Application of Remote Sensing and GIS for Forest Cover Monitoring

in

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List of Abbreviations

AIT	Asian Institute of Technology, Bangkok
DoF	Department of Forestry
FCMP	Forest Cover Monitoring Project (MRC / GTZ)
GIS	Geographic Information System
GTZ	German Agency for Technical Cooperation
IRS	Indian Remote Sensing Satellite
LMB	Lower Mekong Basin
MAF	Ministry of Agriculture
MRC	Mekong River Commission (Phnom Penh)
MRCS	Mekong River Commission Secretariat (Phnom Penh)
NFI	National Forest Inventory
NOFIP	National Office of Forest Inventory and Planning
PNRM	Participatory Natural Resource Management
RS	Remote Sensing
SDC	Swiss Development Cooperation
SMRP	Sustainable Management of Resources in the Lower Mekong Basin Project (MRC / GTZ)
TSU	Technical Support Unit of MRCS
UNEP-GRID	United Nations Environmental Program – Global Resources Information Data Base
WSCP	Watershed Classification Project (MRC / SDC)

EXECUTIVE SUMMARY

This report is prepared for the GIS workshop at Hanoi, Vietnam. It describes the activities of the regional *Forest Cover Monitoring Project* (FCMP) in Lao P.D.R. with the main focus on the methodology of forest cover monitoring processes.

The FCMP was initiated by the *Mekong River Commission* (MRC), co-financed by the *Government of Germany* and implemented through the *Mekong River Commission Secretariat* (MRCS) with assistance from the *German Agency for Technical Cooperation* (GTZ).

All *Lower Mekong Basin* (LMB) countries that are members of the MRC, i.e. Cambodia, Lao P.D.R., Thailand and Vietnam, have been facing rapid destructions of their forests over the past decades with serious consequences for the quality and function of the entire LMB watershed and the livelihood of its rural populations.

The FCMP was initiated because the MRC became aware of the need to generate and collect recent and reliable information on the current status of forest cover and on the location and intensity of its degradation and destruction and, as far as possible, on the socio-economic conditions leading to them. This information was to be generated and collected in order to provide decision makers and planners in the national planning ministries and agencies of the MRC member countries and in the regional MRC itself with a sound decision basis to formulate adequate policies and strategies to preserve the remaining forest cover.

The visual interpretation technique is applied to extract the information on the current status of forest cover and on the location and intensity of its degradation and destruction (*monitoring* information) from hard copy satellite images at 1:250,000 scale acquired in 1992/93 and 1996/97. For the process of monitoring forest cover changes, the so-called interdependent interpretation technique is used. This produces much more reliable

monitoring result than the comparison of 2 independent interpretations. The result of the interpretation was then integrated into a computerized Geographical Information System (GIS), by which different products e.g. forest cover statistics, forest cover change statistics, maps, were analyzed and prepared.

To ensure the homogeneity of the forest cover information in all FCMP country, the new forest and land cover classification system, which was relevant to the watershed management issue, was developed and used in all 4 FCMP countries. The threshold of 20% of crown density is used to differentiate between forest and non-forest areas.

Supplementary information on forest composition was extracted from the national forest inventories of the MRC member countries. Information on the socio-economic conditions leading to forest degradation and destruction as far as available was compiled from national census data and other statistics. These data were integrated into a computerized numerical data base which was linked to the GIS.

At present, there are two sets of forest cover data which were generated by two separate institutions e.g. the Lao National Forest Inventory (NFI) and the MRC Forest Cover Monitoring Project (FCMP). Differences between the statistical results of FCMP and the Lao *National Forest Inventory* (NFI) could be explained and resolved through a study jointly conducted by former NFI and FCMP staff. The results of this study are also discussed in this report.

The German Ministry of Economic Cooperation and Development and the MRC have agreed to fund 2 more years of FCMP post-project support (1999-2000) through the *Sustainable Management of Resources in the Lower Mekong Basin Project* (SMRP). The post-project support is provided in order to facilitate the distribution and marketing of the FCMP results to a wider range of users, to promote the utilization of the FCMP results in a wider range of applications, to further develop the built up technical skills and experiences, and to introduce new technological concepts and techniques such as digital satellite image processing.

1. FCMP - RATIONALE, OBJECTIVES

FCMP Rationale

In watershed management, healthy, natural forests are essential for the stabilization of the hydrological cycle during the wet and dry seasons. Through their horizontal and vertical structure, ground vegetation and subterranean root system, forests alleviate the impact of torrential rains, absorb excess quantities of rainfall and slowly feed the water into the groundwater table and river systems during the dry season. This results in the continuous flow of water for drinking, irrigation, fisheries, river transport and hydropower generation. Forests also fulfill a variety of other functions, which are of paramount importance for the livelihoods of rural populations, such as protection against soil erosion, production of timber and of numerous non-timber forest products, such as rattan, fibres, dyes, honey, fruits and medicinal plants.

The LMB has been covered by a variety of forest formations. These forests sheltered human, animal and plant communities. They have been used sustainably by the local populations for millennia. Only in the course of this century these forests have become subject to rapid and serious degradation and destruction. It has been estimated that between 1950 and 1970 nearly one half of the forest cover disappeared.

A major cause of forest degradation and destruction is the exponential population growth of recent decades resulting in socio-economic imbalances, which cause pressure from landless farmers encroaching on forest land and converting forests by unsustainable shifting cultivation practices on steep slopes. Furthermore, uncontrolled logging and lack of post-harvest management are rapidly degrading and destroying the forests. Forest degradation and destruction in turn further aggravate the problems of securing the livelihoods of the still growing rural populations.

Serious consequences of forest degradation and destruction have become manifest in all LMB countries. The reduction of forest cover has resulted in decreased water retention potential, increased frequency and intensity of flooding and landslides, loss of soil fertility and agricultural productivity, soil erosion, siltation of reservoirs and intrusion of saltwater into the Mekong delta.

Any LMB-wide policies and strategies to preserve the remaining forest cover would have to be based on recent and reliable information on its current status and on the location and intensity of its degradation and destruction. However, such information was not available at a LMB-wide scale in the early 90s. The last LMB-wide survey of forest cover had been done in 1972 and had only provided very general information on the

status of the forest cover, but not on the location and intensity of its degradation and destruction. Some forest cover information was available in the early 90s in the LMB countries, however, this information was also partly outdated and rather inhomogeneous.

Equally, sound information on the socio-economic conditions leading to forest degradation and destruction would be required for any sound planning approach. This information, like the information on forest cover, was only partly available in the early 90s.

The Mekong River Commission, as a regional level planning agency, therefore took the decision in the early 90s to initiate the Forest Cover Monitoring Project (FCMP). This project would generate and collect information on the current status of the forest cover, on the location and intensity of its degradation and destruction, and, as far as possible, on the causes thereof.

The Remote Sensing and GIS are the most modern technology which has been widely used in the field of natural resource management and monitoring. This technology provides a very powerful tool to observe and collect the information on natural resources and dynamic phenominon on the earth surface, and ability to integrate different data and present the data in different formats. Through the use of this technology, the most recent and reliable information could be provided to decision makers and planners in the national planning ministries and agencies of the member countries and in the regional MRC itself, to help them formulate adequate policies and strategies to preserve the remaining forest cover.

FCMP Objectives

Five major outputs had been specified for phases I and II of the project:

1. Establish a Natural Resources Information System.
2. Establish a Forest Cover Monitoring and Trend Analysis System.
3. Enhance cooperation between and within the national and regional planning agencies of the riparian countries and the MRC.
4. Provide training to national planning agencies.
5. Promote the use of project results and capabilities in forest and environmental policy and planning decisions.

It has to be kept in mind that the technical outputs (1. + 2.) were intended to be used at the **macro-planning level**, that is at the regional, national level.

2. TECHNICAL APPROACH - FOREST COVER MONITORING

2.1. General Approach

2.1.1. Overview

The *technical* outputs of the FCMP were defined as follows:

1. Establish a Natural Resources Information System.
2. Establish a Forest Cover Monitoring and Trend Analysis System.

Technically, a *Natural Resources Information System* as well as a *Forest Cover Monitoring and Trend Analysis System* are computer based Geographic Information Systems (GIS) with mapping and data base components.

In principle a *Natural Resources Information System* contains information on the status of a natural resource (such as forest cover and composition) at a given point in time. A *Forest Cover Monitoring and Trend Analysis System* contains information on the status of this natural resource at several (at least 2) given points in time. In addition, the latter contains information on external factors that influence the natural resource, such as socio-economic and bio-physical information. This said, one can combine the above 2 outputs into 1 output as follows:

Establish a Forest Cover Monitoring System, which contains information on the status and composition of forest at several points in time plus information on external factors of influence.

This output comprises 3 major layers of information:

- **forest cover** (e.g.: Where is forest? How many hectares?)
- **forest composition** (e.g.: Species composition and volume within the forest?)
- **socio-economic / bio-physical** (e.g.: What is the population density and growth?)

The most important of these 3 layers under MRC's point of view of watershed management is the first. It is essentially a map layer. The latter 2 layers are tabular information linked to the map layer.

2.1.2. Generation / Collection of Information

Given the FCMP's regional character, it was evident for technical as well as for financial reasons that the information contents of a *Forest Cover Monitoring System* had to be limited in terms of data collection intensity and resolution or scale.

The *first* issue to be resolved was whether information should be *generated* or *collected from existing sources*. Information generation is usually more expensive than collection from existing sources. The FCMP countries together with the MRC decided to use the following approach:

- **generate** forest cover information
- **collect** forest composition and socio-economic / bio-physical information

The decision to *generate* forest cover information was taken because the information available in the FCMP countries was rather inhomogeneous and partly outdated. The information had to be **standardized** to a certain degree in order to be usable for the purpose of monitoring as well as in order to make it usable for MRC's basin development planning activities. This standardization could not be achieved using available information. It was therefore decided to spend the major part of the limited funds on the generation of forest cover information as the most important information layer.

On the other hand the FCMP could *collect* information on forest composition and socio-economic / bio-physical information since this information was available in the FCMP countries at least to an acceptable degree of standardisation. This information was collected and integrated in a computerised database, which was then linked to the information on forest cover. This database will not be discussed any further in this document since it is a state-of-the-art database and contains the data layers of secondary importance.

2.1.3. Data Sources for Generation of Forest Cover Information

The *second* issue to be resolved was as to *how to generate the forest cover information*. Terrestrial mapping was out of question due to time and budget constraints, as could be expected in a regional project covering 4 countries. Mapping from aerial photos or high resolution commercial satellite images like SPOT (as used in the NFI of Lao P.D.R.) was ruled out for the same reasons. That left only Landsat TM or IRS satellite images as mapping options. FCMP decided to use **Landsat TM**.

The *third* issue to be resolved was whether to use *digital* (computerized) or *printed* images for the generation of forest cover information. Advantages of using digital images would have been the possibility to do digital image enhancements and classifications, which are not possible with printed images. The main disadvantage of digital images were their high costs of around US$ 3000 each as compared to US$ 1000 for a printed image. In addition, the hard- and software required for processing of digital images came at a very high price by the time FCMP commenced. Cost aspects are of paramount importance in any kind of information generation, especially when taking into consideration that monitoring requires the repeated purchase of images covering the same area. Another disadvantage of digital images is that their processing requires staff with a least basic experiences in operating computer systems which are far more demanding than normal office applications. Such experienced national counterpart staff were not available at the time the project started. FCMP therefore decided to use **printed images** at a scale of 1:250,000 (a similar approach as used in the NFI of Lao P.D.R.).

2.1.4. Generation of Forest Cover Information

After selecting the appropriate data source for the generation of forest cover information, the FCMP country teams together with the TSU of MRCS jointly developed and agreed upon a *forest and land cover classification system*. This classification system was based on previous experiences made in the FCMP countries, especially on the experiences made during the NFI SPOT satellite image interpretation in Lao P.D.R. Numerous field trips in all 4 project countries, especially in Lao P.D.R., were undertaken during the development of the classification system to carry out practical testing of its applicability

The classification system was designed to be used in all 4 FCMP countries to ensure standardization and homogeneity of the to-be-generated forest cover information, the importance of which has already been discussed above. The classification system as the core of the FCMP's technical output will be discussed in greater detail in chapter 0.

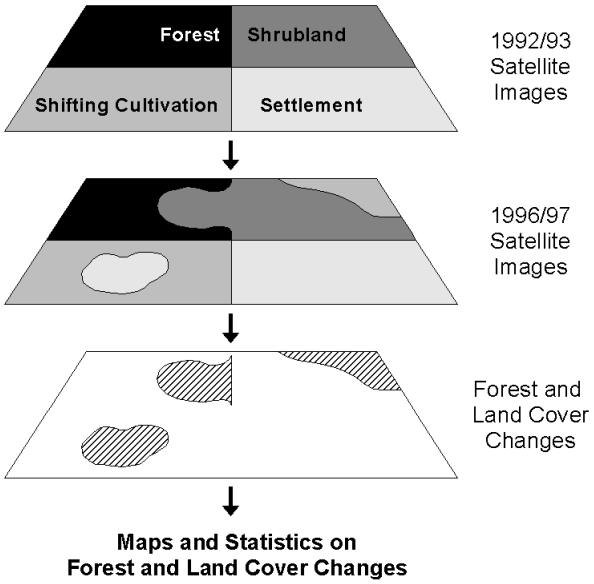
The satellite images were then visually interpreted according to the developed forest and land cover classification system. In Lao P.D.R. this interpretation was done by the above mentioned national image interpretation specialists, who had already done SPOT image interpretation during the NFI. Field trips were undertaken repeatedly during the image interpretation to provide sufficient ground truthing information. Aerial photos were used in all 4 countries to support and verify the satellite image interpretation. In Cambodia, Thailand and Vietnam existing photos could be used. In Laos, new aerial photos were taken by FCMP in 1993 / 94, since the most recent available photos had been taken in the early 1980s and were outdated. These photos were taken in strips distributed across the whole country and covering all major vegetation types in Lao P.D.R.

Two satellite image interpretation rounds were carried out, the first with satellite images from 1992 / 93, the second with satellite images from 1996 / 97. The second interpretation round was designed and carried out as a so called *dependent* interpretation. This means that the interpreters based their interpretation during the second interpretation round on the results produced in the first interpretation round. In this process, corrections are applied wherever interpretation errors from the first interpretation round are found. This dependent interpretation produces much more reliable monitoring results than the comparison of 2 independent interpretations, where the results of the first interpretation are not known during the second interpretation round, thus leading to the overlooking of usually numerous errors made during the first interpretation round.

In addition, a limited number of Landsat MSS satellite images from 1974/75/76 was interpreted to provide some information on forest cover development trends during the past 20 years.

Image interpretation was followed by inputting the interpretation results into GIS. The GIS system used was a relatively simple PC based ArcInfo / ArcView system. This technical approach was choosen because in the Forestry Departments of Lao P.D.R. as well as Thailand staff were already using PC ArcInfo, whereas GIS technology was completely new to the Forestry Departments of Cambodia and Vietnam.

The forest cover monitoring (change) information was produced by comparing (overlaying) the computerized results of the first (1992/93) and second (1996/97) interpretation rounds. The monitoring process is outlined in the following figure.



2.2. Forest and Land Cover Classification System

The Forest and Land Cover Classification System is the core of the FCMP's technical output and may have led to differences between previously compiled national figures and the FCMP results. Therefore it is discussed in greater detail in this chapter.

2.2.1. Overview

Requirements

The general user requirements and information needs to be met by the classification system as well as its limitations were defined prior to designing it as follows :

- The thematic and the spatial accuracy have to be sufficient for conclusions at a **Sub-Regional Level**. It is not intended to meet all requirements at the local planning level.
- The Forest and Land Cover Classes should be **relevant for watershed management issues** such as erosion risk, soil protection and others.
- Repetition of interpretation and mapping as part of a **Monitoring System** must be feasible in a timely manner at reasonable cost.

Limitations

- The classification will focus on **Land Cover** classes, not on **Land Use** classes.
- The forest classes will represent broad **Forest Cover** types. The classification cannot offer sufficient accuracy and detail for local forest planning where parameters like forest type, forest structure, species distribution and detailed crown cover percentages have to be described.
- Class separation can be difficult in **Transition Zones** between two classes. Class boundaries will not have an accuracy of more than ± 250 meters.
- Small **Patches of Forest** may remain undetected due to limitations of the source data (satellite images) and other effects. While this can be accepted at the sub-regional level, it is understood that at local level these patches may add up to an important forest area.

Forest and land cover classes were defined on the basis of previous experiences made in the FCMP countries and on forest definitions and formations as described in the relevant literature. As far as possible internationally accepted criteria of what constitutes a forest were used (FAO, IUFRO, UNESCO). Limits of what vegetation type can be considered as forest were defined on the basis of the density and continuity of the existing tree cover. Special consideration was given to qualitative changes of the forest cover, e.g. changes in canopy density resulting from logging or shifting cultivation practices. Specific forest cover types, e.g. *Inundated Forests* around the Tonle Sap Lake in Cambodia or *Mangrove Forest* in the coastal zone were recognized.

The forest and land cover classes resulting from the integration of the various attributes and criteria as described below were considered as an adequate representation of field conditions and as discernible on Landsat TM satellite images at a scale of 1:250,000.

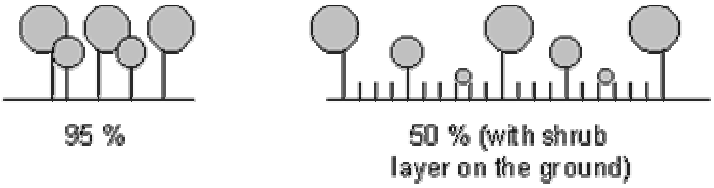
Any percentages and thresholds discussed below used to distinguish classes and to define their boundaries were provided as guidance for *visual interpretation* and have to be considered approximate. Precise *measurements* are not possible on Landsat TM satellite images but would require aerial photos. Therefore the final class boundaries vary in a certain range above and below any defined percentages and thresholds.

The Forest and Land Cover Classification System developed and applied by FCMP is a system designed solely to map **Current Forest Cover** or, more generally speaking, to carry out an **Inventory of Existing Natural Resources**. It does **not** contain or relate to any **Legal Definition of Forest Land**. Depending on a countries specific laws, even areas on which not a single tree grows may be considered as Forest Land. The FCMP results can therefore **not** be used to make statements on the legal status of any area mapped.

2.2.2. Crown Cover and Forest on the Ground

Crown Cover

Crown Cover refers to the density (percentage) of the crowns of woody plants above a certain height (usually 5 - 10 meters). This height threshold needs to be introduced in order to exclude vegetation types formed by woody plants like shrubs or tree seedlings and saplings, which can also reach considerable densities, from being classified as current forest.



Different Crown Cover Classes as seen on the ground

Forest versus Non-Forest

The definitions of Forest and Non-Forest *as seen on the ground* used by FCMP were as follows:

Forest

- Crown Cover ³ **20 %** and
- Tree Height ³ **10 meters**

Forest Regrowth

- Crown Cover ³ **20 %** and
- Tree Height **5 - 10 meters**

Non-Forest

- Crown Cover **< 20 %** or
- Crown Cover ³ 20 % and Tree Height **< 5 meters**

The 20 % Crown Cover threshold was chosen in view of the Dry Dipterocarp Forests, which are abundant in the LMB and which by nature are quite open. For Evergreen and Mixed Forests a 30 % threshold might be more appropriate, but would result in the exclusion of major areas of Dry Dipterocarp Forests from the class Forest if applied as a general threshold. A 10 % threshold as used by FAO and developed in view of the, by nature, very open African Woodlands appeared to be rather low for the forests in South East Asia.

Given the still rather low threshold of 20 %, the areas considered as forest by FCMP include a significant amount of severely degraded forest. Any summary statistics of forest cover produced by FCMP must be interpreted with this fact kept in mind.

The class Forest Regrowth was introduced in order to distinguish between mature and regenerating forest (e.g. after an area has been cleared during a commercial logging operation or in a slash and burn farming system).

It is essential to note that the definitions given above are for distinguishing Forest and Non-Forest *as seen on the ground*. They can not be directly applied to satellite image interpretation without further modification. Nevertheless, they are indispensable in order to come to an understanding of what has been classified as Forest from satellite images.

2.2.3. Crown Cover on Satellite Images

It is evident that single trees can not be detected on Landsat TM or comparable satellite images. Therefore neither precise Crown Cover nor tree height *measurements* can be obtained from these satellite images. For precise measurements aerial photos would be required. However, the color and texture of vegetation as seen on satellite images provide information about its composition and structure, which an experienced interpreter can relate to broad classes of Crown Cover and tree height.

Given these restrictions, 3 Crown Cover Classes *as seen on satellite images* were distinguished in the FCMP Classification System:

- 0 – 19 % (Low)
- 20 – 69 % (Medium)
- 70 – 100 % (High)

These thresholds are estimates rather than measurements. It should therefore be noted that

- Relative differences of Crown Cover will be detected rather than exact thresholds.
- In mountainous areas the appearance of forest on satellite images is variable due to transitions in forest types and site conditions and especially due to illumination and shadow effects. Separation of Crown Cover Classes may therefore be more difficult in these areas.

Optical satellite images such as Landsat TM can only be taken in the cloudless, that is the dry season. During the dry season different Crown Cover Classes of *Deciduous Forests* cannot be interpreted reliably. The crown density of most natural Deciduous Forests is in the Medium Class. The crown density of natural Dry Dipterocarp Forests even ranges at the lower end of the Medium Class. All Deciduous Forests have therefore invariably been classified as Forests with Medium Crown Cover.

Qualitative *changes* of the Crown Cover of forests can be mapped from Landsat TM satellite printed images if the Crown Cover changes are *significant* and *recent*, the forests and the topography of the terrain are more or less homogeneous and if the images have been digitally enhanced prior to producing the prints. Mapping of *selectively logged* areas is therefore almost impossible, particularly when the gaps are filled quickly by secondary vegetation.

2.2.4. The Canopy Density Concept – Forest on Satellite Images

The Canopy Density Concept has to be introduced in order to finally arrive at the definition of precisely what FCMP considered as Forest or as Non-Forest *as seen on satellite images*.

Minimum Mapping Unit (MMU)

In visual interpretation and mapping there is always a tradeoff between mapping accuracy and processing speed. If an interpreter has to map too much detail, he may not be able to complete his task in good time. Therefore usually a Minimum Mapping Unit (MMU) is defined as the smallest unit to be mapped by the interpreter. An internationally recognized standard for the MMU in forest and land cover mapping is 4 × 4 mm at source scale. FCMP originally intended to apply this standard. However, during practical interpretation and mapping work, it was even lowered to about 2 × 4 mm in order to not miss too many small structures.

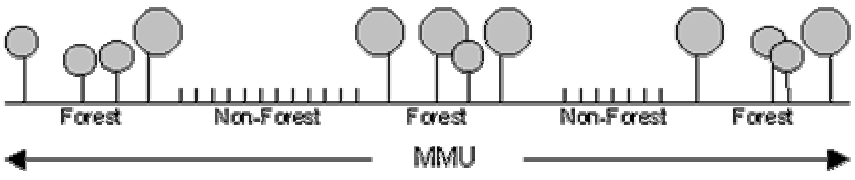
At the scale of the Landsat TM satellite images used by the FCMP (1:250,000), 2 × 4 mm are equivalent to an area of 0.5 × 1 km or 0.5 km^2.

Given the heterogeneous forest and land cover, which is to be found in major parts of South-East Asia, a MMU of 0.5 km^2 may contain forest and other land cover types at the same time. All features smaller than the MMU therefore have to be assigned to or grouped into an appropriate class.

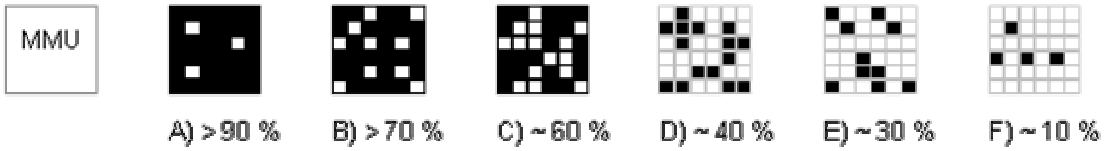
This makes it necessary to introduce the term Forest Cover.

Forest Cover

Forest Cover is the percentage of areas *within* a MMU where the Crown Cover is ³ 20 %.



Forest Cover as seen on the ground (~ 60 %)



Forest Cover as seen on satellite image (Forest in black)

Canopy Density as Combination of Crown Cover and Forest Cover

Canopy Density is defined as the combination of Forest Cover and Crown Cover. Forest Cover and Crown Cover are the deciding factors for the assignment of any MMU *as seen on satellite images* to 1 out of 3 Forest Canopy Density classes or to the Non-Forest Class. These classes are:

1. FOREST, High Canopy Density	**FC**	**³ 90 %**
	AND	
	CC	**³ 70 %**
2. FOREST, Low-Medium Canopy Density	**FC**	**³ 70 %**
3. FOREST, Mosaic	**FC**	**³ 40 %**
NON-FOREST	**FC**	**< 40 %**

Classification of MMU using Forest Cover (FC) and Crown Cover (CC) Minimum Thresholds
(CC to be estimated within FC only)

To be classified as Forest in general, a MMU as a whole must have a Forest Cover of at least 40 %. Forest Cover is the percentage of areas within a MMU where the Crown Cover is at least 20 %. The MMU may then be further classified into 1 out of 3 Canopy Density Classes (High, Low-Medium, Mosaic).

Examples

To be classified as *Forest, High Canopy Density*, a MMU must have a Forest Cover of at least 90 % **and** this Forest Cover must have a Crown Cover of at least 70 %.

A MMU is classified as *Forest, Low-Medium Canopy Density*, in any of the following 3 situations:

- Forest has small gaps in it (Forest Cover ³ 70 % but < 90 %), but is otherwise dense (Crown Cover ³ 70 %).
- Forest has no gaps in it (Forest Cover ³ 90 %), but is open or disturbed (Crown Cover ³ 20 % but < 70 %)
- Forest has small gaps in it (Forest Cover ³ 70 % but < 90 %) and is open or disturbed (Crown Cover ³ 20 % but < 70 %)

The areas A – F from the above figure, assuming that the Forest Cover has a Crown Cover of ³ 70 %, would be classified as:

A	Forest, High Canopy Density
B	Forest, Low – Medium Canopy Density
C	Forest Mosaic
D	Forest Mosaic
E	Non-Forest
F	Non-Forest

Assuming that the Forest Cover has a different Crown Cover of ³ 20 % but < 70 %, only 1 area would be classified differently:

A - Forest, Low – Medium Canopy Density

These examples show that the classification system is quite conservative in assigning areas to the class *Forest, High Canopy Density*. On the other hand, it is rather generous in assigning areas to the class *Forest Mosaic*, which contains areas that have major gaps and are only about half covered by actual forest. The most common forest types of South-East Asia, i.e. the Degraded Evergreen / Mixed Forests and all Deciduous Forests (including the Dry Dipterocarp Forests), were normally - that means if there were no major gaps - classified as *Forest, Low – Medium Canopy Density*.

These characteristics have to be kept in mind when reading and interpreting the FCMP forest and land cover statistics. Dense evergreen forests, as many people imagine when discussing about forests in South-East Asia, can only be found in the class *Forest, High Canopy Density*. All other classes are more or less open or disturbed.

2.2.5. Vegetation Types and Other Land Cover Types

So far, only the classification of areas as Forest (of different canopy density classes) or Non-Forest by their *quantitative* characteristics has been discussed. The FCMP classification system also differentiates various Vegetation Types and Other Land Cover Types by their *qualitative* characteristics, like Evergreen Forest, Deciduous Forest, Wood / Shrubland, Bamboo, Agriculture, or Urban Areas. These types can be identified from Landsat TM satellite images by an experienced interpreter, mainly by their color.

Details on how to identify Vegetation Types and Other Land Cover Types will not be discussed here. The interested reader might instead refer to the FCMP *Technical Notes 2, Interpretation and Delineation from Satellite Images*.

2.2.6. FCMP Forest and Land Cover Classes

The FCMP Forest and Land Cover Classification System can finally be summarized as follows:

FOREST CLASS	**CANOPY DENSITY**	**CODE**
Evergreen	High Low-Medium Mosaic	11 12 13
Mixed (Evergreen / Deciduous)	High Low-Medium Mosaic	17 18 19
Deciduous	Low-Medium Mosaic	20 22
Regrowth	(no further differentiation)	40
Plantations	(no further differentiation)	54
Others	(no further differentiation)	55
NON-FOREST CLASS	**SUB-CLASS**	**CODE**
Evergreen Wood / Shrubland		61
Dry Wood / Shrubland		64
Bamboo		63
Grassland		62
Cropping Mosaic (mainly Shifting Cultivation)	cropping area < 30% cropping area > 30 %	81 82
Agriculture		91
Barren Land		92

Rocks		93
Urban Area		94
Water		95
Wetland		97
Others		96
Clouds		99

(CODE has been used for encoding in GIS)

No further differentiation of Canopy Density Classes (as discussed above) has been applied to *Forest Classes* of minor area extent such as *Regrowth* or *Plantations*.

The Class *Wood / Shrubland* comprises of former Forest areas which have been severely degraded and whose Crown Cover has been reduced to < 20 %, and, to a lesser extent, of climax formations on very poor soils. It also contains former shifting cultivation areas on which forest vegetation gradually regrows but has not reached sufficient density and height to be classified as *Forest Regrowth*.

The Class *Cropping Mosaic* is a mixture of shifting cultivation areas and various stages of fallow. Major parts of it are very similar to the Class *Wood / Shrubland*. For the 1996/97 interpretation cycle FCMP decided to assign *only* those areas to the Class *Cropping Mosaic*, on which *recent* shifting cultivation was clearly recognizable in order to get a better picture of the *actual* extent of *recent* shifting cultivation. Therefore many areas which had been mapped as *Cropping Mosaic* in 1992/93 were assigned to the class *Wood / Shrubland* in 1996/97.

2.3. Comparison of NFI and FCMP Results

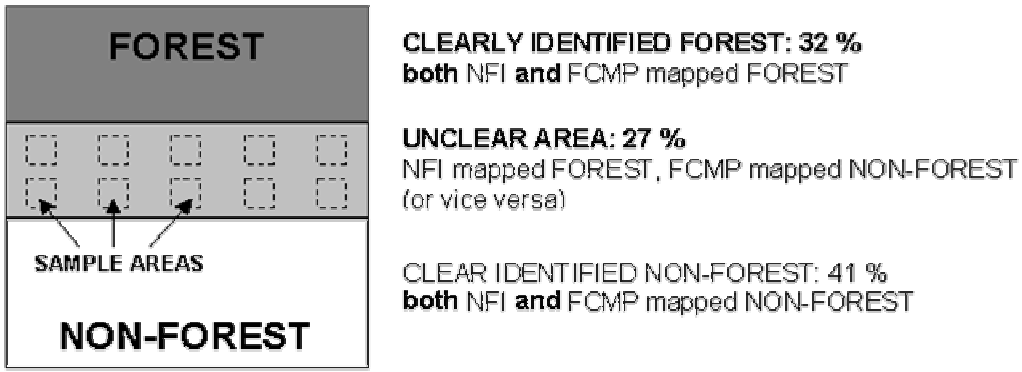
Problem

Two independent Forest Figures exist in Lao P.D.R.: the FCMP and the NFI figures. They are different.

As discussed above, the FCMP Forest Figure is 40 % (rounded) for 1992/93. (The 1992/93 FCMP figure is discussed here because it is timewise closer to the NFI figure than the 1996/97 FCMP figure and therefore more comparable.)

The NFI Forest Figure of 50 % (rounded) is based on the interpretation and mapping of SPOT XS satellite image hardcopies at 1:100,000 or 1:50,000 scale taken in 1989/1992. (Remark: a second NFI Forest Figure of 47 % (rounded) exists, which is based on statistical sampling.)

Since all data the Forest Figures are based on are available as digital maps, they can easily be overlaid with each other. The overlay shows the following problem:



(for SAMPLE AREAS see below)

Explanation

The differences in the **Unclear Area** have the following reasons:

- **Subjectivity of Interpretation**: areas with relatively few trees can sometimes be mapped as either Forest or Non-Forest, depending on the subjectivity of the interpreter.
- **Effects of Time**: the FCMP Forest Figure was produced 3 years later than the NFI Forest Figure. In some cases Forest may have been destroyed in the meantime.
- **Differences in the Classification Systems**: these are not likely to account for the major differences in the Forest Figures. Both the NFI and FCMP surveys had a minimum mapping area of 0.5 km^2. Both used the threshold of 20 % Crown Cover of trees of about 10 meters height for the definition of forest.
- **Differences in Source Data Scales**: FCMP used images at 1:250,000 scale, whereas NFI used images at 1:100,000 or 1:50,000 scale respectively. It is therefore theoretically possible that small patches of forest were mapped in the NFI survey, which remained undetected by FCMP. It is the main reason that makes the differences between NFI and FCMP result.

Solution

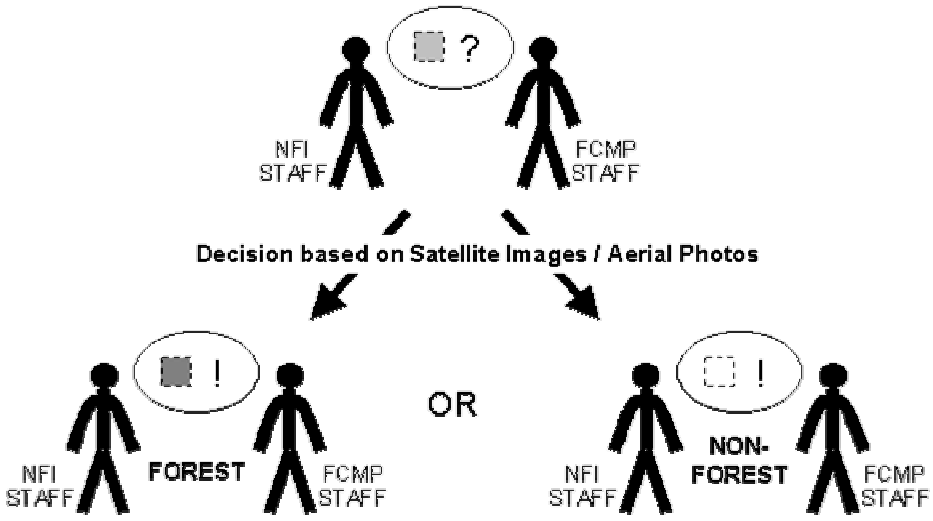
A **Sample Survey** was conducted in the **Unclear Area** to help eliminate the differences between the NFI and FCMP Forest Figures and to obtain a **Corrected Forest Figure**.

In the **Unclear Area** more than **300 Sample Areas** were established. These Sample Areas were re-checked more carefully from Landsat TM digital satellite images taken in 1992/93 and in case of doubt from the aerial photos taken by FCMP in 1993/94.

The Sample Survey covered only the **Northern Part of Lao P.D.R.** (roughly 53 % of the country) due to time restrictions.

The Sample Survey was done **jointly** by **NFI** and former **FCMP** national counterpart staff.

The **Procedure** used was as follows: a mixed team of NFI and former FCMP national counterpart staff examinated each Sample Area and classified it as either Forest or Non-Forest.



3. Potential Utilization of Results

Because of scale restriction, the FCMP results could be in combination with other data e.g. slope, watershed classes, population density, used to identify the critical areas for protection and intervention.

It should be kept in mind that identification of areas as discussed below will not produce information sufficiently accurate to implement field activities, but rather give an indication of which areas should be considered for detailed data collection and planning and which areas do not need to be investigated any further.

Identification of Areas for Reforestation and Protection

As FCMP's sister project, the regional *Watershed Classification Project* (WSCP) was established in 1997. It has generated comprehensive data on Slope and Watershed Classes. However, these data are only of limited use in the macro-level planning process, since they describe a desirable, but not necessarily real situation: e.g. Watershed Class 1 (on steep slopes) *should be* under permanent forest.

The combination of these WSC data with the FCMP data on Forest and Land Cover would take forestry and environment-related macro-level planning activities a significant step further: it would enable planners to pre-assess the impact of projects and measures on watershed quality and function and thus to optimize the allocation of resources and funds.

A prominent example are *reforestation activities*: by combining the WSCP Watershed Classes and the FCMP Forest and Land Cover Data one could identify areas that *should be* under permanent forest but *are* currently not forested. These areas would be *priority intervention areas*, where reforestation measures besides their immediate economic benefits would have the most beneficial effect on watershed quality and function.

A second example is the proper establishment of *protected area networks*: in this case the overlay of FCMP and WSCP data would help to identify forested areas on steep slopes, that means areas which *generally* need to be protected. Combining this knowledge with information on population density and pressure, one could then rank these areas by their potential endangering and thus identify areas which are in *immediate* need of protection. This would help to focus the generally limited resources available for protection (monetary as well as human) in a most meaningful way.

Identification of Areas for Commercial Plantations

The criteria used to identify areas suitable for the establishment of fully commercially operating forest plantations are certainly different from the criteria used to identify areas for reforestation activities under watershed protection aspects. Present Land *Use* and accessibility play major roles in the identification of potential plantation areas. In many cases, the present Land *Cover* gives a quite strong indication of the present Land *Use*, especially in Non-Forest areas. Combining the FCMP Forest and Land Cover data with data on road infrastructure and population distribution might therefore help to identify areas where the establishment of forest plantations would cause minimal land use conflicts and at the same time can be expected to generate sufficient economic benefits.

4. Future Development and Planning

4.1 Further Development of Technical Skills and Experiences.

The *non-technical* FCMP result are the built up technical skills and experiences, which are probably even more important than the *technical* result. Besides facilitating the distribution of FCMP results, SMRP aims at further development of these technical skills and experiences through the post-project support.

In all the 4 member countries of the MRC, especially in Lao P.D.R. and Cambodia, technical skills and experiences in satellite image interpretation, GIS application, and database processing have been significantly strengthened during the operation of FCMP. These skills and experiences are of paramount importance for the further development of planning capacities in the forestry departments of both countries.

In order to further strengthen and enhance these skills and experiences, SMRP provides the opportunity of continued on-the-job-training to the national counterpart staff through an international GIS and RS consultant.

This on-the-job-training aims on the one hand at the improvement of the existing *technical* skills of the national counterpart staff through the reworking of existing products (e.g. the 1:250,000 maps). These technical skills are further improved through the introduction of new techniques (e.g. processing of digital satellite images, see chapter 0) for the development of new products (maps at larger scale).

On the other hand, the existing *analytical* skills of the national counterpart staff in the field of GIS applications shall be improved, e.g. through extending the range of applications of FCMP results as discussed in chapter 0.

Through continued training of the national counterpart staff, SMRP envisages to strengthen technical skills and

experiences of the respective teams to even better address the requirements of the forestry departments of the partner countries for reliable data and knowledge generation and production of relevant and accurate products in the future.

SMRPs vision is to further develop the built up GIS and RS units to a point that they can independently design new products and react to and fulfill user requirements for existing and for new products in a flexible and market-oriented manner.

4.2. Future Technology Development

As discussed in chapter 0, FCMP decided to give preference to using printed satellite images for the generation of forest cover information because of the lack of local technical skills and the at that time high costs of digital satellite images and processing software.

Technical skills have been built up by FCMP during its operation. Digital satellite images today have become much more affordable with the successful launch of the new Landsat 7 satellite. The prices for processing hard- and software have dropped considerably over the past couple of years.

It seems therefore logical to take the next step and to move from manual interpretation of printed satellite images to computerised processing of digital satellite images.

SMRP and the partner countries have therefore agreed to introduce the concepts and techniques of working with digital satellite images to the former FCMP national counterpart staff. A consultant has been employed to conduct training on processing of digital satellite images and to produce a series of prototype maps at larger scale together with the national counterpart staff.

The first digital satellite images and the processing software have already been purchased by SMRP.

The striking advantage of digital satellite images compared to printed satellite images is that GIS data sets and maps at larger scales can be produced in less time. SMRP intends to employ the digital technology to produce a series of GIS data sets and forest cover maps at scales between 1:50,000 and 1:100,000. **Such maps could be used for planning applications below the provincial level.** This would take the capacities and information generated under the FCMP a significant step further, since the original FCMP products could only be used for planning at the macro level, that is at the regional, national, and at most the provincial level.