, B., 1991).

The inventory design is a stratified, systematic cluster sampling. The primary sampling units are square tracts (cluster). In order to get as high precision as possible in the estimates the inventory is linked to the former Reconnaissance Survey. Those aerial photos that were interpreted during the Reconnaissance Survey have been used as a sampling frame for the inventory. On each photo 100 plots have been interpreted in the NRS. Those plots are systematically distributed over the photo in a 10 x 10 square grid system. In the north-west and south-east corner of each photo two NFI inventory tracts have been located. On each aerial photo those nine photo-plots located most to the north-west and most to the south-east form square within which the tracts are located (figure 2.1).

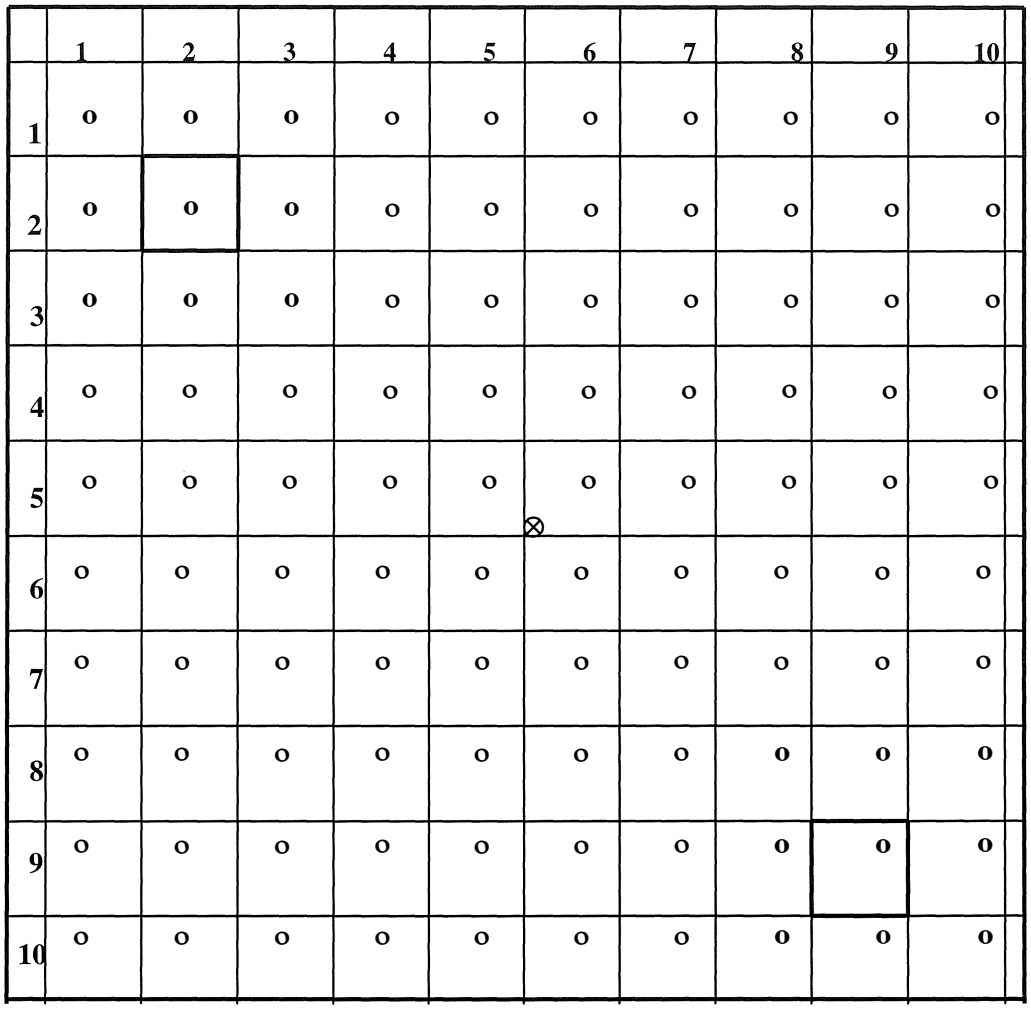

Figure 2.1: Location of the tracts in every aerial photo in relation to NRS sample plots

The exact position of tracts is in accordance with the 1 x 1 km grid net of the topographic map scale 1: 50 000.

Depending on the accessibility for field work the tracts have been divided into two groups. One group with accessible tracts and another group with non-accessible tracts (stratum 4). NFI field work was carried out on accessible tracts only.

According to the land use or forest type of the nine plots, the accessible tracts have been divided into the following three strata:

Stratum 1: Current forest (five or more plots out of nine classified as current forest)

Stratum 2: Potential forest (five or more plots out of nine classified as potential forest)

Stratum 3: The remaining tracts

The field tracts are selected by the simple random sampling with the proportion, 3/4 of stratum 1 and 1/4 of stratum 2 and 3. The outcome of the stratification is shown in the table2.1:

Table 2.1: The result of the field tracts selection within Savannakhet Province.

Stratum	Description	Number of total tracts in the photos	Number of the field tracts
1	Current Forest	59	35
2	Potential Forest	19	8
3	The remaining tracts	27	8
4	In-accessible tracts	60	0
Total		165	51

2. 2. 2. Inventory method in accessible areas

Tracts

The clusters consist of square tracts with a side length of 1 000 m. Along the tract-sides, there are different type of sample plots. The tracts are drawn on the map in scale 1: 50 000 and on aerial photos during the preparations for the field work. The different sides of the tract are called North, East, South and West (figure 2.2).

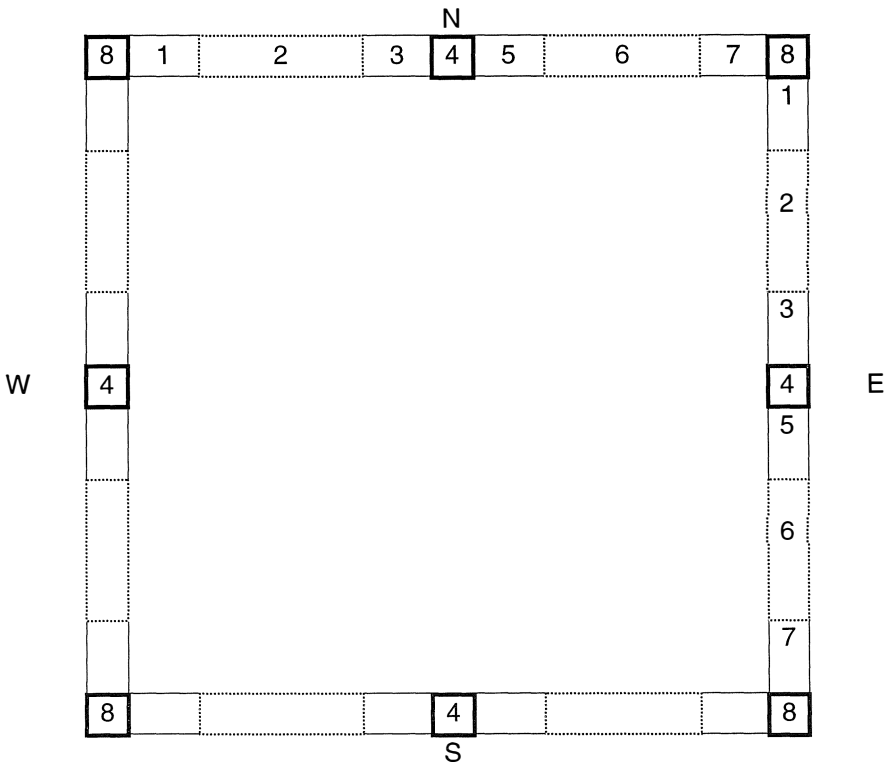

Figure 2.2. An inventory tract with the different types of sample plots.

Sample plots

There are three different types of sample plots on a tract:

Plot type A: Square plots 20 m x 20 m located in the corners of the tract and in the middle of each tract side. There are eight plots of this type in each tract the plots have the number 4 and 8 on each side.

Plot type B: Rectangular plots 20 m x 40 m located directly before and after each plot of type A. There are sixteen plots of type B in one tract. The plots are numbers 1, 3, 5, 7 on each side.

Plot type C: Rectangular plots 20 m x 400 m located between the plots of type B covering the whole tract line that is not covered by plots of type A or B. There are eight plots of type C in one tract and there are numbered 2 and 6 in each tract-side.

Area description

Area description is done in the plot type "A" only. Land use class or forest type however, is to be determined also on plot type "B" and "C". The purpose of the description is to get information on the distribution of the land area on different land use classes and on the distribution of forest land on different forest types. Land use class or forest type shall refer to that compartment within which the plot is situated. Most of the other variable refer either to the plot of 20 m x 20 m as description unit or to a circular plot with the radius of 25 m and the same center as the square plot. A unit of a certain land use or forest type should have a minimum area of 0.5 hectare to be distinguished and recorded. Some important variables recorded in the area description are: Land use class or forest type , Crown density, Stand structure, Measures, Damage, Altitude, Topography, Slope, Aspect, Surface, Underbrush, Distance to road and Slope conditions.

Tree enumeration

On plot type 'A', trees with DBH equal or greater than 100 mm are enumerated. On plot type 'B' and 'C' trees with DBH equal or greater than 300 mm (type B) and with DBH equal or greater than 600 mm (type C) are measured. On all enumerated trees, DBH is measured. The principle is that a tree without buttress or with buttress less than 10 dm the

measurement is taken at point 13 dm above ground and the tree with buttress higher than 10 dm, diameter is taken 3 dm above the end of buttress.

Sample tree measurement

On all plots, sample trees are selected among the enumerated trees. This is done according to the following probabilities:
Trees with diameter greater than or equals to 600 mm: 100 percent of enumerated trees.
Trees with diameter between 300 mm and 599 mm: 50% of enumerated trees. Trees with diameter between 100 mm and 299 mm: 25 % of enumerated trees.

For all sample trees, the stump diameter should be taken and measured at 3 dm above the ground or the end of buttress (tree has buttress). And tree height is also measured, tree height measurements should be taken with Clinometer. The readings should be made with the percent scale of the instrument. Tree height is measured at the tip of the tree, crown point and ground level.

In order to create form factor functions, the upper diameter has been measured by use of Wide Scale Relascope instrument on a sub-sample of Relascope Trees. On those trees three different points should be measured, at breast height or 3 dm above end of buttress, at the crown point and at half the height of the bole and the height of those points are also measured.

2. 2. 3. Inventory method for inaccessible areas

If the tract is located too far away (>10 km) from the road, or the terrain is too steep or the condition around the tracts is not safe, the tract is classified as inaccessible.

The inventory method for unacessible areas in the provinces of Saravane and Savannakhet was based upon aerial photos in scale 1:10 000 and 1:20 000 and using the two-stage sampling. The primary sampling unit is a sample of aerial photos distributed along a number of parallel flight lines. The sample plots laid out on the selected photos are secondary sample units. Every photo in scale 1:10 000 consists 4 plots (figure 2.3).

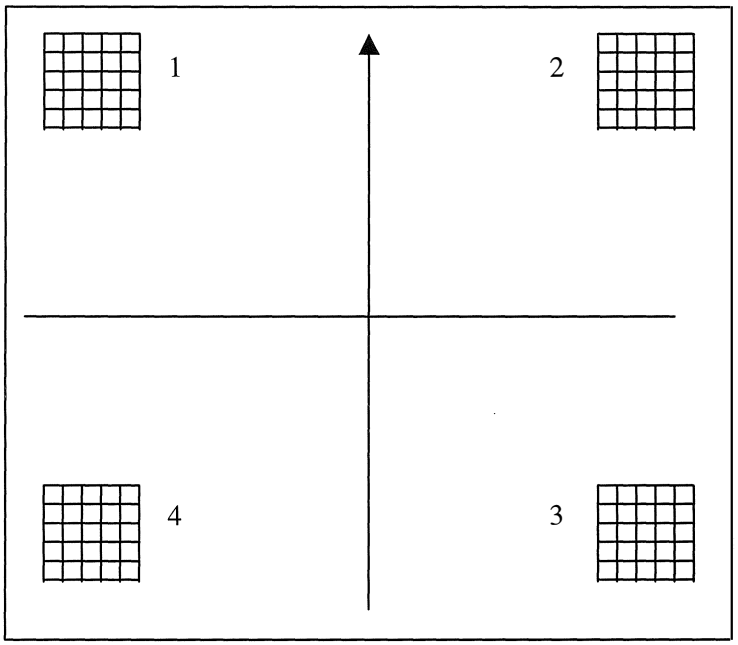

Figure 2.3: Lay-out of photo plots as secondary sampling units on each selected air photo, scale 1:10 000.

The sample plot is a square with sides 10 x 10 mm. To simplify some of the measurements a subdivision of the plot into 25 part-plots should be done. The rather big size of the plot (approximately 1.0 ha) is chosen with the purpose that the method should be applicable also on the photos in scale 1:20 000, in which case the plot is 5 x 5 mm. In the case the scale 1:20 000 is used 8 plots are laid out on every selected photos.

2. 2. 4. Land use and forest types classification

Land use/forest type system applied in NOFIP

The same system for classification of forest vegetation in Lao PDR, is used in the NRS, the NFI and also on land use map (Figure 2.4). The applied system is based upon an older FAO system. As it has turned out during the time of the work on the NFI, it is not perfectly adapted to the condition in Lao PDR. It has been necessary to further specify it after every field season .The basis for the distinction between forest and other land use groups is the crown cover. In addition, the land use classes have been put together into the following groups:

(1). Areas of Current forest

Areas of current forest are defined as areas being suitable forest production and having a tree cover with a crown density of at least 20 %. Forest plantations are excepted from the rule of a minimum crown density.

(2). Areas of Potential Forest

Previous forest areas where the crown cover has been reduced below 20 % for some reason (logging, shifting cultivation) and not permanently being used for other purposes (i.e. housing, agriculture etc).

(3). Other wooded Areas

Other wooded areas are defined as areas with a certain cover of trees or shrubs but being unsuitable for forest production, that the crown cover can never be 20 %.

(4). Areas of Permanent Agriculture

Areas of Permanent Agriculture included areas for production of crops, fruit trees etc. and areas permanently being used for grazing.

(5). Other Land use

Areas with Other Land use includes land that for various reasons is 'non-productive' and areas being used for other purposes than agriculture and forestry.

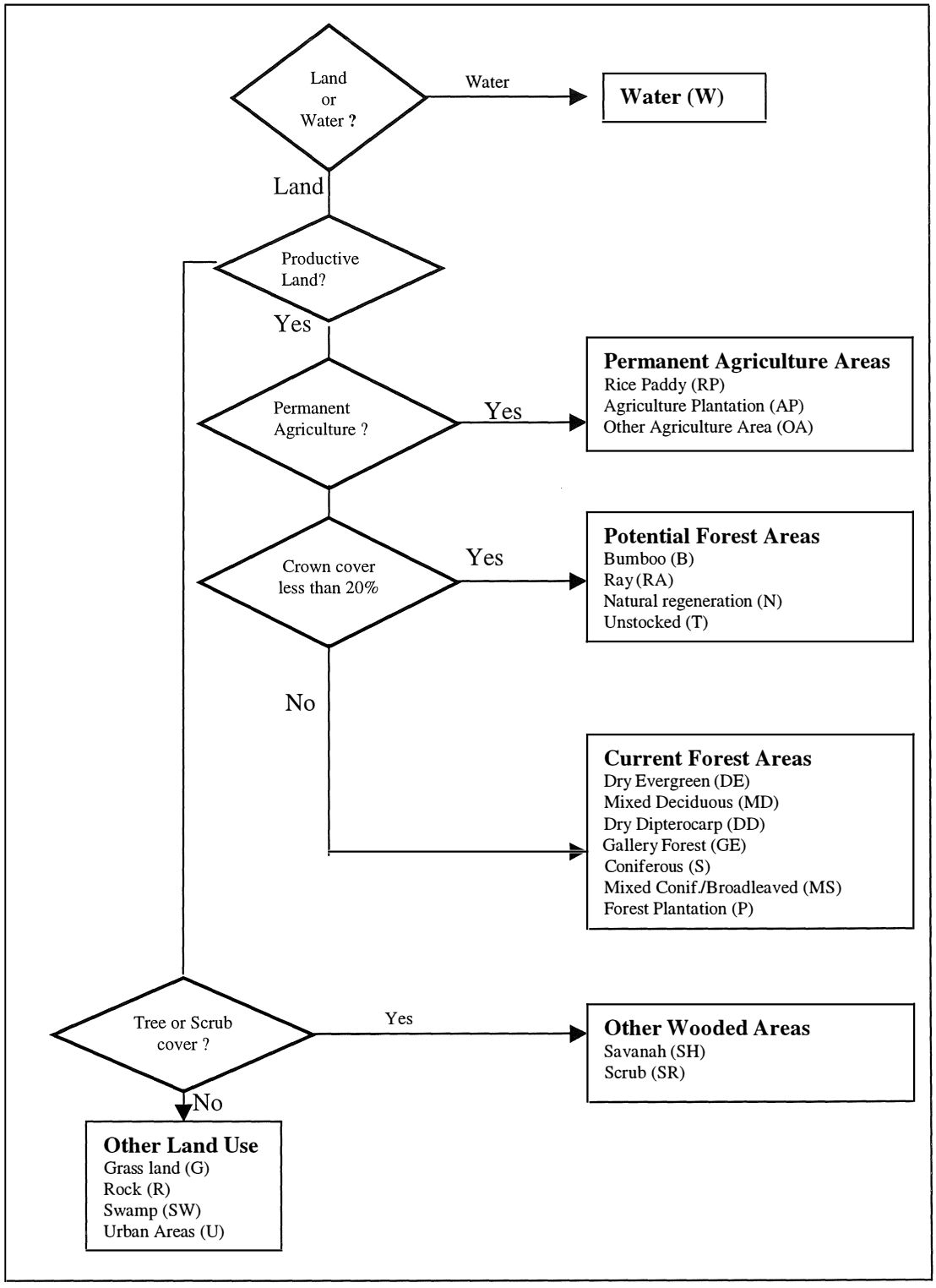

Figure 2.4: Forest type and land use classification system applied in NOFIP.

Other Land Use/ Forest type classification systems applied in Lao PDR

Beside the NOFIP system some other forest type classification systems have been used in Lao PDR.

FAO

The Forest Resources Assessment Project (FRA) carried out globally by FAO has developed another system.

Forests are ecological systems with a minimum crown coverage of land surface (10%) and generally associated with wild flora, fauna and natural soil conditions; and no subject to agronomic practices. For the present assessment (FAO, 1990), forests are defined with a minimum crown cover 10%, a minimum tree height more than 5 m, and only forest areas more than 100 ha (minimum area) are considered.

The main **land use classes** from the FAO yearbook, agricultural and other land classes need to be accounted for, giving a total class set as follows:

1. Arable land
2. Land under permanent crops
3. Permanent meadows and pastures
4. Forest and wooded land
    - 4.1. Forest
    - *Natural forest*
    - *Plantation forest*
    - 4.2. Other wooded land
    - *Forest fallow*
    - *Scrubs*
5. Other land

Definition used in remote sensing survey is **land cover classes**. A brief definition of the land cover classes used in the pan-tropical survey of forest resources based on high resolution satellite data is presented in the box below.

Land Cover Classes used in the pan-tropical survey

LAND COVER CLASSES	Average height	Canopy coverage	Description
Closed Forest	> 5 m	> 40 %	Continuous tree formation of natural origin
Open Forest	> 5 m	10-40 %	Continuous tree formation of natural origin
Shrubs	1-5 m	> 10 %	Low woody vegetation of natural origin
Other Land Cover		< 10 %	Land with woody vegetation below 10 %
Plantation	> 1 m	(dense)	Forestry or agricultural plantation
Water			Sea, lake, reservoirs, rivers
COMPOSITE CLASSES			
Fragmented Forest	(forest) > 5 m	(forest) > 10 %	Mosaic of forest and non-forest with forest fraction between 10 and 70% of total area (estimated average 33%)
Long Fallow			Mosaic of mature forest, secondary forest, various stages of natural re-growth and cultivated areas with cultivated areas covering between 5 and 30% of total area
Short Fallow			Mosaic of young secondary forest, various stages of natural re-growth and cultivated areas with cultivated areas covering between 30 and 50% of total area

IUCN

The International Union for Conservation of Nature defines "Forest" as 'woody vegetation with a closed tree canopy' and woodland as 'woody vegetation with an open tree canopy'. The division, which we follow, is commonly drawn at 40% canopy cover (IUCN, 1991).

GTZ

The Forest Cover Monitoring Project (GTZ) have produced a uniform forest cover map of the Lower Mekong Basin (LMB). The classification focus on **land cover classes** (MRC/GTZ,1997).

Forest cover was defined as follows:

* An area is considered as **forest** if the tree cover (crown cover) is at least 20% and if tree height can be assumed to be about 10 m or more.

* If the tree cover is equal or more than 20% but tree height ranges only between 5 and 10 m an assignment to the class ' **forest re-growth** ' appeared to be appropriate, even if some stunted forests will be included.

* Areas with less than 20% tree cover or with trees of less than about 5 m height are considered as **' wood-and shrub land '**.

2. 2. 5. Area and volume calculation

Compile and checking the original NFI data

The data from the field work, are checked before analysis by the NFI field staff. Then data are put into the computer, the program is used under windows and is written in 'MS Visual Basic 3.0' (Professional edition). The data entry program for the NFI data has been developed by NOFIP. It has facilities for double data entry as well as identity testing. Double data entry means that all data is entered two times. First all data is entered into the computer, in NFI system the data is put into the field data base. Then the data is entered one more time, and automatically compared to the data already stored in the field data base. If there is any difference, a warning is shown and the user should check the field forms and make sure the correct value to enter.

When the two data bases are identical and tested the data derived from second data entry is copied to the Field subdirectory and becomes the Field data base.

When the Field data base has been created, the data bases must be tested and corrected until there are no more errors that can be corrected.

The new Main data base have been created from the Field data base with the purpose to make the data processing faster. There is a special program that creates the new Main data base.

Accessible Area

Area calculation

Area calculation method was divided into two steps. First calculation of stratum areas and second calculation of area distribution on land use groups. For more detail of area calculation see appendix 2.

Volume estimation

Volume calculation was done in three steps:

- Volume calculation for a single tree
- Average volume per ha

• Total volume within the accessible area

Volume calculation for single tree

Calculating the volume for single tree using volume function. In general volume of a single tree is calculated by the formula below:

$$V = f(D,H,F) = \frac{D^2 * \pi}{4} * H * F$$

Where: D = Diameter at 1.3 meters or 3 decimeters above buttress end

H = The height of crown point

F = Form factor function

The method to calculate H and F is shown in appendix 2.

Volume per ha and total volume

The calculation of average volume per ha and total volume within accessible area (appendix 2)

Inaccessible Area

Area estimation for inaccessible area was referred to aerial photo interpretation.

The calculation method and result for inaccessible area (Appendix 2)

It is impossible to accurately calculate the average volume per ha for different land use group within inaccessible area, but in order to estimate total volume for the province area, the total volume within inaccessible area, has to be considered. One simple way to do that, is using the average volume per ha from accessible areas and multiply with the area for different land use group within inaccessible area. The method probably involves some systematic errors because the standing volume in inaccessible area should be different from that in accessible parts. The result of total volume inside province area (Appendix 2)

2. 3. The Forest type and Land use map

2. 3. 1. Method for map production

The Land use and Forest type map was based upon satellite data and improved by data from aerial photo interpretation, topographic map and data from field check.

2. 3. 2. Satellite image data

The satellite (SPOT) data consist of transparent, multi-spectral and precision corrected satellite image maps in scale 1: 100 000. The image maps are mosaics of data from satellite scenes taken between 1986 and 1992. The bulk of the data is from the period Nov 1987 to March 1990. Satellite imagery has been interpreted, visually according to the principle of satellite imagery interpretation. Every individual area which visible from imagery has been classified and delineated, based on NFI classification system and for current forest, crown density and stand structure are also classified. Other important information such as roads, rivers are also included. The land use and forest type map is mainly based on SPOT satellite image data.

2. 3. 3. Aerial photo data

A national cover of black and white aerial photos has been taken between 1981 and 1982, they are in scale 1: 30 000 and produced with the support of USSR.

The objective of using aerial photo when producing the land use map is to provide some information which can not be specified from satellite image, such as area with frequent clouds, or where the color of imagery is too strange etc. Sometimes it is difficult to distinguish different forest types or stand structure classes. In those cases the old aerial photos are used as a reference.

2. 3. 4. Topographic map data

The topographic map most commonly used is in the scale 1:100 000, and produced in 1985-1986 by the National Geographic Department. It is based upon the aerial photos of 1981-1982. The equidistant is 20 meters in the plain and 40 meters in the mountains.

The national borders and the provincial borders are marked on the map and derived from old topographic map of 1965-1972. The maps are with Gauss projection and Krasovskie ellipsoide.

The national and the provincial border on the land use map are derived from the topographic map. Also road system and villages and other names are taken from the topographic map. Every land use map sheet matches a corresponding topographic map sheet.

2. 3. 5. Data from field check

To improve the experience of the photo interpreters and to control and upgrade interpretation data, field check has been carried out within some areas. For practical reasons only area visible from the road or easy to access were field checked.

2. 3. 6. Out put

The final result is a Land use and forest type map with some information such as locations, areas of the different land use and so on (Figure 2.5). The map is available in map sheets, scale 1:100 000. Also province maps, scale 1:250 000 maps and a digital version is available.

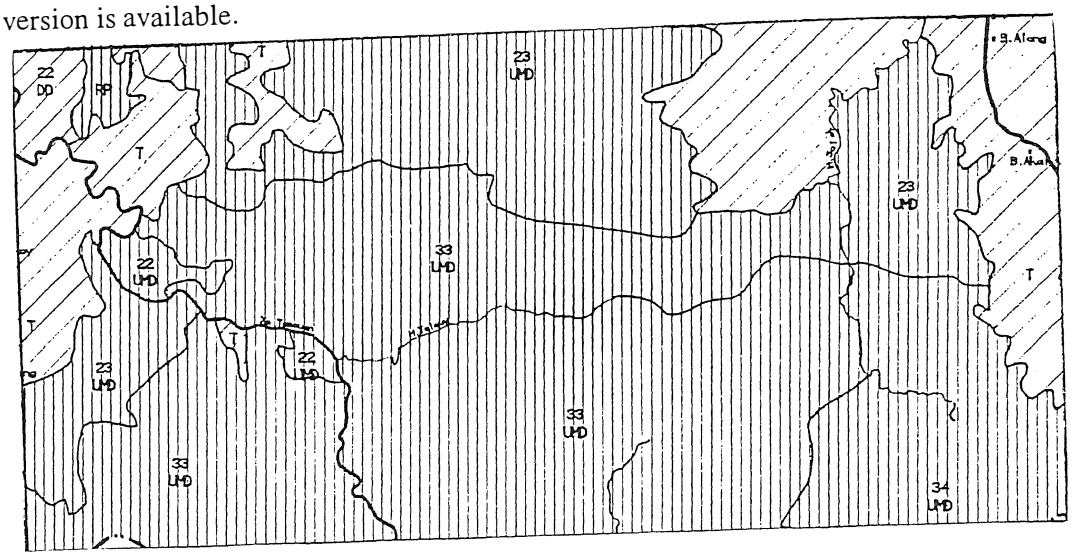

Figure 2.5: Sample of the Land Use and Forest types Map

For the forest types which were classified as current forest, crown density and stand structure have been classified and shown on the land use map.

Crown density is defined as the cover of the horizontal projection of the crown in percent of the ground surface (table 2.2).

Table 2.2: Crown density description

Code number	Percent of crown cover, %	Description
1	20-39	Open
2	40-69	Semi-dense
3	>70	Dense

The classification of Stand structure is based on the mean diameter of the stand, actually the quadratic mean diameter at breast height ($\sqrt{\sum D^2 / n}$), (table 2.3).

Table 2.3: Stand structure description

Code number	DBH, mm	Description
1	<100	Regeneration and sapling
2	100-299	Polewood
3	300-599	Small sawtimber
4	>599	Large sawtimber

The entire mapping operation has been carried out by the staff in the photo interpretation section of NOFIP.

2. 4. Forest Management Inventories

2. 4. 1. Purpose and system

NOFIP is responsible for conducting management inventories. The forest management inventory consists of the inventory statistics of forest, forest classification, and demarcation of forest areas, formulation of management plan, laying down the rules, allocation of forest and forest land use, technical guidance as well as monitoring. Actually, these works are only carried out within the production forest areas.

The applied inventory system is a compartment inventory with systematic sampling using a line plot method. Compartments are first demarcated by means of aerial photographs and each compartment is then inventoried separately. Sampling units are usually square, rectangular or circular plots, according to the inventory design.

2. 4. 2. The system for Dongkapho production Forest (Lao-Swedish Forestry Programme)

Methodology

The Forest Management Planning unit of NOFIP has developed a forest management planning (FMP) system for a part of the natural high forest to be managed as State Production Forest (SPF) for sustainable timber production. The FMP system was tested in Dongkapho SPF in Savannakhet province in 1993, at the same time producing a forest management plan for this forest. The inventory was based on aerial photos at scale 1:20 000 taken in February 1993. The inventory included the following steps:

1. Delineating the gross SPF areas considering information from the Village Surveys.

2. Dividing the gross area into two SPF, Dongkapho North SPF and Dongkapho South SPF.

3. Dividing the two SPF into compartments of size 50-200 hectare following natural borders as far as possible.

4. Delineating, by help of photo interpretation and field checks, the following forest categories inside compartments:

Conservation Forest

Protection Forest

Non-Productive Land

Production Forest

The Production Forest was further delineated in to the following forest types:

* Natural High Forest (NHF)
* Dry Dipterocarp Forest (DDF)
* Degraded Forest

5. Carrying out management inventory in the NHF and the DDF areas of the compartments. The inventory was a line-plot method with plot size 20 x 25 meters, aiming at one plot per 5 hectare of NHF, equivalent to 1 % sampling density. All trees above DBH 20+ were identified and measured.

6. Drawing of a forest management map concept at scale 1:20 000, based on aerial photos, and finally producing the land use map.

7. Measurement of the area of the compartments and sub-compartments on the map concept and tabulating of the data.

8. Processing of field data and area data in a computer. Calculating the volume of each tree using volume estimation functions from the NFI. Each print-out contains information for each compartment, block and total for the SPF.

Result

The total area of Dongkapho SPF, as delineated and classified by the SPF team and the standing volume in the High Natural Forest and Dry Dipterocarp Forest is summarized in section 4.3.2.

2. 4. 3. The system applied in Dongsithouane production forest (FOMACOP)

Methodology

Another inventory system is applied by the Forest Management and Conservation Project (FOMACOP). The purpose is to carry out forest inventories and prepare forest management plans aiming at ecologically, economically and socially sustainable management of the natural forests managed by communities and state forestry organizations. The starting point of these instructions was the system developed by the NOFIP and the Lao-Swedish forestry co-operation, and tested in the DongKapho forest.

The applied inventory system is similar with the design in Dongkapho. But the sample plots are variable-radius circular plots, the plot radius and area depending on the tree diameter. The bigger the diameter of the tree is, the longer is the radius and larger the plot. With this method, the measurements are concentrated on big trees, which account for the greatest share of the volume and value of the forest. The sample plots are measured at 125 meters distances along survey lines 400 m apart. This means that there will be about 1 sample plot for each 5 ha. The sampling ratio is between 0.63 and 2.51% depending on the tree size.

The forest inventory includes different stages of work as follows:

1. Tentative, approximate delineation of the Village forest and State production forest gross area on a topographic map in scale 1:100 000

2. Aerial photography (normally on scale 1:20 000)

3. Village survey of all villages surrounding and within the area including identification of village borders and delineation of the village forest areas and state production forest areas.

4. Interpretation of aerial photographs:

-Detailed drawing of the borders of village forest areas and state production forest areas. on the aerial photos

-Identification of existing roads, tracks, streams etc.

-Delineation of forest management areas (FMA).

-Demarcation of compartments and estimation of their forest categories type.

5. Drawing of a map concept in scale 1:20 000.

6. Calculation the areas of compartment.

7. Field data collection in the compartments through systematic variable-radius circular sample plots method.

8. Put field data into the computer and checking.

9. Calculation of results, production of print outs and drawing of various maps.

10. Preparation of the final inventory report.

Demarcation of the forest compartments

Compartments should be reasonably homogenous in several respects, e.g. site quality, stand density, stand structure, tree size and species composition, management objectives, slope and aspect, accessibility, and administrative boundaries. A large, uniform forest stand may be divided into several compartments and each of them managed differently. The principle in compartment demarcation is to form suitable management units, which are also inventory units. Inventory results are calculated and presented by compartments. The size of the compartment should be 50-150 ha. The minimum size of the compartment is 2 ha.

Design of the line plot layout

Depending on the size of compartments the line plot layout could vary, but in general, it is a base line straight through the compartment with crossing survey lines placed at right angles at 400 m intervals. The distance between survey lines is 400 m and 125 m between the sample plots. With this design, there will be about one sample plot per 5 ha. The plots should be distributed systematically over the compartment by help of base lines and survey lines.

Measurement of trees:

All standing, living or dead, trees equaling or exceeding the minimum diameters are measured.

A Forest Management Area

A Forest Management Area (FMA) consists of forests within the administrative boundaries of a village. Normally a FMA includes different categories of forest land and forest types, e.g., Dry Dipterocarp forest, non productive land, stream buffer zones, mixed deciduous and dry evergreen forest etc. In this report the inventory of a High Natural Forest (NHF) area (totally seven FMA) is summarized. For the dry dipterocarp forests, the inventory result is not yet calculated.

The inventory method in this well-stocked natural high forest was compartment inventory with systematic grid of sample plots. The field work was carried out in 1996 before the rainy season. Actually the result should be presented by compartment, but to make it easy for the comparison later, the result is presented as the total area and summarized to get the total area and volume for seven FMA. (section 4.3.3.)

2. 5. Government guide lines

2. 5. 1. The Forestry Law

The Forestry law of Lao PDR was completed in October, 1996. The law consists of seven parts, with 75 articles, the law determines the principles, the regulations and the measures on the management, use, conservation, preservation, rehabilitation and expansion of forest resources and forest land in Lao PDR. The Law aims at "maintaining a natural equilibrium making the forest and forest land a sustainable source of livelihood for the population, securing the protection of watersheds, preventing of soil erosion, conserving of flora, aquatic and wild animals and the environment and contributing to national socio-economic development in perpetuity".

2. 5. 2. Forest categories

This section will give the definition of forest category which refer to the Forestry Law, Lao PDR, October 1996. And also mentions to the forest categories in the current used and propose used in Savannakhet Province. There are areas of all three different forest categories (defined on the map) within the Province area.

Protection forest

The protection forest is forest and forest land designated for protection of watersheds, prevention of soil erosion, protection of strategic region for national defense, prevention of the natural disasters, environment etc.

There are two protection forest areas within Savannakhet province and those areas are:

* Xebanghiang
* Phoulamphung

Protected forest (conservation)

The protected forest is forest and forest land set aside for the purpose of conservation of fauna, flora species, nature and various things of historical, cultural, Tourists, environmental values, education and importance for scientific study and research areas.

There are nine protected forest areas in Savannakhet province:

* Phou xanghe (National protected area)
* Dong phouviang (National protected area)
* Xebangnouan (National protected area)
* Dongnongphu
* Dongnatat
* Dongnaxai
* Dongmak-u
* Donglaolouang
* Huayxakhong

Production forest area

Production forest is forest and forest land appropriated to meet the requirement for timber and forest resources of the socio-economic development of the country and the livelihood of the population in a sustainable and environmentally sound manner. There are four production forest areas within the province areas of Savannakhet:

* Dongphakada
* Dongnanhom
* Dongkapho
* Dongsithouane

2. 5. 3. Instructions in relation to timber extraction

Harvesting of timber and forest products can be operated in those production forests which have already been inventoried for management and harvesting, and with the management plan, aiming at securing sustainable and rotational timber extraction already formulated (article 25).

The felling of trees for household constructing, repairing and using is authorized only in production forest of the village. Only with the trees of non-prohibited category of volume not exceeding five cubic meters in log per family in need, to be cut in defined area and in accordance with the rules laid down by village administrative authority. For the gathering of forest produces for household use, it should follow the village rules, which are approved by the district agriculture/forestry office (article 28).

Chapter III

Approach to estimate growing stock for small areas

3. 1. The approach

In line with the objective of the study a method (approach) of combining data from NFI and land use map for estimating growing stock and allowable cut has been developed. For practical reasons an abbreviation, "CNL" is introduced herewith as the name of the approach.

This chapter will describe the methodology of the CNL. The approach is illustrated in the flow charts (figure 3.1 and figure 3.2), and further described in sections 3.2-3.4.

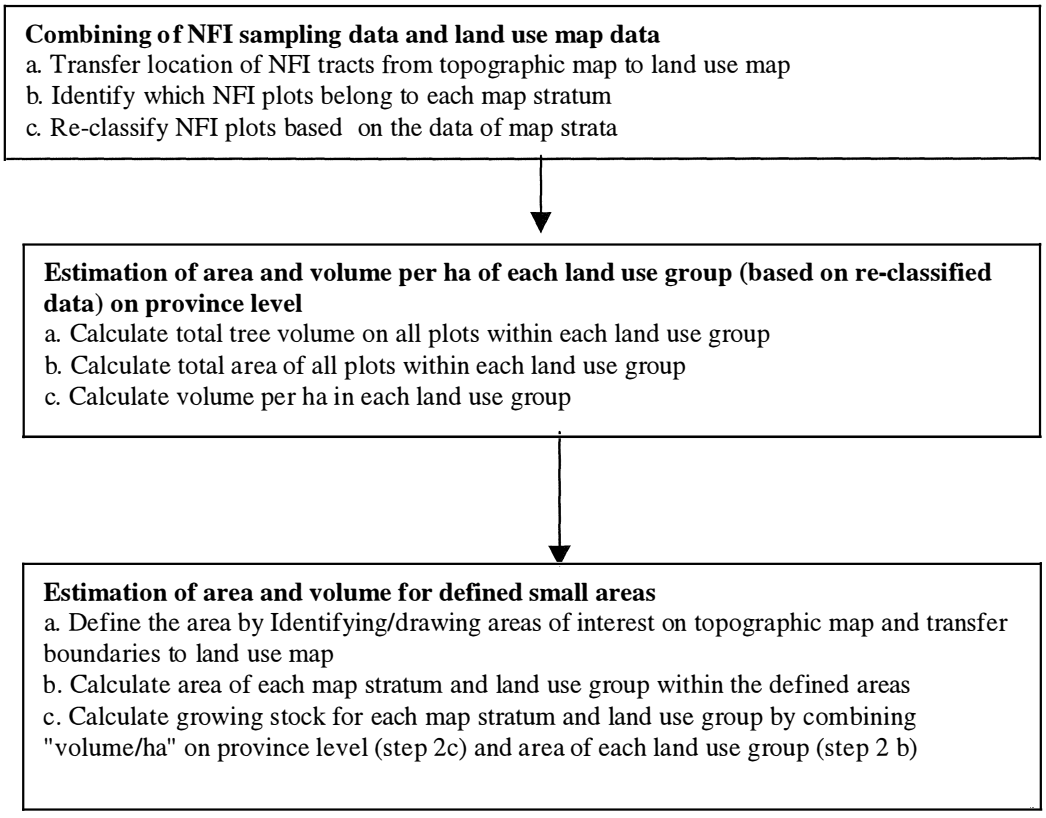

Figure 3.1: The main steps in the approach (CNL)

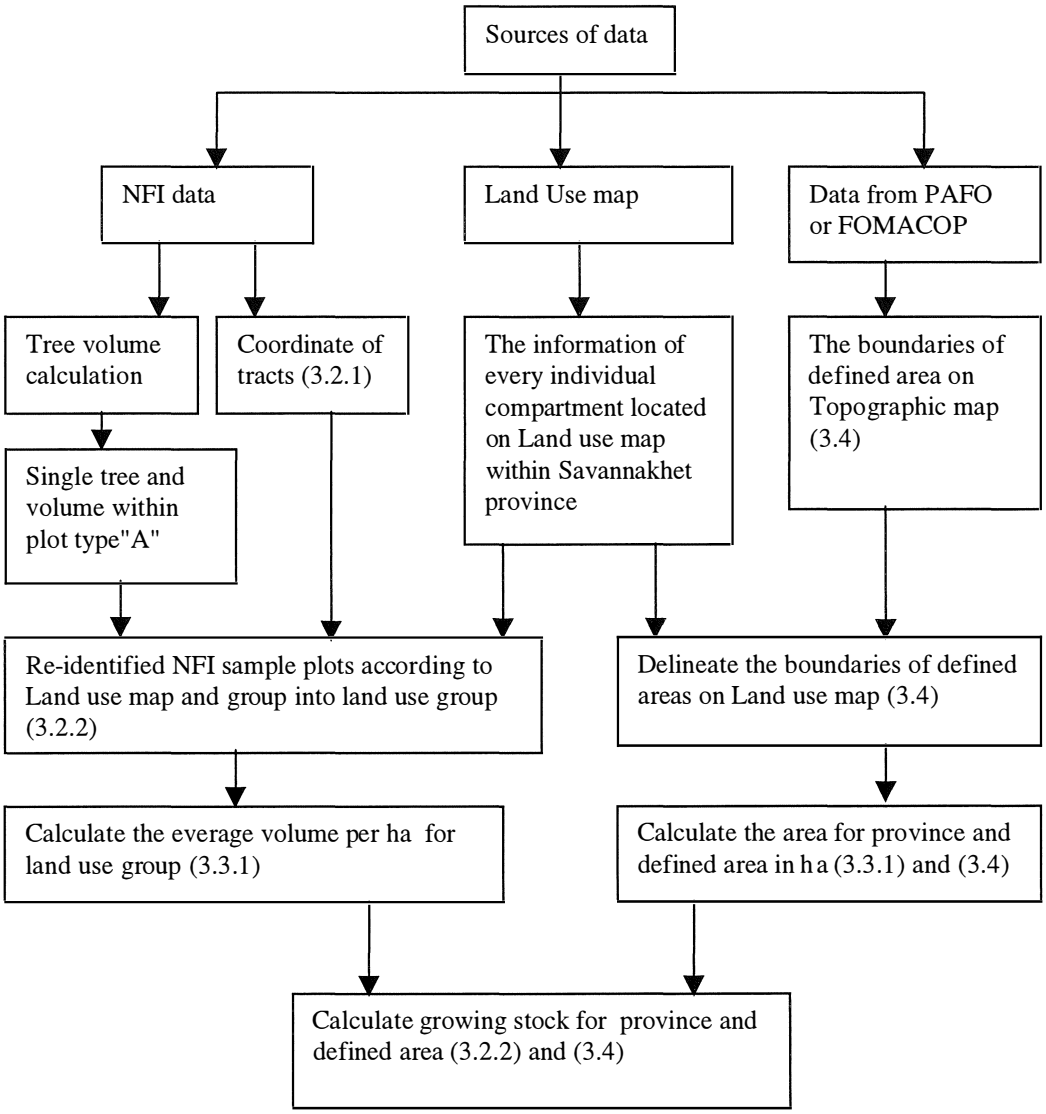

Figure 3.2: The use and combination of various data

The estimate of average volume per ha is based upon two sources of data, the NFI and the Land use map. Data needed from the NFI are the coordinates of the tracts and tree volume within samples of plot type "A". All information on the Land use map is needed. In section 3.2, the method to combine the two data sources is described.

3. 2. The method to combine the data from the NFI and the Land use map.

3. 2. 1. Transferring the location of the NFI tracts from the topographic map to the land use map.

The location of the tracts has been marked (during the NFI) on the topographic map in scale 1:50 000. The South-West corner of every tract was recorded by using the X, Y coordinates (table 3.1). The coordinates of every tract are shown in appendix 3. A technique for transferring the location of the tract from the topographic map to the Land use map with the aid of the ArcView-GIS software was used in the study.

Table 3.1: Example, the coordinate of every tract was recorded by using grid-line X, Y system.

Tract number	Grid X	Grid Y
1002	184 94	18 06
1006	184 93	18 61
1009	185 46	18 61
1010	185 28	18 60

3. 2. 2. Identification of which NFI plots belong to each map stratum (forest type /land use on the map) and re-classification of NFI plots

The locations of the tracts on the topographic map were transferred to the Land use map. A control was done, no transfer mistakes or identification errors had been made. After that, a tract of exactly 1 x 1 centimeter was laid out in the map scale 1:100 000 (figure 3.3)
For every plot of type "A", the land use and forest type was re-classified according to land use map.

As an example, for tract number 1029, the sample plots have been re-classified according to land use map, as in the table below (compare figure 3.3):

Table 3.2: the NFI plots have been re-classified according to land use map

Plot number	NFI			Land Use map		
	Land use	c. density	s. structure	Land use	c. density	s. structure
N4	DD	3	3	DD	2	2
N8	DD	3	3	DD	2	2
E4	RP			RP		
E8	RP			DD	2	2
S4	DD	2	2	DD	2	2
S8	RP			DD	2	2
W4	DD	2	3	DD	2	2
W8	DD	2	3	DD	2	2

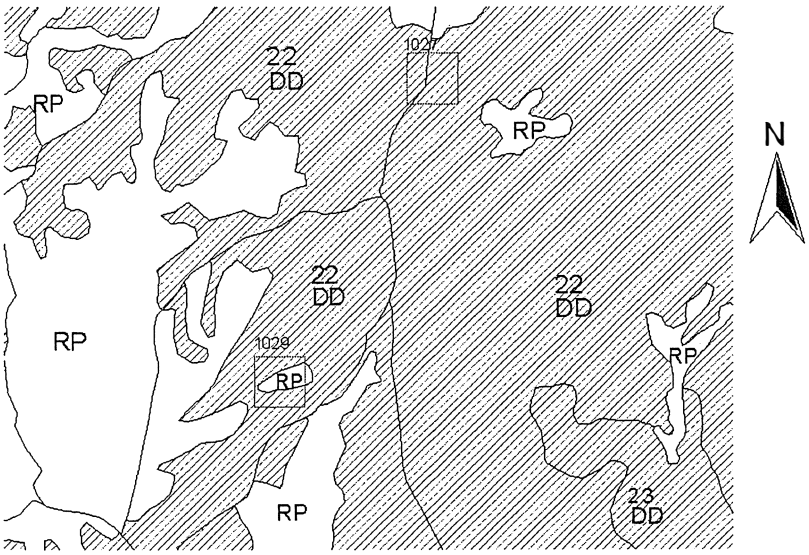

Figure 3.3: The tracts were transferred from Topographic map to land use map

Based on land use/forest type on the land use map, the sample plots were re-classified and referred to the different land use groups. The number of sample plots distributed in different land use group is shown in table 4.1

3. 3. Area and volume calculation on province level

3. 3. 1. Area calculation

Area calculation is based on the land use map, where the area of every map stratum has been calculated with the aid of Arcview-GIS software. The area can be calculated in many different ways, in groups or individual land use and forest type according to the preference of the user. In this case, in order to make it easy to make comparisons with the area calculation from NFI (appendix 2), the calculation of province area has been made in two steps. First, calculation of the area in different land use groups, and second, summation on province level. The calculation is expressed by the simple formulas below:

$$A_t = \sum_{h=1}^{L} A_h$$

$$A_h = \sum_{i=1}^{n} a_{hi}$$

Where A_t = The total province area

L = The number of strata

h = Stratum number

A_h = The total area for stratum h

a_{hi} = Area of compartment i within stratum h

In the calculation for Savannakhet province, the accessible area and the in-accessible area could not be separated, because the boundaries were not defined on the topographic map. The results of the area calculation (CNL) for the whole province is shown in table 4.2

3. 3. 2. Calculation of volume (including precision)

The estimation of growing stock (single tree and average volume per ha) is based upon two sources of data, the NFI and the land use map.

The volume calculation of single trees is slightly different from the NFI results, presented by NOFIP in 1996, because new crown point height functions and new form factor functions to calculate volume of single tree have been applied in this study.

All sample plots within Savannakhet province have been stratified into different land use groups (section 3.2.2), in order to calculate the average volume per ha. The CNL method is based on the principle of Stratified Random Sampling (SRS). It means, the calculation of tree volume can be calculated step by step, such as the average volume per ha for different land use groups, total volume per land use group, and total volume for the specified area. The formulas below were used in the calculation:

(1) Estimation of the average volume per ha in each land use group

$$\bar{y}_{sh} = \frac{1}{n_h}\sum_{i=i}^{n_h} y_{hi} \quad \text{and} \quad \bar{y}_h = \frac{\bar{y}_{sh}}{a_s}$$

Where: y_{hi} = The tree volume inside the plot *i* th within land use group h

$\bar{y}_{sh}$ = The average volume per sample plot for land use group h

n_h = The number of sample plots within land use group h

$\bar{y}_h$ = The average volume per ha for land use group h

a_s = Area of sample plot (0.04 ha)

(2) Estimate total volume for land use group h within province area

$$\hat{\tau}_h = A_h \bar{y}_h$$

(3) Estimate total volume within province area

$$\hat{\tau}_{st} = \sum_{h=1}^{L} A_h \bar{y}_h$$

(4) Estimate average volume per ha for province area

$$\bar{y}_{st} = \frac{1}{A_t}\sum_{h=i}^{L} A_h \bar{y}_h$$

The precision of the estimates

Standard error (SE) of estimators are calculated as $SE(x) = \sqrt{\hat{\text{var}}(x)}$, (x) is the variable of interest.

$$\hat{\text{var}}(\bar{y}_h) = \frac{s_h^2}{n_h}$$ Unbiased estimator of variance of the estimator ($\bar{y}_h$)

Where $$s_h^2 = \frac{1}{n_h - 1}\sum_{i=1}^{n_h}(y_{hi} - \bar{y}_{sh})^2$$ Sample variance

$$\hat{\text{var}}(\hat{\tau}_h) = A_h^2\left(s_h^2/n_h\right)$$ Unbiased estimator of variance of the estimator ($\hat{\tau}_h$)

$$\hat{\text{var}}(\hat{\tau}_{st}) = \sum_{h=1}^{L} A_h^2\left(s_h^2/n_h\right)$$ Unbiased estimator of variance of estimator ($\hat{\tau}_{st}$)

$$\hat{\text{var}}(\bar{y}_{st}) = \frac{1}{A_t^2}\hat{\text{var}}(\hat{\tau}_{st})$$ Unbiased estimator of variance of estimator ($\bar{y}_{st}$)

The standard error of estimators measures the precision with which an estimate from one sample approximates the true population value. And thus can be used to construct a confidence interval to assess the precision of the estimate.

The results of average volume per ha, total volume and its standard error for different land use groups and for the whole province area (CNL) is presented in table 4.4.

3.4. Calculate area and volume for the defined areas

3.4.1. Defining areas on the land use map

There are two protection areas, four production areas and nine protected (conservation) areas which have been defined in Savannakhet province (section 2.5.2). The boundaries of each individual area have been delineated on the topographic map in scale 1:100 000. The information was collected from the Provincial Agriculture and Forestry Office (PAFO) and other projects, such as FOMACOP. As a second step, that information has

been transferred from topographic map to land use map by the aid of ARC/INFO coverage system. As a result, for each one of the 15 areas mentioned above, individual land use maps have been extracted and some of them are shown in appendix 4. Using this technique, new project areas and other areas could also be defined at any time.

3. 4. 2. Area calculation

The area of all individual map strata located within each defined area is calculated by using Arcview/GIS software. Actually, it could also be done manually using millimeter paper. For example, if any share of a compartment is located inside, the area of that part is calculated. Based on available information for each map stratum, the distribution on land use/forest type, crown density and stand structure of the defined area is calculated (appendix 3).

3. 4. 3. Volume calculation

The general principles of volume calculation described in section (3.3.2), is based upon average volume per ha and the area of interest. In case, the growing stock for a small area is estimated, using the average volume per ha for land use group as described in section 3.3.2, will not be perfectly suitable, because it is too general and does not reflect local variation. The approach of CNL is to make use of information of stand structure and crown density and not only land use/forest type (see also table 4.7-4.9, 4.11-4.13). Two "small areas" have been selected with the purpose to compare estimated values with management inventory results, and each area is described separately below:

Dongkapho SPF

The location of the boundary of Dongkapho SPF has been collected from the land use map of "Dongkapho State Production Forest" (specific land use map). That boundary has been transferred to land use map (general land use map), and the area calculated (appendix 3). Volume calculation is based on the area of current forest and the average volume per ha from table 4.13, because the management inventory in this area only collected data on trees with a minimum tree diameter of 20 cm. The result of the volume calculation for Dongkapho SPF (CNL) is presented in section 4.3.1.

Dongsithouane (7 FMA)

The location of the boundary of Dongsithouane production forest (includes seven Forest Management Areas) has been collected and delineated on the topographic map, scale 1:100 000. This information is available in the FOMACOP project, Savannakhet province. After transferring that information to the land use map, the seven FMA have been indicated (appendix 4). To make it easy to compare the estimates of growing stock with the management inventory results, the areas of Natural High Forest, have been selected. There is exactly one compartment (map stratum) of NHF in each FMA. All those compartments have the same crown density (2) and stand structure (3). The average volume per ha have been applied is from table 4.9, and the result is shown in section 4.3.2.

Chapter IV

Evaluation of the approach

4. 1. How to group data in suitable strata

In stratified sampling, the population is partitioned into strata (for example) land use groups and a sample is selected by some design within each stratum. Because the selections in different strata are made independently, the variances of estimators for individual strata can be added together to obtain variances of estimators for the whole population. Since only the within-stratum variances enter into the variances of estimators, the principle of stratification is to partition the population in such a way that the units within a stratum are as similar as possible. Then, even though one stratum may differ markedly from another, a stratified sample with the desired number of units from each stratum in the population will tend to be "representative" of the population as a whole (Steven K. Thompson, 1992).

The sample plots were not distributed in all land use groups (table4.1). The sampling design was mainly aiming at current forest, because to estimate growing stock and allowable cut was regarded the most important objective.

Table 4.1: The number of sample plots in Savannakhet province distributed within different land use group, according to land use map (sample plots were laid out in accessible area only)

Land use groups	No. of sample plots (n_h)	Area of sample plots(a_{sh}), ha	Area of sample plots in , %
Current Forest	252	10.08	61.76
Natural High Forest	*40*	*1.60*	*9.80*
Dry Dipterocarp.	*212*	*8.48*	*51.96*
Potential Forest	90	3.60	22.06
Other Wooded area	0	0	0
Agricultural Land	58	2.32	14.22
Other Land use	8	0.32	1.96
Total	408	16.32	100.00

If we compare the area of land use groups (table 4.2) and the sample plots within them, the sample plots selection are related to its areas. For example the area of current forest cover 62.14% of total province area and the sample plots are represented within them are 61.76% of total sample plots. Because the sample plots were laid out in accessible area

only, and according to the results of area calculation for accessible area from NFI (appendix 2), current forest represent about 58% of total land area, and Natural High Forest (NHF) is represent only 15% of total land area or about 26% of current forest area. It means the dominant forest type of current forest within accessible area is Dry Dipterocarp (DD) forest type, therefore it can be the reasonable, that the number of sample plots within NHF are lower than DD.

Table 4.2: The results of area estimation for land use groups and total area within Savanakhet province (CNL)

Land Use /Forest type	Area	
	%	1000 ha
Current Forest	62.14	1,352.7
Natural High Forest	*30.56*	*665.2*
Dry Dipterocarp	*31.58*	*687.4*
Potential Forest	24.32	529.4
Other Wooded Area	0.43	9.4
Agriculture Land	11.31	246.1
Other Land use	1.79	38.9
Total	100.00	2,176.5

There are four forest types, which are classified as current forest within Savannakhet province (table 4.3). For estimating growing stock, current forest was divided into two sub-groups, Natural High Forest (three first forest types) and Dry Dipterocarp. The Dry Dipterocarp forest is very different from the other, tree diameter is comparably small, the crowns do not spread out widely, some of the tree species in this forest type will never occur in other forest types. On the other hand, the three first forest types are more similar to each other, the sample plots are few in Gallery forest type, and there are not any sample plots within Dry Evergreen forest type. So, in order to estimate growing stock the Dry Dipterocarp forest type should be treated separately from the other.

Table 4.3: The areas of forest types classified as current forest within Savannakhet province (CNL).

Forest type	Percent, %	Area, 1000 ha
Dry Evergreen	3.18	43.0
Mixed Deciduous	45.04	609.2
Gallery forest	0.97	13.0
Dry Dipterocarp	50.82	687.4
Total	100.00	1,352.6

The variance of estimators is one of the keys to indicate the precision of estimators. When land use and forest types are grouped as similar as possible, it will minimize the variances of the estimators.

According to table 4.4, the standard error of the average volume per ha for dry dipterocarp forest type is the lowest, one is the variety of growing stock within them are small, and the other should be the sample plots are large enough, if compare with other land use groups.

Table 4.4: The average volume per ha and total volume for all tree species in different land use groups in the province and its standard error (CNL).

Land use Groups	Area		Volume per ha		Total volume	
	%	1000 ha	m^3/ha	SE	1000 m^3	SE,1000 m^3
Current Forest	62.14	1,352.7	71.55	9.42	96,790	12,878
Natural High Forest	*30.56*	*665.2*	*101.57*	*19.14*	*67,564*	*12,732*
Dry Dipterocap	*31.58*	*687.4*	*42.52*	*2.81*	*29,225*	*1,932*
Potential Forest	24.32	529.4	20.23	3.38	10,711	1,787
Other Wooded area	0.43	9.4	-	-	-	-
Agricultural land	11.31	246.1	18.89	5.08	4,648	1,250
Other land use	1.79	38.9	-	-	-	-
Total	100.00	2,176.5	51.53	6.00	112,149	13,061

However, the sample plots are only laid out in accessible areas, if the volume per ha in current forest is systematically different in accessible areas compared to inaccessible areas the figures (total volume) in table 4.4 are biased. With the idea to evaluate the growing stock for whole province and how big difference if compare with the NFI result, the figure has been made.

This CNL method can also provide information about the volume of commercial tree species and non-commercial tree species within different land use group, shown in tables below:

Table 4.5: The average volume per ha and total volume for commercial tree species in different land use and its standard error (CNL).

Land Use Groups	AREA		Volume per ha		Total volume	
	%	1000 ha	m^3/ha	SE	1000 m^3	SE, 1000 m^3
Current Forest	62.14	1,352.7	32.26	3.74	43,634	5,056
Natural High Forest	*30.56*	*665.2*	*29.78*	*7.17*	*19,810*	*4,772*
Dry Dipterocarp	*31.58*	*687.4*	*34.66*	*2.43*	*23,823*	*1,670*
Potential Forest	24.32	529.4	10.62	2.06	5,620	1,092
Other Wooded area	0.43	9.4	-	-	-	-
Agricultural land	11.31	246.1	9.54	2.92	2,349	719
Other land use	1.79	38.9	-	-	-	-
Total	100.00	2,176.5	23.71	2.40	51,602	5,222

Table 4.6: The average volume per ha and total volume for non-commercial tree species in different land use and its standard error (CNL).

Land Use Groups	AREA		VOL/ha		VOLUME	
	%	1000 ha	m^3/ha	SE	1000 m^3	SE,1000^3
Current Forest	62.14	1,352.7	39.30	8.33	53,156	11,266
Natural High Forest	*30.56*	*665.2*	*71.79*	*16.91*	*47,754*	*11,247*
Dry Dipterocarp.	*31.58*	*687.4*	*7.86*	*0.94*	*5,402*	*646*
Potential Forest	24.32	529.4	9.62	2.19	5,091	1,160
Other Wooded area	0.43	9.4	-	-	-	-
Agricultural land	11.31	246.1	9.34	3.34	2,299	822
Other land use	1.79	38.9	-	-	-	-
Total	100.00	2,176.5	27.82	7.35	60,546	11,355

The variety of the average volume per ha for commercial tree species and non-commercial tree species distributed in different land use and forest type is illustrated in the figure below.

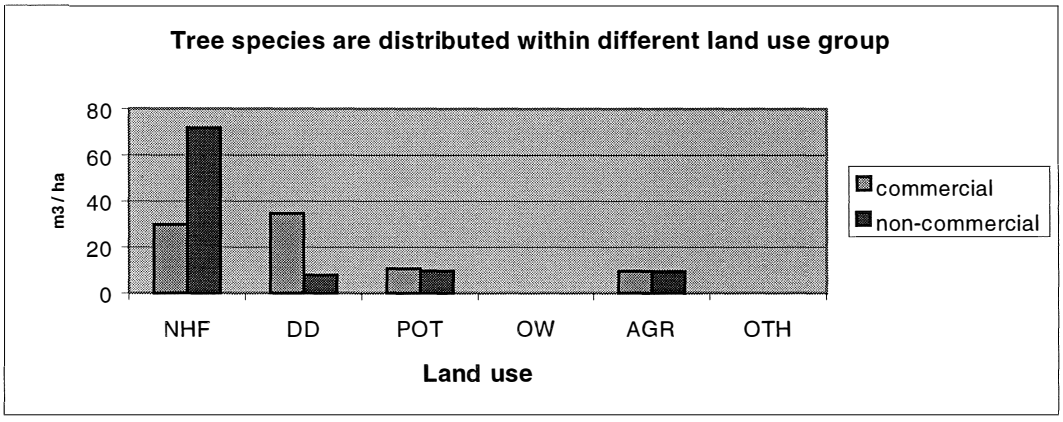

Figure 4.1: The difference between commercial and non-commercial tree species (m^3 / ha) in different land use groups (CNL).

There are over 300 tree species in Lao PDR (field manual, 1991). In the Dry Dipterocarp forest type (DD), some tree species, such as *Dipterocarpus intricatus; Dipterocarpus obtusifolius; Terminalia tomentosa; Shorea obtusa; Shorea siamensis; Dipterocarpus tuberculatus,* are the dominant tree species and characteristically for this type of forest, and all of them are specified as " commercial tree species" , so in case, estimate volume per ha for DD, commercial tree species much higher compared with non-commercial tree species. Other assumption, there are many tree species in the Natural High Forest (NHF) and some of them could not be specified in the field (what tree species they are?), these species were specified as " un-known species" and grouped to non-commercial tree species, that can be the reason why the volume of non-commercial tree species is higher than commercial tree species in the NHF.

For every forest type classified as current forest, the crown density and stand structure has been classified. So, in order to estimate volume per ha one should study not only the average volume per hectare of each forest type but also if crown density or stand structure could improve the estimate.

The tables below shows the average volume per ha on the sample plots according to different crown density only, and both crown density and stand structure.

Table 4.7: Average volume per ha for Natural High Forest and Dry Dipterocarp forest types according to different crown density (CNL).

Forest types	Crown density 1			Crown density 2			Crown density 3		
	No.plot	Vol/ha	SE	No.plot	Vol/ha	SE	No.plot	Vol/ha	SE
NHF	8	22.08	6.96	21	96.65	30.39	11	168.77	26.9
DD	26	32.98	4.43	186	44.07	2.96	-	-	-

Table 4.8: The average number of trees per ha, average volume per ha and its standard error for the Dry Dipterocarp forest type according to crown density and stand structure (CNL).

Crown density	Stand structure	Number of sample plots	Average number of trees per ha	Average volume per ha	SE
1	2	12	131	32.26	7.97
1	3	14	236	33.60	4.90
2	2	181	210	43.81	3.01
2	3	5	160	45.24	19.02

Table 4.9: The average number of trees per ha, average volume per ha and its standard error for the Natural High Forest type according to crown density and stand structure (CNL).

Crown Density	Stand Structure	Number of sample plots	Average number of trees per ha	Average volume per ha	SE
1	3	8	147	22.08	6.96
2	2	8	319	46.67	12.20
2	3	13	379	127.41	47.18
3	3	11	543	168.77	26.99

The stand structure in the Dry Dipterocarp forest type seem to be not improve the estimator (volume per ha), if they are the same crown density (table 4.8). But, in the Natural High Forest, stand structure much improves the estimator, even the same crown density. So, in order to estimate total volume for any small area, the average volume per ha for Dry Dipterocarp (table 4.7), and Natural High Forest (table 4.9) can be applied.

The figures above (table: 4.4-4.9), that refer to the minimum tree diameter 100 mm. Anyhow, the CNL can also provide the average volume per ha with the minimum diameter larger than 100 mm, according to the need of users. Example to compare the result of growing stock in Dongkapho State Production forest, between CNL and the management inventory. First, the minimum tree diameter has to be identified, because the result of growing stock from management inventory was based on the minimum tree diameter 200 mm. So, CNL should determine the average volume per ha with the minimum tree diameter 200 mm. The simplest way, is to exclude trees diameter below 200 mm, from NFI field work and calculate the average volume per ha in the same way as in section 3.3.2. The results are shown below.

Table 4.10: The average number of trees per ha and volume per ha for different land use groups with the minimum tree diameter 200 mm (CNL).

Land Use Group	Number of tree per ha	Volume per ha	
		m^3/ha	SE
Current Forest	101	61.967	9.507
NHF	111	83.925	18.406
DD	91	41.173	6.231
Potential Forest	36	14.924	3.040
Other wooded area	-	-	-
Agricultural land	33	16.589	4.728
Other Land use	76	-	-

Table 4.11: Average volume per ha for Natural High Forest and Dry Dipterocarp forest types according to different crown density, with the minimum tree diameter 200 mm (CNL).

Forest types	Crown density 1			Crown density 2			Crown density 3		
	No.plot	Vol/ha	SE	No.plot	Vol/ha	SE	No.plot	Vol/ha	SE
NHF	8	16.77	4.83	21	79.58	29.66	11	141.06	27.86
DD	26	26.11	4.37	186	43.28	7.06	-	-	-

Table 4.12: The average number of tree per ha, average volume per ha and its standard error for the Dry Dipterocarp forest type according to crown density and stand structure, with the minimum tree diameter 200 mm (CNL).

Crown density	Stand structure	Number of sample plots	Average number of trees per ha	Average volume per ha	SE
1	2	12	60	28.49	7.28
1	3	14	80	24.07	5.40
2	2	181	94	43.38	7.25
2	3	5	90	39.41	18.09

Table 4.13: The average number of trees per ha, average volume per ha and its standard error for the Natural High Forest type according to crown density and stand structure, with the minimum tree diameter 200 mm (CNL).

Crown Density	Stand Structure	Number of sample plots	Average number of trees per ha	Average volume per ha	SE
1	3	8	53	16.77	4.83
2	2	8	78	27.61	8.60
2	3	13	127	111.56	46.02
3	3	11	157	141.06	27.86

The results of the growing stock estimate in Savannakhet province will be more precise if the sampling units are laid out in all different types of current forest (table 4.14) and the variance of estimators minimized by increase of the number of sample plots. The sample plots were laid out in all different types of the Dry Dipterocarp forests, that's mean the sample plot will tend to be "representative" of the Dry Dipterocarp forest type as a whole.

Table 4.14: the different combinations of forest type, Crown density and Stand structure occurring on the land use map of Savannakhet Province. For each combination the area covered on the map and the number of NFI sample plots (accessible areas) falling within that area is presented (CNL).

The combinations of forest type			Area		Sample plots	
Forest type	C.density	S.structure	1000 ha	%	Number	%
Natural High	1	2	1.0	0.1	0	0.0
Forest (Dry	1	3	63.0	4.7	8	3.2
Evergreen,	2	2	120.7	8.9	8	3.2
Mixed	2	3	268.4	19.8	13	5.2
Deciduous,	3	2	9.8	0.7	0	0.0
Galleryforest	3	3	162.2	12.0	11	4.4
types)	3	4	40.1	3.0	0	0.0
Dry Dipterocarp	1	2	136.8	10.1	12	4.8
	1	3	36.4	2.7	14	5.6
	2	2	493.5	36.5	181	71.8
	2	3	20.7	1.5	5	2.0
Total			1,352.6	100.0	252	100.0

4. 2. Error in estimates

4. 2. 1. Basic principles

Sampling provides estimates of the population characteristics of interest. If the sample size would be expanded until all N units of the population were included in the sample, then the population characteristic would be known exactly. Some obvious questions are how best to obtain the sample and make the observation and, once the sample data are in hand, how to use them in the best way to estimate the characteristic of the whole population. While the population characteristic remains fixed, the estimate of it depends on which sample is selected. However, a large sample size will give a high precision, but balanced against the advantages of a large sample size are the limitations of time and cost, one is free to choose alternative sizes and shapes of units, and such choices may affect the cost of the survey and the precision of estimators.

The sampling design for the NFI in Savannakhet province was a stratified, systematic cluster (tract) sampling. Totally 51 tracts, equaling 408 sample plots were allocated (within accessible area), to estimate the growing stock for the accessible area and also assume the growing stock for whole population (whole province area).

The CNL is the combination data between the NFI and the Land use map to estimate growing stock for any small area in Savannakhet province.

The section below is the discussion of the types of survey errors and the accuracy of estimates derived from surveys (CNL).

4. 2. 2. Types of Survey Errors

Estimates derived from sample surveys are subject to two types of errors, sampling errors and nonsampling errors.

Nonsampling errors

Non sampling error can be attributed to many sources. In CNL method, three main types of errors are identified: location of tracts, time of survey, and the precision of the land use map as described below:

Location of tracts and sample plots:

The location of the tracts were marked on the topographic map scale 1:100 000, and also marked on the air photos scale 1: 30 000. To access the tract (in the field), a reference point could be identified on map and on air photo. The nearest suitable point on the tract side was taken as starting point and reached through measuring and walking by compass from the reference point. The location of the tract can be defined accurately in the field, if the reference point is clear and the distance from that point to the tract is short.

But in reality it is often difficult to identify the location of tracts, if there were not any referent point, which is a source of error and misrepresentation of field data.

Time of survey

The information on land use map is based on satellite (SPOT) scenes taken between 1987 and 1992 (most of the imagery were taken in 1987). The NFI field operation was carried out in 1992. If the time is different the information can also be different, especially the area where logging or clearing of land take place during that time.

The precision of land use map

The precision of the land use map depends upon the satellite image and the quality of the air photo interpretation. That means, if the interpretation was done incorrectly, especially where the sample plots were located, that will be affected to the precision of the approach. One "error" concerns the "smallest mapping unit" or the aggregation on the

map. On the land use map any stands smaller than about 10 ha are aggregated with a neighbouring stand for practical reasons. For example, there is a tract laid out on current forest area, according to map stratum, within that stratum, there are small areas which are not current forest located, some of sample plots were located exactly in these small areas, then the information which derive from these sample plots will not represent the characteristic of current forest.

The precision of the land use map is limited at a level, if area of map stratum is smaller than 10 ha.

Conclusion: In three types of errors above, the third (the precision of land use map) are likely to be the most serious.

If we compare the result of the classification of land use and forest type between the land use map and the NFI field work (table 4.15). The figures shows the number of sample plots within different land use and forest type according to land use map, and the number of sample plots within different land use and forest type which have been recorded from the field. The number of sample plots in form (bold) indicated, that numbers were classified the same from both sizes. Suggestion, when one of three types of errors is occurred, that will lead to the field data (NFI) can be different if compared with land use map.

Table 4.15: The comparison between the number of sample plots CNL and the number of sample plots from the NFI field operation.

CNL		Number of sample plots from NFI field work					
Land use	No.of spp	NHF	DD	POT	OTHW	AGR	OTH
NHF	40	**25**	7	3	1	2	2
DD	212	11	**164**	9	2	19	7
POT	90	17	10	**34**	0	13	16
OTHW	0	0	0	0	**0**	0	0
AGR	58	7	13	7	2	**24**	5
OTH	8	0	0	0	0	3	**5**

Sampling errors

Sampling error occur when estimates are derived from a sample rather than a census of the population. The sample used for a particular survey is only one of a large number of possible samples of the same size and design that could have been selected. This CNL is

the combination of two data NFI and land use map, NFI design (field work) was carried out in accessible area only, so the out come of CNL (volume per ha) will not be suitable to apply to in-accessible area. On the other hand, NFI design, the tracts or sample plots were aim at current forest only (not in detail), the design could not separated Natural High Forest and Dry Dipterocarp, so, according to table 4.14, the sample plots were too large in DD forest type if compare to NHF.

4. 2. 3. Assessing the Precision of Estimates

Having selected a sample and used the sample data to make an estimate of the population mean or total such as an average volume per ha or total volume, it is desirable in addition to make an assessment regarding the precision of the estimate. The customary approach is to construct a confidence interval within which one is sufficiently sure the true population value lies or, equivalently, placing a bound on the probable error of the estimate.

The standard error of a survey estimate measures the precision with which an estimate from one sample approximates the true population value**. The smaller the standard error of an estimate the more precise is that estimate**. And thus can be used to construct a confidence interval for a survey parameter to assess the precision of the estimate.

Let I represent a confidence interval for the population mean μ. Choosing some small number α as the allowable probability of error, the procedure should have the property that $P(\mu \in I) = 1-\alpha$. The quantity 1-α is named the confidence coefficient, and the interval is called a 100(1-α)% confidence interval. Typical (arbitrary but conventional) choices for the value of α are 0.01, 0.05, and 0.1. With α=0.05, for instance, the confidence coefficient is 0.95 or 95% confidence interval of the true population value lies.

When all the stratum sample sizes are sufficiently large, an approximate 100(1-α)% confidence interval for the population total is provided by:

$$\hat{\tau}_{st} \pm t\sqrt{\hat{\text{var}}(\hat{\tau}_{st})}$$

Where t is the upper $\alpha/2$ point of the normal distribution. For the mean the confidence interval is

$$\hat{\mu}_{st} \pm t\sqrt{\hat{\text{var}}(\hat{\mu}_{st})}$$

As a rule of thumb, the normal approximation may be used if all the sample sizes are at least 30. With small sample sizes, the t-distribution with an approximate degree of freedom may be used.

4. 3. Comparison with data from other sources (Management Inventory)

4. 3. 1. General

In order to evaluate the CNL approach of estimating growing stock in small area, some areas with independent inventory data have been identified. The growing stock has been estimated using the CNL and compared with the independent data for those areas. The result has been evaluated in two areas of production forest, Dongkapho and Dongsithouane. The comparison of area, average volume per ha and total tree volume in each area is described in section 4.3.2 and section 4.3.3.

4. 3. 2. Dongkapho production forest

Area

In the management inventory of the area of Dongkapho SPF, summarized in the table 4.16, there are three different forest categories, Non-productive Forest land, Protection Forest and Production Forest. Production Forest is further divided into three forest types, Natural High Forest, Dry Dipterocarp and Degraded Forest. In the table 4.6, Natural High Forest and Dry Dipterocarp can be called " net production forest" because Natural High Forest includes only the areas with an average volume per ha greater than 70 m^3/ha and Dry Dipterocarp Forest includes only the areas with an average volume per ha greater than 40 m^3/ha. The remaining, low-stock area of those forest types is classified as Degraded Forest.

Table 4.16: Area calculation, Dongkapho SPF (management inventory result).

Forest category/ Forest type	North	South	Total	%
Production Forest				
Natural High Forest	3,890	2,035	5,925	62
Dry Dipterocarp	201	-	201	2
Degraded Forest				
Low-Stocked	728	492	1,220	13
Natural Regeneration	473	64	537	6
Young Follow	8	18	26	0
Sub-total Production Forest	***5,300***	***2,609***	***7,909***	***83***
Protection Forest	1,135	136	1,271	13
Non-Productive Forest land	379	22	401	4
Total	**6,814**	**2,767**	**9,581**	**100**

After the area of the management plan had been superimposed on the land use map, the distribution on forest types according to that map was calculated (table 4.17). A land use map for Dongkapho SPF based on aerial photos had already been produced in connection with the management inventory in 1993.

Table 4.17: Area calculation, Dongkapho SPF (CNL)

Dongkapho	Land use/forest types	C. density	S. structure	Area, ha	Adjusted area with 0.764, ha
	MD	1	3	485	371
North	MD	2	2	124	95
	MD	2	3	104	79
	MD	3	3	7,120	5,440
	DD	2	2	57	44
	T			20	15
	N			839	641
	G			169	129
Sub-total				**8,918**	**6,814**
	MD	2	2	58	44
South	MD	2	3	160	122
	MD	3	3	3,385	2,586
	T			28	21
Sub-total				**3,631**	**2,774**
G-total				**12,549**	**9,588**

The evaluation was complicated because of a scale error, which had been made in the preparation of the land use map linked to the management inventory. As a result, the total area on the land use map had to be adjusted during evaluation. The correction factor could not be exactly determined but a factor of 0.764 was approximated and found feasible for both the North and the South part of Dongkapho SPF.

To compare the area calculation of the CNL and the management inventory, the corresponding classes in two tables above have been simplified and identified as far as possible. It means the land use and forest type (table 4.17) is converted to forest categories referring to the management inventory principle. As an example, areas of Natural High Forest (NHF) in the management inventory are compared with areas of Mixed Deciduous Forest of more than 70 m^3/ha according to the CNL. A comparison of the results is shown in table 4.18 and figure 4.2. The Northern and Southern part of the area are compared separately.

Table 4.18: Area comparison of the two approaches, Dongkapho SPF

Forest categories	Area, ha			
	North(CNL)	North(M Inv)	South(CNL)	South(M Inv)
NHF(MD, > 70m^3/ha)	5519	3890	2708	2035
DD (> 40m^3/ha)	44	201	0	0
Degraded Forest (T,N)	1122	1209	66	574
Protection Forest	0	1135	0	136
Non-productive Forest (G)	129	379	0	22
Total	6814	6814	2774	2767

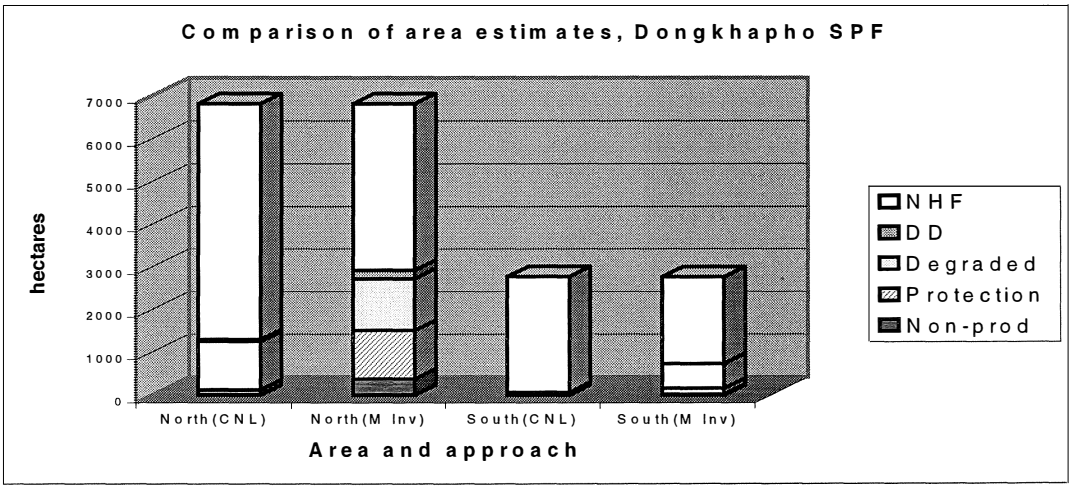

Figure 4.2: Area comparison between the CNL and the management inventory

As we see, in both areas, the area of NHF is less according to the management inventory than the CNL. The possible explanations to the differences could be as follows:

- The time of survey is different, the CNL represents 1989 and the management inventory represents 1993, so, there could be a real change of forest cover.
- During 1986 to 1992, some area had been logged by selecting logging, according to management inventory reported. In this case the total area of forest would not have changed but the area of the Net production forest could have changed.
- The CNL could not identify the area of Protection forest. Some areas of Production Forest according to CNL should actually have been included in the area of Protection Forest.

Tree volume

The area of NHF and DD according to the management inventory report has been selected as the area to estimate growing stock for Dongkapho SPF. The calculation of area, average volume per ha and total volume is shown in each block (table 4.19).

Table 4.19: The calculation of areas and standing volume, Dongkapho SPF (management inventory results).

SPF/Block	Forest type	Area, ha	Standing Volume		
			m^3/ha	Total	%(NHF)
Dongkapho North					
1	NHF	663	129	85,750	11
2	NHF	938	124	116,080	15
	DD	21	54	1,150	
3	NHF	1,546	121	186,450	25
	DD	180	65	11,710	
4	NHF	743	117	87,140	12
Sub-total	*NHF*	*3,890*	*123*	*475,420*	*63*
	DD	*201*	*64*	*12,860*	
Dongkapho South	NHF	2,035	138	279,930	37
Total	NHF	5,925	127	755,350	100
	DD	201	64	12,860	
Grand total		6,126	125	768,210	

In the CNL calculation, the areas of NHF and DD in the table 4.18 have been selected. In each combination of forest type (Type), crown density(C.) and stand structure (S.), the calculation of standing volume have been made and summaries for Dongkapho North, Dongkapho South and for all Dongkapho SPF (table 4.20).

Table 4.20: The calculation of areas and standing volume, Dongkapho SPF (CNL)

Dongkapho	Combination			Area	Standing Volume			
	Type	C.	S.	, ha	m^3/ha	SE	Total	SE
North	MD	2	3	79	111.56	46.02	8,813	3,636
	MD	3	3	5,440	141.06	27.86	767,366	151,558
	DD	2	2	44	43.38	7.25	1,909	319
Sub-total	MD			5,519	140.64	27.47	776,179	151,602
	DD			44	43.38	7.25	1,909	319
South	MD	2	3	122	111.56	46.02	13,610	5,614
	MD	3	3	2,586	141.06	27.86	364,781	72,046
Sub-total	MD			2,708	139.73	26.69	378,391	72,264
Total	MD			8,227	140.34	20.41	1,154,570	167,944
	DD			44	43.38	7.25	1,909	319
Grand total				8,271	139.82	20.31	1,156,479	167,944

For the comparison, the result of the two approaches (table 4.19 and table 4.20) has been summarized in table 4.21.

Table 4.21: Comparison the result of the two approaches, Dongkapho SPF

SPF	Forest type	CNL					Management inventory		
		Area, ha	Volume / ha		Standing volume		Area, ha	Vol/ha	S. vol
			m^3/ha	SE, m^3	1000 m^3	SE, m^3		m^3/ha	1000 m^3
North	NHF	5,519	141	28	776.2	151.6	3,890	123	475.4
	DD	44	43	7	1.9	0.3	201	64	12.9
South	NHF	2,708	140	27	378.4	72.3	2,035	138	279.9
Total	NHF+ DD	8,271	140	20	1,156.5	167.9	6,126	125	768.2

The average volume per ha in Dongkapho South is more or less the same (140 m^3/ha in the CNL compared to 138 m^3/ha in the management inventory). In Dongkapho North the CNL estimate of NHF is higher (141 m^3/ha) compared to the management inventory (123 m^3/ha). The average volume per ha for the whole area of " net production forest " in Dongkapho SPF is higher (140 m^3/ha in the CNL compared to 125 m^3/ha in the management inventory).

As a result, the total standing volume in the CNL is 1,156,500 m^3, with an approximate 95% confidence interval for the total standing volume is 1,156,500 ± 329,100 m^3, the total standing volume is about 50% higher in the CNL than in the management inventory. Most of discrepancy can be explained by difference in "net production forest area". As mentioned earlier, the area of the "net production forest" also includes some areas classified as Protection forest in the management inventory. This fact also explains some of the difference in total standing volume.

4. 3. 3. Dongsithouane Production Forest

The results of the two approaches for estimating, area, average volume per ha and total volume of the seven Forest Management Areas inside Dongsithouane Production Forest are shown in table 4.22 and table 4.23.

Table 4.22: Summary of total area, volume per ha and total volume of the seven FMA, Dongsithouane Production Forest (management inventory).

FMA	Area, ha	Average volume per ha (m^3/ha)				Total Volume, 100m^3			
		Live stem	Bole volume			Live stem	Bole volume		
			All live	D. trees	R. tap		All live	D. trees	R. tap
2	685	145	133	7	12	990	914	47	80
3	4,032	87	75	3	4	3,521	3,007	104	146
4	1,291	119	110	3	5	1,536	1,419	34	64
5	1,668	115	102	3	1	1,915	1,708	52	17
6	847	95	86	4	6	806	726	32	48
7	558	107	97	1	0	597	542	4	2
8	377	130	122	5	13	492	459	20	51
Total	9,458	104	93	3	4	9,857	8,775	293	408

Live stem is the volume of the stems measured from the ground level or starting point of the stem to the top of the tree. Bole volume is the volume of the stems measured from the ground level or the starting point of the stem to the crown point. Bole volume has been separated among living trees (All live), dead trees (D.tree) and resin tapped (R.tap).

To make it easy to compare the estimates of area and growing stock with the management inventory results, the areas of Natural High Forest, have been selected. There is one compartment (map stratum) of NHF in each FMA. All those compartments happen to have the same crown density (2) and stand structure (3). The average volume per ha is derived from table 4.9 (127 m^3/ha and its standard error 47 m^3/ha). The result is shown in the table below.

Table 4.23: The estimation of area and the total volume of the seven FMA, Dongsithouane Production Forest (CNL).

FMA	Area, ha	Average volume per ha		Total volume	
		m^3/ha	SE, m^3	100 m^3	SE,100m^3
2	683	127.41	47.18	871	322
3	1,602	127.41	47.18	2,041	756
4	1,182	127.41	47.18	1,506	558
5	1,707	127.41	47.18	2,175	805
6	857	127.41	47.18	1,092	404
7	575	127.41	47.18	733	271
8	474	127.41	47.18	604	224
Total	7,080	127.41	47.18	9,021	1,386

The area of the FMA 3 is very different between two approaches. Possibly, there is an error in the photo or the satellite interpretation. If we compare the total area of six FMA (excluding FMA 3), it is about 50 ha different (5,478 ha in the CNL compared 5,426 ha in the management inventory). Unfortunately the CNL result could not separate the volume of living tree, dead trees and resin tapped. In order to compare the result of the two approaches, table 4.24 has been made.

Table 4.24: Comparison the result of two approaches, seven FMA, Dongsithouane Production Forest.

FMA	CNL					Management inventory		
	Area, ha	Volume per ha		Total volume		Area, ha	Bole volume	
		m^3/ha	SE, m^3	1000 m^3	SE,1000 m^3		m^3/ha	1000 m^3
2	683	127	47	87.1	32.2	685	152	104.1
3	1,602	127	47	204.1	75.6	4,032	81	325.7
4	1,182	127	47	150.6	55.8	1,291	118	151.7
5	1,707	127	47	217.5	80.5	1,668	107	177.7
6	857	127	47	109.2	40.4	847	95	80.6
7	575	127	47	73.3	27.1	558	98	54.8
8	474	127	47	60.4	22.4	377	141	53.0
(-3)	*5,478*	*127*	*47*	*698.0*	*116.5*	*5,426*	*115*	*621.9*
Total	7,080	127	47	902.1	138.6	9,458	100	947.6

In the management inventory result, average volume per ha range from 81 m^3/ha (FMA 3) to 152 m^3/ha (FMA 2), average volume per ha for whole seven FMA is about 100 m^3/ha, and 115 m^3/ha (excluding FMA 3). Average volume per ha according to the CNL is 127 m^3/ha. Total standing volume for seven FMA is lower in the CNL (902,100 m^3) than in the

management inventory (947,600 m^3), but, the standing volume is about 10% higher (698,000 m^3 in the CNL compared to 621,900 m^3 in the management inventory), if we excluded FMA 3. In the CNL, an approximate 95% confidence interval for total volume of seven FMA is 902,100 ± 302,200 m^3, an approximate 95% confidence interval for total standing volume of six FMA (excludes FMA 3) is 698,000 ± 254,000 m^3.

4. 4. Conclusions

- It should be possible to apply the CNL approach in other areas if the areas are similar with two areas which have been tested, the areas should be about or above 10,000 ha, at least for the CNL is used for approximate estimates needed for assessing allowable cut.
- The CNL approach gave slightly higher figures than the management inventory (average volume per hectare of Natural High Forest), but the differences can be explained by the time factor (different year of survey) and classification standards.
- In Savannakhet Province, there are 11 different combinations of forest types- crown density- stand structure occurring on the map. NFI sample plots were located in eight of these combinations, but in some combinations there are very few plots, meaning unprecise estimates. To improve the precision of the estimates one should try to add data of neighbouring province, if the physical conditions are similar.
- According to the CNL results, the total forest cover (current forest) in Savannakhet province is about 1.4 million hectares or about 62% of the total province area. About 50% of current forest area is Natural High Forest, and about 37% of current forest is Dry Dipterocarp (crown density 2 and stand structure 2).
- One can not make estimates for inaccessible areas (no sample plots) unless some field data are gathered as a complement.

Chapter V

Defining "Allowable cut"

5. 1. General

The general purpose of this chapter is to provide some insights into how timber yield could be estimated (an example from Sweden is given) and to give some guidelines or ideas how the Allowable Annual Cut (AAC) should be estimated in Lao PDR. It also analyses what information is required and how existing data could be appraised and utilised. It includes what sources of information should be used, which one is the most important in Lao PDR, especially in Savannakhet province. Finally, it considers how to apply the CNL data for estimating AAC (on province level or in the small areas).

5. 2. The Swedish HUGIN system for long-term forecasts of timber yields and possible cut

possible cut. (description mainly extracted from the report "Large-scale Forestry Scenario Models: Experiences and Requirements". EFI Proceedings No. 5, ed. By Risto Päivinen, Leena Roihuvuo and Markku Siitonen. ISSN 1237-8801, ISBN 952-9844-13-1. European Forest Institute 1996)

5. 2. 1. Introduction

Since the first National Forest Inventory in Sweden was completed in 1929, there have been a large number of long-term forecasts of timber yields. In Sweden, long-term forecasts of timber yields have usually dealt with the production of timber yields, with no consideration given to economic aspects. In a few studies, the results from the forecasts have been used afterwards to calculate costs and net revenues (Nilsson & von Segebaden, 1962; Bengtsson et al., 1989).

The Forest Management Planning Package (Jonsson, Jacobsson & Kallur, 1993) is a system that optimises the net present value. It is designed for companies and other large forest owners, and has been used at the management level.

Hereafter, the Swedish HUGIN-system for long-term forecasts of timber yield is described. The system is designed for national or regional analyses of different scenarios

of silviculture programs and cutting levels. The system has been developed at the Department of Forest Survey, Swedish University of Agricultural Sciences.

5. 2. 2. A general outline of the system

The HUGIN-system primarily aims at regional (subnational) long-term forecasts of timber yields to analyse different forest management strategies or for strategic planning for large companies. Normally, a longterm forecast refers to a period of one hundred years divided in to 10-year periods. The forecasts are based on data from the Swedish National Inventory (NFI) and specific assumptions on future silviculture and cutting. The main results from a forecast describe the state of the forest, growth and potential cut. It only covers the land class ”forest land”.

5. 2. 3. Growth forecasts

A basic assumption of the forecasts is that the natural site productivity and the climate conditions will remain unchanged during the period studied. The growth simulators are constructed to be valid for all forest land in Sweden, for all types of stands and within a wide range of management alternatives.

Different methods used for describing the tree growth, a review of the work on growth and yield forecasts in established stands is given in Hägglund (1981).

5. 2. 4. Forest management program

The way to prescribe how treatment should be carried out in the system is quite flexible. To make the use of the system easier, standard management programs are included, based upon what is considered to be good management according to present standards.

It is possible to study the effects of the following types of treatment in the HUGIN system.

- Establishment of new stand by planting, sowing or by natural regeneration
- Precommercial thinning (cleaning)
- Thinning
- Fertilization
- Final felling (clear-cutting)
- Draining of wet forest land

The division into different treatment classes is made according to relative age, defined as the ratio of the actual stand age and the age of final felling. Depending on tree species,

the age of the final felling of each plot is determined from the site index classes according to the silvicultural act.

5. 2. 5. Calculation of cutting level

The system can be used in two different ways:

1. The user of the system can give the amount of thinning and clear cutting for each period and study the effect on the development of the state of the forest.
2. The user can obtain the highest possible cutting level for each decade under the condition of the sustainable yield. In this case, harvesting details for the first period mush be provided. The cutting level is then based on the growth level in every period, and calibrated depending on the state of forest.

This calculation is made after each period, and gives a total amount of cutting for the next period. The amount of the total cut to be thinned is calculated depending on age distribution and thinning rate, adjusted by the actual growing stock on thinning plots related to expected growing stock on these plots.

5. 2. 6. Result presentation

The results of calculation are presented in standard tables that give the state of the forest at every ten-year periods and the cut volume and area divided into various classes i.e. diameter, site-index and age classes. The cut volume for each model and decade is presented in m^3 total volume over bark and solid volume, respectively and in kg dry weight. Functions used to obtain tree biomass have been developed by Marklund (1987 and 1988).

5. 2. 7. Application and discussion

So far the HUGIN system has been used in two forest cutting calculations for all of Sweden. The first, AVB 85 (Bengtsson et al, 1989), was the first large scale test of the system. In 1990, a committee was set up by the Government to make suggestions for a new forest policy. One step in this work was to make longterm calculations of the development of the forest and possible cut. For this purpose, a project called AVB 92 was started, in which the HUGIN system was used. In connection with this, some checks were made of the results of the AVB 85 calculations. These tests showed that the forecasts made in 1985 were adequate. The most evident difference was that mortality

was overestimated in the forecast. In 1998 a third cutting calculation (or "consequence analysis") using the HUGIN system is underway.

5. 3. Outline how is the timber harvesting done in Lao PDR to day

Sustainable forest management became a key forest policy objective in the 1990s. New legislation has been introduced to provide directions and regulatory framework for forestry development since the early 1997. Forest regulations are currently being drafted and they are to be completed and approved in 1998. Draft regulations for governing harvesting operations, management contracting and planning, and village forestry already exist. A National Code of Timber Harvesting Practice was drafted in mid-1997. The purpose of the Code is to provide guidelines for carrying out timber harvesting operations in order to protect the environment and promote forest development of Regional Timber Harvesting Code for the Asia-Pacific countries.

Until now, there are many different "actors" involved in the harvesting planning and setting of cutting targets.

- The Concessionaire, are the people who had asked the Government for permission to cut and to discuss possible cutting areas. The concessionaire should follow up management plan such as logging volume, planting, etc., and also pay the tax to the Government.
- The Province of Agriculture and Forestry Office (PAFO), who tries to locate potential concession areas and helps the concessionaire in discussing with Department of Forestry (DoF), and Ministry of Agriculture and Forestry (MAF). They also agree with DoF, NOFIP to establish a management plan. They finally suggest annual quota/cutting area based on the management plans.
- NOFIP, section of Forest Inventory and Management is responsible for the field data collection and for producing the final "Management Plan" for any concession areas.
- Department of Forestry (Logging and Wood based Industry, Supervision division) will follow up and control management plans, and forward the proposed logging volume to MAF.
- Ministry of Agriculture and Forestry (MAF) will compare the proposed cutting volume with the reported cutting from the year before and consider how to maintain even cutting level.

There are many constraints with the system used so far:

- The rules for setting of quotas and defining targets are unclear
- There is very little follow up of the actual cutting performance and the statistics is not complete
- Management planning does not cover all types of cutting

5. 4. Principles and data requirements for estimating AAC

The allowable annual cut could be defined as the relationship between growth and felling. The growing stock can be increased when felling is less than growth. At least two main types of information are needed for the AAC estimation.

- Yield estimates
- Estimates of actual and potential cutting

5. 4. 1. Yield estimates

Yield estimates are an important element of a sustainable forest management system, and serve as one of many aspects in planning the harvest. Ultimately, sustainability depends on the conduct of field operations. Nonetheless, yield estimates remain an important part of the whole process, and remain necessary to provide the basis for planning and control. Below is a brief overview of information sources that may facilitate the estimation of timber yields for natural forests. These data may be obtained from various sources, not necessarily at a single point in time.

Resource inventory:

The first prerequisite for estimation of the AAC is a resource inventory describing the nature and extent of the forest resource. In Lao PDR, the existing information includes data from: the National Forest Inventory (NFI), the management inventory and also the CNL data, these sources of data can be provided as a convenient basis for AAC estimation. (It provides data on growing stock, number of trees per hectare composition and structure of the existing (productive) forest. Unfortunately any data on growth and changes can rarely be provided).

Growth model:

Growth models have become an indispensable part of yield prediction systems. One particular attraction of dynamic growth models is the ability to conduct sensitivity analyses and explore implications of management alternatives, which should, if used wisely, lead to a better understanding of the model, of the ecosystem, and in turn to better management. Hundreds, and possibly thousands of growth models have been published in the world. Unfortunately for Lao PDR, relatively few of these relate to tropical forests (see Vanclay 1995b), or an explanation of all the steps and considerations involved. The models may be more or less theoretically or empirically based, and may make predictions at the whole-stand, size-class or individual-tree level.

The quality of a growth model depends heavily on the quality of the data used to calibrate and test the model, and since tropical trees are rarely amenable to system analysis (i.e., growth rings may not be visible or may not be annual), data from re-measured permanent sample plots are required. Plots need to be established and re-measured regularly over long periods. Several publications give detailed in instructions and sound advice for the establishment and maintenance of plots (e.g., Alder and Synnott 1992, Beetson et al. 1992, Sheil 1995, Whitmore 1989). If no growth data are available locally, it may be possible to obtain suitable growth estimates from the literature, or to locate suitable sources of comparable data via systems such as TROPIC (Vanclay 1995c).

Since 1996, some permanent sample plots have been established and measured in the various types of the natural forest of Lao PDR. These plots are used to find out the growth rate of forest, which is an essential parameter in the management planning of production forest. The activity has been carried out under Forest Management and Conservation Project (FOMACOP). The detailed instructions for plot establishment and measurement, and how the measurements could be used to create growth models for uneven-aged forests are not describe in this paper (see FOMACOP, 1996). As mentioned above, the sample plots need to be re-measured regularly over long periods.

Cutting cycle:

For plantation forest, it is comparatively easy to determine the optimum rotation age at which the forest should be felled and replanted (e.g., Leech 1993). A rather simple analysis reveals when the mean volume of timber produced is maximized this optimum is

increased slightly by a size premium for large logs, and decreased by discounting, by risk (disease, fire), and by tree breeding. However, in natural forest, there are many more factors to take into account, and there may be no simple optimum. Some of the factors to be considered included:

1. Silvicultural requirements for the desired species to regenerate after logging.
2. Harvesting infrequently enough to allow an economically viable harvest, and to allow the canopy to recover to maintain ecosystem integrity (e.g., Horne and Gwalter 1982).
3. Harvesting frequently enough to maintain near-optimal density, to minimize losses to mortality, and to avoid damage from excessively heavy harvesting.

The final choice of the cutting cycle is often rather arbitrary. For tropical forests, cutting cycles are typically in the range 20-40 years (Vanclay 1994a).

Area control:

Area control (where a certain area or proportion of total area to be cut each year is defined) offers some advantages, provided that the selected cutting cycle is realistic. A minor variation of area control is a form of volume control where a nominated proportion of the standing volume may be harvested each year. For example, the Queensland Department of Forestry allowed an annual harvest of 1.6% of standing volume, based on assumption that the standing volume should be removed over two successive 30-year cutting cycles Vanclay (1991). Dwight (1965) and Leuschner (1984) reviewed several similar formulae of historic interest. These approaches increase the complexity of yield estimates (since they require volume estimates, etc.), but offer few significant advantages over the basic method of area control.

Area control can and is used in Lao PDR, especially in the concession area, where the logging plan has been applied.

5. 4. 2. Estimates of actual and potential cutting

The felling in Lao PDR could come from many different sources, not only production forest, although some types of felling will not occur every year. By following up the wood consumption (industries, customs, etc..), it is possible to estimate the actual logging and also, in combination with yield estimates, make a more realistic estimate of the potential cut.

Some important felling types in Savannakhet Province:

- Selective felling of natural forest (commercial cutting)

Selective felling of natural forest is carried out in the production forest only (or concession areas), each production forest the harvesting plan has been made. This type of felling is rather simple to put in the account, if the felling is regulated.

- Clear felling of any forest land for conversion to other land use

Improvement of the national road network, electric lines, agricultural settlers have been so far had relatively minor effects on forest land, clear felling always take place. This type of felling can be estimated in area unit or by tree volume.

- Felling for household use

Felling for household or local use is according to the regulation. The felling of trees for household construction, repair and use is only authorised in production forest of the village, and only with the trees of non-prohibited category of volume, the felling volume is not exceeding five cubic meters in log per family. If the villagers follow the rule, the felling can be easily estimated.

- Thinning and clear cutting of new or old plantations

This type of felling does not usually affect natural forest, because the new plantation is primarily to be established on degraded forest lands, denuded lands which are set aside and lands where trees are allowed to be cut out and which are not used for other purpose. The clear cutting of old plantation should be account and added to potential felling.

- Other felling (disaster windbreak, dead trees)

Other felling such as disaster windbreak, dead trees cause by uncontrolled fires or dead trees cause by man made (illegal felling), that should be account and carefully control.

5. 5. Using the CNL approach for estimating AAC

A main objective of this study is to develop a method to estimate the allowable cut on province level. An approach, CNL, has been tested for estimating growing stock and some other variables for small areas. The advantages of using CNL are that any area can be defined and estimation is quite fast because data (from NFI and Land Use map) are available already. But there are also other types of information required for estimating AAC, that are not provided though CNL, some examples:

- Growth and yield estimates
- Cutting cycle and forest management

- Data on new plantations
- Imposed logging because of dam projects, disasters, conversion of forest to other land use and so on
- Restrictions in forest land use, sensitive areas etc.

Another aspect is that NFI and map data sooner or later get out-dated.

Although, there are many difficulties in defining a sustainable cutting level, it is necessary to try to improve the planning and monitoring system. The CNL could be one small step forward.

5. 6. Final remark

Because of time constraints by the end of the study, I have not given this part as much time as it requires.

Hopefully, the questions raised and the information needs pointed out could give some ideas for further research.

Bounpone Sengthong

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Appendix 1

LIST OF TABLES AND FIGURES IN THE REPORT

Chapter 2

Chapter 3

Chapter 4

Appendix 2 The NFI methodology of estimating area and standing volume (accessible area and inaccessible area) Savannakhet Province

The description of the NFI calculation methodology and its results (below) was taken from the NFI report 1996.

1. General

The inventory design is a stratified, systematic cluster sampling. The primary sampling units are square tracts (cluster). In order to get as high precision as possible in the estimates the inventory is linked to the former Reconnaissance Survey. Those aerial photos that were interpreted during the Reconnaissance Survey has been used as a sampling frame for the inventory. On each photo 100 plots have been interpreted in the NRS. In the north-west and south-east corner of each photo two NFI inventory tracts have been located. On each aerial photo those nine photo-plots located most to the north-west and most to the south-east form square within which the tracts are located.

Depending on the accessibility for field work the tracts have been divided into two groups. accessible tracts and inaccessible tracts (stratum 4). Accessible tracts have been divided into the following three strata (according to the land use or forest type of the nine plots):

Stratum 1: Current forest (five or more plots out of nine classified as current forest)

Stratum 2: Potential forest (five or more plots out of nine classified as potential forest)

Stratum 3: The remaining tracts

Table 2.1: The number of tracts distributed in different strata within Savannakhet Province.

Stratum	Description	Number of tracts in the photos
1	Current Forest	59
2	Potential Forest	19
3	The remaining tracts	27
4	In-accessible tracts	60
Total		165

The area of each stratum can be express from the number of tracts, by using the formulars below:

$$A_k = A_p * P_k$$

A_k Area of stratum k in ha

A_p Total province area

P_k Proportion of stratum k

$$P_k = \frac{n_k}{n}$$

n_k Number of tracts within stratum k

n Number of tracts within province area

Standard error of P_k and A_k

$$SE = A_k * e(P_k)$$

and $$e(P_k) = \sqrt{\frac{P_k * (1 - P_k)}{n}}$$

Standard error was using the simple random sampling principle, so the outcome should be overestimate. According to the NRS supposition, standard error under random sampling is probably 25% higher than systematic sampling. So the results below, standard error of P_k and A_k was multiplied with 0.75.

Table 2.1. The result of strata area and its standard error

Stratum	P_k	$e(P_k)$	A_k **,ha**	**SE, ha**	**SE, %**
1	0.358	0.028	778,264	28,947	3.72
2	0.115	0.019	250,627	19,279	7.69
3	0.164	0.022	356,155	22,343	6.27
4	0.364	0.028	791,455	29,053	3.67
(1-3)	**0.636**	**0.028**	**1,385,046**	**29,053**	**2.10**
(1-4)	**1.000**		**2,176,501**		

2. Area and volume calculation in accessible area

2. 1. Area calculation

The calculation based on plot type "A" which has been collected from the field and combined with the data above (stratum area)

The area calculation is expressed by a table belows:

Table 2.2. The formation of area calculation

Stratum	P_{jk}	$e(P_{jk})$	Area, ha	SE, ha	w_{jk}
1	P_{j1}	$e(P_{j1})$	A_{j1}	$e(A_{j1})$	w_{j1}
2	P_{j2}	$e(P_{j2})$	A_{j2}	$e(A_{j2})$	w_{j2}
3	P_{j3}	$e(P_{j3})$	A_{j3}	$e(A_{j3})$	w_{j3}
Total	P_{jT}	$e(P_{jT})$	A_{jT}	$e(A_{jT})$	1.000

$$P_{jk} = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i}$$

P_{jk} Proportion of land use group j within stratume k

x_i Total number of plot type "A" in the tract number i within stratum k

y_i Number of plot type "A" in tract number i within land use group j and within stratum k

n Total number of tracts within stratum k

$$P_{jT} = \sum P_{jk} * w_{jk}$$

P_{jT} Proportion of land use group j within all strata

w_{jk} Stratum weight for land use group j within stratum k

$$w_{jk} = \frac{A_{jk}}{A_{jT}}$$

A_{jk} Area of land use group j within stratum k

A_{jT} Area of land use group j within all strata

$$A_{jk} = A_k * P_{jk}$$

A_k Area of stratum k

$$e(P_{jk}) = \frac{\sqrt{n}}{\sum x_i} * \sqrt{\frac{\sum y_i^{\,2} - 2P_{jk}\sum x_i y_i + P_{jk}^{\,2}\sum x_i^{\,2}}{n-1}}$$

$e(P_{jk})$ Standard error of P_{jk}

$$e(P_{jT}) = \sqrt{\sum \left(w_{jk}{}^2 * e\left(P_{jk}\right)^2 \right)}$$

$e(P_{jT})$ Standard error of P_{jT}

The result of area calculation for the accessible area within Savannakhet province is shown in the table below

Table 2. 3. The area of different land use groups within accessible area inside Savannakhet province

Land use groups	Area		
	%	1000 ha	SE, 1000 ha
Current Forest	57.70	799.2	51.9
Natural High Forest	*15.25*	*211.2*	*31.8*
Dry Dipterocarp	*42.46*	*588.0*	*51.7*
Potential Forest	13.98	193.6	27.3
Other Wooded Area	1.29	17.8	6.9
Agricultural Land	17.95	248.6	32.3
Other Land use	9.09	125.9	33.2
Total	100.00	1385.0	41.3

2. 2. Volume calculation

Volume calculation was done in three steps:

- volume calculation for a single tree
- Average volume per ha
- Total volume within the accessible area

2. 2. 1. Volume of single tree

Calculating the volume for single tree using volume function. In general volume of a single tree is calculated by the formula below:

$$V = f(D,H,F) = \frac{D^2 * \pi}{4} * H * F$$

Where: D = diameter at 1.3 meters or 3 decimeters above buttress end

H = the height of crown point

F = form factor function

Crown point height function (H)

Crown point is the point where the stem clearly ramifies. The height of crown point is the length of the a straight line connecting the foot of the tree (ground level) with the grown point. For every sample tree, the H has been measured in the field. For the none-sample tree the H could be derived by using the relationship between observe D and H from sample trees. The model used was the simple linear model

$$H = a+b*D$$

Where H the height of crown point (dm)

D diameter (mm)

a and b coefficients

The result of the crown point height functions has been created by Eriksson 1994. The results are shown in the table 2.4:

Table 2.4: Result of the crown point height function from the regression analysis . Estimated coefficients for a, b, R^2, and SE

Species name	Species code	Number of trees	a	b	Squared mult.r	SE
Dipterocarpus tuberculatus	31	286	33.087	0.1180	0.185	24.815
Adina cordifolia	69	23	47.050	0.0040	0.000	14.836
Hopea feerea P.	104	34	58.667	0.1360	0.231	28.581
Shorea obtusa	122	347	24.087	0.1150	0.167	28.245
Syzygium cumini	167	35	5.197	0.1780	0.448	26.731
Dipterocarpus obtusifolius	174	70	35.118	0.1840	0.467	24.618
Pterocarpus telatus	188	23	44.198	0.0870	0.084	36.627
Xylia kerrii	192	67	29.729	0.1290	0.140	34.782
Vitex pubescens	197	23	14.618	0.1660	0.243	33.562
Cratoxylon prunifolium	204	35	42.737	0.0680	0.065	20.927
Anisoptera robusta	231	19	86.430	0.1570	0.083	39.929
Irvingia malayana	234	43	27.140	0.0890	0.164	23.019
Lagerstroemia balansae	247	169	48.781	0.1500	0.250	36.127
Terminalia corticosa	250	30	0.083	0.2580	0.470	35.268
Pentacme siamensis	266	118	26.828	0.1340	0.250	28.710
Other commercial sp.	-	271	30.080	0.1760	0.221	43.756
Non com.sp. with code	-	386	20.579	0.1890	0.361	34.815
Non com.sp without code	400	168	24.120	0.2060	0.292	41876
Unknown sp.	0	438	47.340	0.1560	0.287	34.984

Form factor functions (F)

In general form factor are calculated by formula below:

$$F = \frac{V_{Tree}}{V_{Cyl}}$$

where V_{Tree} is The true volume of the tree

V_{Cyl} is The cylinder volume

Using the Relascope trees, where measurements are made at three different height on the bole a "true" volume (V_{Tree}) could be calculated. V_{Tree} can then be compared with the cylinder volume (V_{Cyl}), calculate by using the cross sectional area at breast height or at 3 dm above buttress end in case of buttress. The relationship V_{Tree}/V_{Cyl} is defined as the form factor(F). To produce form factor function the work has been done according to the following steps:

- Calculation of V_{Tree} and V_{Cyl} for all Relascope trees
- Elaboration of F for different tree species and tree species groups

The volume of V_{Tree} can be calculated according to the following:

A_1 = Basal area at breast height or 3 dm above buttress end

A_2 = Basal area at half of bole

A_3 = Basal area at crown point

H_0 = Stump height or buttress height (in case of buttress)

H_1 = Breast height (13 dm) or height 3 dm above buttress height

H_2 = Height at half of the bole

H_3 = Height at crown point

The volume of V_{Tree} can be calculated by adding the volume of the root cylinder, the two truncated cones from breast height or from 3 dm above end of buttress, to half of the bole, and from half of the bole to crown point. This is done using the following formula:

$$V_{Tree} = A_1 * (H_1 - H_0) + \left((A_1 + A_2) + \left(\sqrt{(A_1 * A_2)}\right) * (H_2 - H_1)/3\right) + \\ + \left((A_2 + A_3) + \left(\sqrt{(A_2 * A_3)}\right) * (H_3 - H_2)/3\right)$$

The reference volume (V_{Cyl}) was then calculated as the cylinder volume from stump height or 3 dm above buttress end in case of buttress, to crown point using only the basal area at breast height or 3 dm above buttress end;

$$V_{Cyl} = A_1 * (H_3 - H_0)$$

The model used in the regression was the simple linear model of F=a+b*L, where L is the usable length $(H_3 - H_0)$ in dm. The results have been created by Eriksson 1994 and presented in table 2.5:

Table 2.5: Result of the form factor function from the regression analysis. Estimated coefficients for a, b, R^2, and SE

Species name/group	Species code	No of trees	a	b	R^2	SE
Dipterocarpus tuberculatus	31	59	0.942	-0.0020	0.304	0.072
Shorea obtusa	122	78	0.909	-0.0010	0.196	0.090
Lagerstroemia balansae	247	68	0.876	-0.0020	0.138	0.124
Other commercial sp.	-	293	0.873	-0.0010	0.303	0.104
Non commercial sp.	-	158	0.871	-0.0010	0.206	0.107
Un known sp.	0	151	0.823	-0.0010	0.117	0.109

2. 2. 2. Average volume per ha and total volume

The average volume per ha and total volume for accessible area is based upon the volume in plot type "A" only. The calculation should be done on three steps, everage volume per ha within a tract, stratum and all strata.

To simplify the calculation of average volume per ha and total volume for accessible area, one should follow the table below:

Table 2.6: The formation of volume calculation

Stratum	Area,ha	SE,ha	w_{jk}	Vol/ha	SE	Total volume	SE
1	A_{j1}	$e(A_{j1})$	w_{j1}	Vh_{j1}	$e(Vh_{j1})$	V_{j1}	$e(V_{j1})$
2	A_{j2}	$e(A_{j2})$	w_{j2}	Vh_{j2}	$e(Vh_{j2})$	V_{j2}	$e(V_{j2})$
3	A_{j3}	$e(A_{j3})$	w_{j3}	Vh_{j3}	$e(Vh_{j3})$	V_{j3}	$e(V_{j3})$
Total	A_{jT}	$e(A_{jT})$	1.000	Vh_{jT}	$e(Vh_{jT})$	V_{jT}	$e(V_{jT})$

Volume per ha for land use group j within a tract i

$$Vh_{ji} = \frac{V_{ji}}{A_{ji}}$$

Volume per ha for land use group j within stratum k

$$Vh_{jk} = \frac{\sum V_{ji}}{\sum A_{ji}}$$

Volume per ha for land use group j within all strata

$$Vh_{jT} = \sum w_{jk} * Vh_{jk}$$

Total volume

$$V_{jT} = Vh_{jT} * A_{jT} \quad \text{or} \quad V_{jT} = \sum V_{jk}$$

Standard error of Vh_{jk} , Vh_{jT}, V_{jk} , V_{jT}.

$$e(Vh_{jk}) = \sqrt{\frac{n * \sum Vh_{ji}^{\,2} - \left(\sum Vh_{ji}\right)^2}{n^2 * (n-1)}}$$

$$e(Vh_{jT}) = \sqrt{\sum \left(w_{jk} * e(Vh_{jk})\right)^2}$$

$$e(Vh_{jk}) = \sqrt{\left(e(Vh_{jk}) * A_{jk}\right)^2 + \left(V_{jk} * e(A_{jk})^2\right)}$$

$$e(V_{jT}) = \sqrt{e(Vh_{jk})^2}$$

Table 2.7: The average volume per ha and total volume for the different land use groups and its standard error within accessible area.

Land use groups	Area			Volume			
				Volume per ha		Total volume	
	%	1000 ha	SE	m^3/ha	SE	$1000m^3$	SE, $1000m^3$
Current Forest	57.70	799.2	51.9	68.89	5.06	55,058	5,648
Natural High Forest	*15.25*	*211.2*	*31.8*	*96.95*	*6.61*	*20,471*	*3,569*
Dry Dipterocarp	*42.46*	*588.0*	*51.7*	*58.82*	*3.56*	*34,587*	*4,770*
Potential Forest	13.98	193.6	27.3	9.04	1.24	1,750	349
Other Wooded area	1.29	17.8	6.9	5.65	0.27	101	46
Agricultural Land	17.95	248.6	32.3	14.20	2.84	3,530	850
Other land use	9.09	125.9	33.2	4.86	0.28	611	198
Total	100.00	1,385.0	41.3	44.08	4.42	61,051	6,390

3. Area and volume calculation in inaccessible areas

3.1. Area calculation

The area calculation was according to the number of sample plots which derive from aerial photo interpretation. First calculate proportion of land use groups and than calculate the area of each land use group, using that proportion multiply with the total area of inaccessible area.

Proportion of land use group j

$$P_{j4} = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i}$$

x_i = total plot area (part-plot) within photo number i

y_i = area of plot (part-plot) within photo number i for land use group j

n = total number of air photos

Areas of land use group j

$$A_{j4} = A_4 * P_{j4}$$

Standard error of P_j and A_j

$$e(P_{j4}) = \frac{\sqrt{n}}{\sum x_i} * \sqrt{\frac{\sum y_i^2 - 2P_{j4}\sum x_i y_i + P_{j4}^2 \sum x_i^2}{n-1}}$$

$$e(A_{j4}) = \sqrt{(A_4 * e(P_{J4}))^2 + (P_{j4} * e(A_4))^2}$$

Table 2.8: Area calculation for different land use group within inaccessible area

Land use groups	Area		
	%	1000 ha	SE, 1000 ha
Current Forest	63.13	499.6	27.9
Natural High Forest	*61.60*	*487.6*	*28.0*
Dry Dipterocarp	*1.53*	*12.1*	*5.2*
Potential Forest	30.65	242.6	22.1
Other Wooded Area	1.58	12.5	3.4
Agricultural Land	1.98	15.6	3.3
Other Land use	2.66	21.1	3.3
Total	100.00	791.5	29.1

3.2. Volume estimation

It is impossible to accurately calculate the average volume per ha for different land use group within inaccessible area, but in order to estimate total volume for the province area, the total volume within inaccessible area, has to be considered. One simple way to do that, is using the average volume per ha from accessible areas and multiply with the area for different land use group within inaccessible area. The method probably involves some systematic errors because the standing volume in inaccessible area should be different from that in accessible parts. The result of total volume inside Savannakhet province shown in the table belows:

Table 2.9: The estimation of area and volume in the whole province area

Land use Group	Accessible area				Inaccessible area			Whole province area		
	volume per ha	Area		volume	Area		Volume	Area		Volume
		%	1000ha	$1000m^3$	%	1000ha	$1000m^3$	%	1000ha	$1000m^3$
Current forest	68.89	57.70	799.2	55,058	63.13	499.6	47,977	59.68	1,298.8	103,036
NHF	96.95	15.25	211.2	20,471	61.60	487.6	47,267	32.10	698.7	67,738
DD	58.82	42.46	588.0	34,587	1.53	12.1	711	27.57	600.1	35,298
Potential forest	9.04	13.98	193.6	1,750	30.65	242.6	2,193	20.04	436.1	3,943
Other wooded area	5.65	1.29	17.8	101	1.58	12.5	71	1.39	30.4	171
Agricultural land	14.20	17.95	248.6	3,530	1.98	15.6	222	12.14	264.2	3,752
Other land use	4.86	9.09	125.9	611	2.66	21.1	102	6.75	146.9	714
Total	44.08	100.00	1,385.0	61,051	100.00	791.5	50,566	100.00	2,176.5	111,616

Appendix 3

Areas of land use and forest type distributed in each forest category in Savannakhet province (CNL)

List of contents:

App 3. 1. The coordination of tracts before transfer from Topographic map to the land use map

TRACTno.	Grid X	Grid Y	TRACTno.	Grid X	Grid Y
1002	184 94	18 06	1044	186 00	18 11
1006	184 93	18 61	1046	186 10	18 19
1009	185 46	18 61	1048	185 61	18 54
1010	185 28	18 60	1049	185 99	18 46
1011	185 02	18 60	1051	185 75	18 40
1012	185 08	18 54	1053	185 62	18 36
1013	185 43	18 45	1054	185 83	18 36
1014	185 50	18 42	1056	185 96	18 32
1016	185 34	18 32	1057	185 68	18 32
1017	185 41	18 36	1059	186 10	18 04
1019	184 94	18 26	2002	184 88	18 67
1021	185 03	18 18	2004	184 86	18 47
1022	185 09	18 12	2006	185 24	18 06
1024	185 31	18 03	2009	186 43	18 55
1026	185 52	17 84	2011	186 55	18 40
1027	185 20	17 89	2014	186 66	18 34
1029	185 17	17 83	2016	185 74	18 26
1031	185 31	17 82	2019	186 61	18 04
1032	185 37	17 76	3002	184 87	18 12
1033	185 47	17 76	3005	184 93	18 83
1034	185 52	17 71	3008	185 18	18 42
1036	185 76	17 84	3012	185 12	18 33
1039	185 57	18 03	3015	185 18	18 11
1042	185 63	18 13	3018	185 84	17 83
1043	185 70	18 11	3022	185 90	18 12
			3025	186 12	18 30

Area calculation

Using the CNL methodology to calculate the area for each forest category, the different land use and forest types are listed, for the land use or forest type classified as current forest, crown density and stand structure also indicated in the table.

App 3. 2. Production Forest areas

There are 4 production forest areas: Dongphakada, Dongnanhom, Dongkapho and Dongsithouan (include 7FMA) and the 7FMA is calculated separately.

App 3. 2. 1.Area of Dongphakada production forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
MD	2	3	11,080
DD	1	2	15,890
DD	2	2	15,460
T			10,911
SR			101
RP			9,317
Total			62,759

App 3. 2. 2. Area of Dongnanhom production forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
MD	1	3	1,023
MD	2	2	1,938
MD	2	3	7,727
MD	3	2	286
T			10,164
RA			129
SR			455
RP			4,740
R			13
Total			26,475

App 3. 2. 3. Area of Dongsithouan production forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
MD	1	3	311
MD	2	2	1,039
MD	2	3	50,861
MD	3	3	9,710
GE	2	2	2,604
GE	2	3	1,097
DD	1	2	3,864
DD	1	3	128
DD	2	2	127,103
DD	2	3	9,057
T			258
SH			1,076
SR			2,025
RP			10,123
R			90
Total			219,346

App 3. 2. 4. Area of the 7 Forest Management Areas (FMA) within Dongsithouan Production Forest

FMA	Land use/Forest type	Crown Density	Stand Structure	Area,ha
	MD	**2**	**3**	**683**
2	DD	2	2	5,336
	RP			416
3	**MD**	**2**	**3**	**1,602**
	DD	2	2	2,426
	RP			294
4	**MD**	**2**	**3**	**1,182**
	DD	2	2	5,357
	SR			123
5	**MD**	**2**	**3**	**1,707**
	DD	2	2	987
	SR			20
	RP			282
6	**MD**	**2**	**3**	**857**
	DD	2	2	1,272
	RP			19
7	**MD**	**2**	**3**	**575**
	DD	2	2	3,994
	DD	2	3	58
	RP			293
8	**MD**	**2**	**3**	**474**
	DD	2	2	776
	RP			164
Sub-total (MD)				7,080
Total				35,978

App 3. 2. 5. Area of Dongkapho State Production Forest

SPF	Land use/Forest type	Crown Density	Stand Structure	Area,ha
North	MD	1	3	485
	MD	2	2	124
	MD	2	3	104
	MD	3	3	7,120
	DD	2	2	57
	T			20
	N			839
	G			169
	Sub-total			*8,918*
South	MD	2	2	58
	MD	2	3	160
	MD	3	3	3,385
	T			28
	Sub-total			*3,631*
Grand total				12,549

App 3. 3. Protection Forest areas

There are two areas of protection forest in Savannakhet province

App 3. 3. 1. Area of Xebanghiang protection forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
MD	1	3	3,034
MD	2	2	38,341
MD	2	3	12,534
MD	3	2	7,599
MD	3	3	12,572
MD	3	4	29,300
B			44,311
T			60,912
RA			746
RP			47
R			850
G			10,133
U			40
Total			220,419

App 3. 3. 2. Area of Phoulamphung protection forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
DE	3	4	757
MD	1	3	8,984
MD	2	2	2,856
MD	2	3	37,972
MD	3	3	43,430
MD	3	4	9,160
DD	1	3	8,554
DD	2	2	5,636
T			54,738
RA			89
SH			1,069
RP			543
G			3,414
Total			177,202

App 3. 4. Protected Forest areas

There are 9 protected forest areas, 3 of them are the national protected forest areas (Phouxanghe, Dongphouviang and Xebangnouan).

App 3. 4. 1. Area of Xebangnouan protected forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
MD	2	3	8,197
MD	3	3	4,193
DD	2	2	6,211
SR			3,332
RP			2,727
Total			24,660

App 3. 4. 2. Area of Phouxanghe protected forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
DE	3	3	37,384
MD	1	3	636
MD	2	2	9,023
MD	2	3	32,743
MD	3	3	7,254
DD	1	2	1,465
DD	1	3	694
DD	2	2	385
B			1,689
T			8,474
N			6,772
RA			315
RP			1,699
R			1,332
G			138
Total			110,003

App 3. 4. 3. Area of Dongphouviang protected forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
MD	1	3	1,722
MD	2	2	3,391
MD	2	3	13,451
MD	3	3	7,413
DD	1	3	1,104
DD	2	2	24,869
T			11,209
SR			360
RP			1,602
U			29
Total			65,150

App 3. 4. 4. Area of Dongnongphu protected forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
MD	2	3	248
T			344
RP			48
Total			640

App 3. 4. 5. Area of Dongnaxai protected forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
MD	1	3	692
MD	2	2	572
MD	2	3	947
MD	3	3	192
DD	2	2	29,239
RP			2,808
Total			34,450

App 3. 4. 6. Area of Dongnatat protected forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
DE	2	3	946
DE	3	3	2,337
MD	1	3	549
DD	1	3	290
T			2,057
RP			110
W			87
Total			6,376

App 3. 4. 7. Area of Dongmak-u protected forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
MD	2	2	173
MD	2	3	14,522
DD	1	2	18,530
DD	1	3	1,318
DD	2	2	2,770
T			6,789
RP			9,777
Total			53,879

App 3. 4. 8. Area of Donglaolouang protected forest

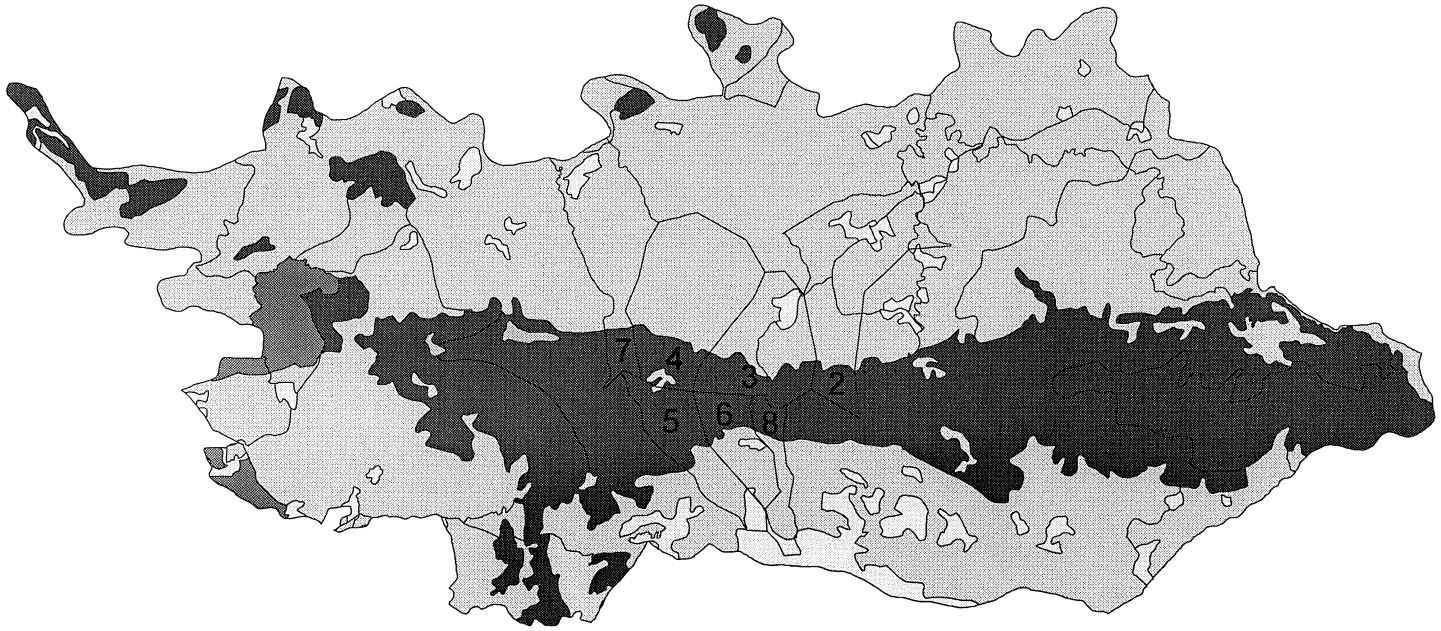
Land use/Forest type	Crown Density	Stand Structure	Area,ha
MD	2	2	4,693
MD	2	3	2,171
GE	1	3	84
DD	1	2	9,727
DD	2	2	36,344
T			10,714
RP			3,890
Total			67,623

App 3. 4. 9. Area of Huay xakhong protected forest

Land use/Forest type	Crown Density	Stand Structure	Area,ha
MD	2	3	1,372
DD	2	2	162
T			1,416
RP			50
Total			3,000

Dongsithouan SPF

App 4:1



Land use
MD
DD
GE
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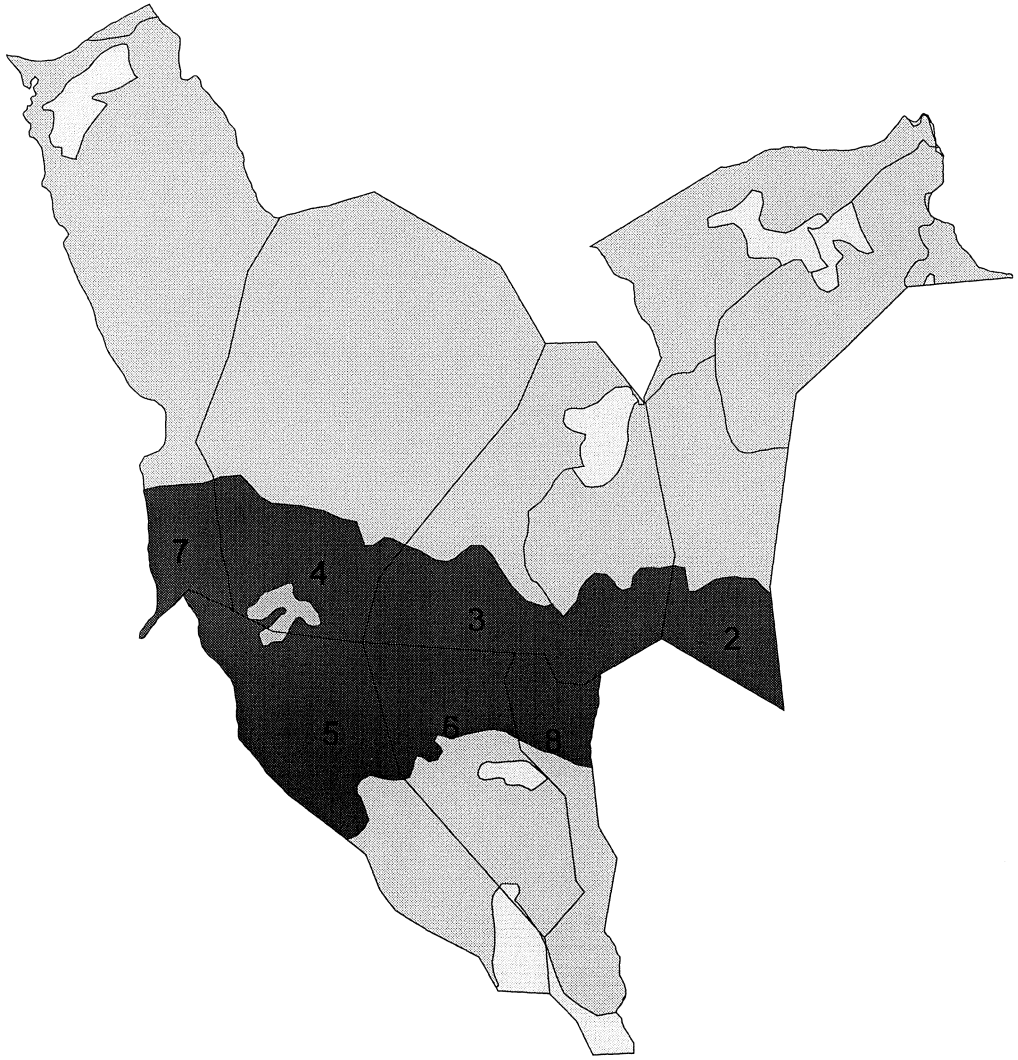
40 0 40 Kilometers

Seven Forest Management Areas in dongsithouan SPF



Land Use
MD
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RP

10 0 10 20 Kilometers

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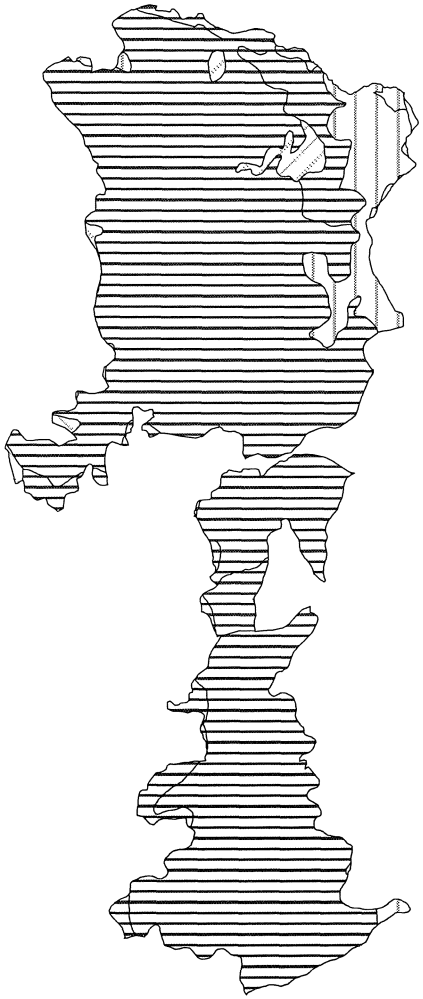
Dongkapho SPF



Land Use
MD
DD
T
G

N
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9 0 9 18 Kilometers

Serien Arbetsrapporter utges i första hand för institutionens eget behov av viss dokumentation. Rapporterna är indelade i följande grupper: Riksskogstaxeringen, Planering och inventering, Biometri, Fjärranalys, Kompendier och undervisningsmaterial, Examensarbeten samt Internationellt. Författarna svarar själva för rapporternas vetenskapliga innehåll.

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