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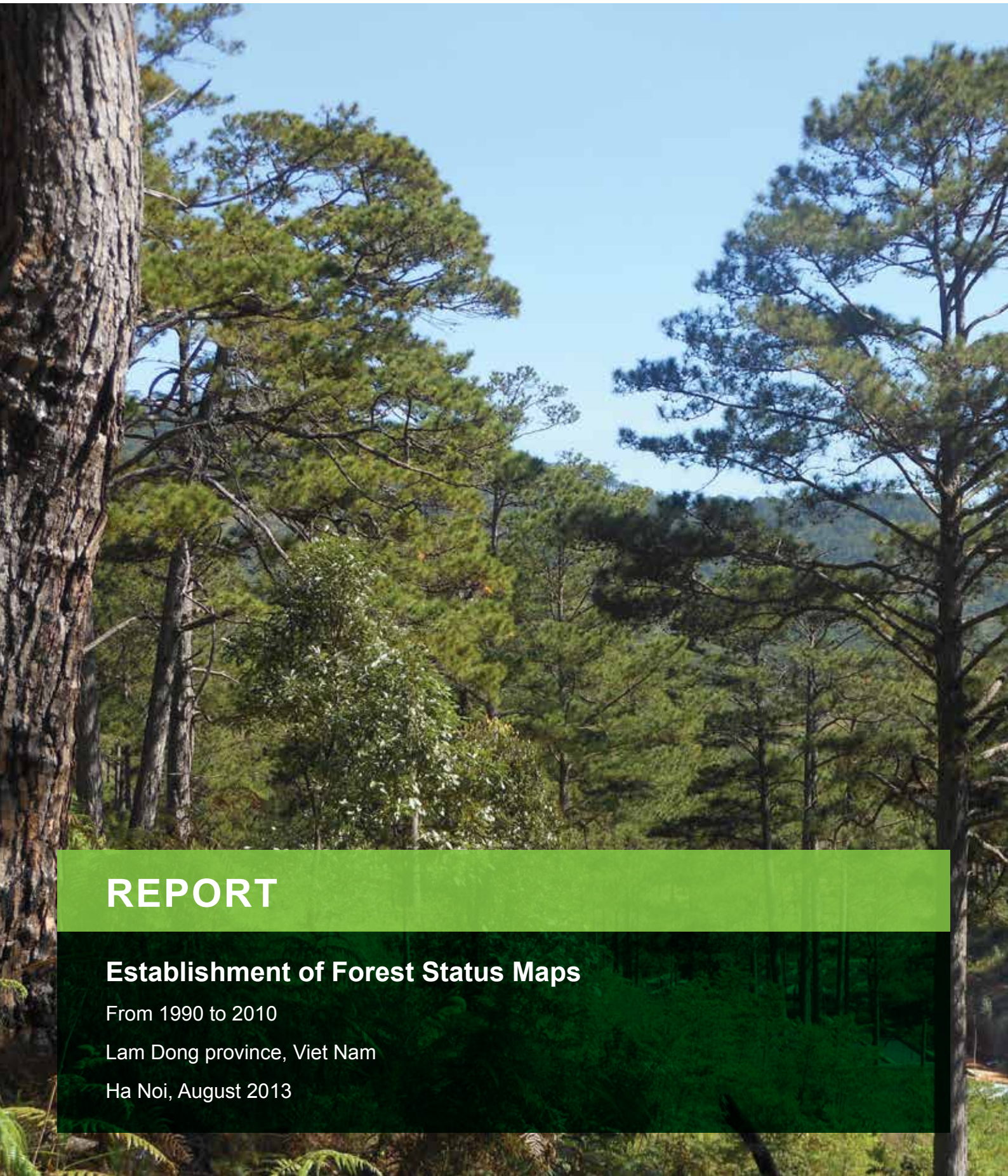

# REPORT

## Establishment of Forest Status Maps

From 1990 to 2010

Lam Dong province, Viet Nam

Ha Noi, August 2013

This report has been produced by the USAID-funded Lowering Emissions in Asia's Forests (USAID LEAF) program in its support for the development of the Lam Dong Provincial REDD+ Action Plan (PRAP). It is one of five technical reports that have been developed to help the Lam Dong Department of Agriculture and Rural Development (DARD) in defining an appropriate Forest Reference Level for the Province from which its policies and measures introduced to reduce emissions and increase greenhouse gas (GHG) removals from the forestry sector can be measured against. Specifically, the report provides a detailed description of the technical approaches for generating land cover and forest status maps based on the application of remote sensing technology and geographical information systems (GIS) for the years 1990, 1995, 2000, 2005, and 2010 in addition to maps showing forest cover change at five-year intervals between 1990 and 2010. This information will support further analysis aimed at identifying the driving forces of this change, areas vulnerable to future deforestation and forest degradation, as well as REDD+ activities to be considered and proposed in the Provincial REDD + Action Plan (PRAP) of Lam Dong province.


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The report is available through the USAID LEAF website at:

**ttp://www.leafasia.org/resources_tools**


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# Abbreviations

| | |
|---|---|
| DBH | diameter at breast height |
| FAO | Food and Agriculture Organization |
| DONRE | Department of Natural Resources and Environment |
| DOIT | Department of Industry and Trade |
| ETM+ | Enhanced Thematic Mapper Plus |
| FIPI | Forest Inventory and Planning Institute |
| FLITCH | Forests for Livelihood Improvement in the Central Highlands in Vietnam |
| FPI | Department of Planning and Investment |
| FREC | Forest Resources and Environment Center |
| FPD | Forest Protection Department |
| GHG | greenhouse gases |
| GoV | Government of Vietnam |
| GIS | geographical information system |
| GPS | global positioning system |
| MARD | Ministry of Agriculture and Rural Development |
| MONRE | Ministry of Natural Resources and Environment |
| NFCMAP | National Forest Resource Changes Monitoring and Assessment Program |
| NFI&S | National Forest Inventory and Statistics |
| NRAP | National REDD+ Action Program |
| PRAP | Provincial REDD+ Action Plan |
| RS | remote sensing |
| TM | Thematic Mapper |
| UN-REDD | United Nations - Reducing Emission from Deforestation and Forest Degradation |

# 1 Introduction

Over the past decade, various national and international organizations have made significant efforts to work out mechanisms to combat deforestation and reduce emissions of greenhouse gases (GHG) from the forest and land use sectors. They have attempted to quantify different values of forest resources and forest environmental services and propose workable market payment incentive mechanisms so as to effectively manage these valuable resources. Among these efforts, the most prominent initiative is the Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+) mechanism. This performance based mechanism is aimed at compensating developing countries for conserving and protecting their forest resources, thereby reducing GHG emissions and increasing GHG removals. REDD+ mechanisms also seek to generate additional social and environmental benefits, or 'multiple-benefits', which include biodiversity conservation, improvement of local livelihoods and gender equity.

The United States Agency for International Development (USAID) funded Program "Lowering Emissions in Asia's Forests" (LEAF) is being implemented by Winrock International in partnership with SNV Netherlands Development Organisation, Climate Focus and The Center for People and Forests (RECOFTC) in six countries: Viet Nam, Laos, Cambodia, Thailand, Malaysia and Papua New Guinea. The purpose of the program is to strengthen the capacity of developing countries in the Asian region to produce meaningful and sustained reductions in GHG emissions from the forestry and land use sectors, thereby allowing these countries to benefit from the emerging international REDD+ program framework.

In Viet Nam the USAID LEAF program was approved by the Ministry of Agriculture and Rural Development (MARD). USAID LEAF will provide support for the successful implementation of the Vietnam National REDD+ Action Program (NRAP).

The province of Lam Dong has been selected as one of six pilot provinces under the NRAP to pilot REDD+. USAID LEAF is supporting the development of the Lam Dong Provincial REDD+ Action Plan (PRAP).

This report summarizes the tasks, methodology and outcomes in assessing historical forest and land use change between 1990 and 2010. Two distinct tasks are described. The first is the development of historical land use /forest cover maps for 1990, 1995, 2000, 2005 and 2010. The second task described is the time series analysis to assess forest and land use change for four time periods, 1990-1995, 1995-2000, 2000-2005 and 2005-2010.

This analysis provides the activity data for inclusion in the Lam Dong Forest Reference Level, as well as providing historical data upon which to develop policies and measures to reduce future deforestation and forest degradation rates.

## 1.1 Goals

The Forest Resource and Environment Centre (FREC) of the Forest Inventory and Planning Institute (FIPI), in collaboration with the Lam Dong Agro-Forestry Company has been tasked under the LEAF project to map land and forest cover changes for 1990 – 2010 in Lam Dong province. This effort will assist the ongoing development of a Provincial REDD+ Action Plan (PRAP) in Lam Dong Province.

The main objective of this work is to assess the changes in land use and forest resources in Lam Dong province, as well as to analyze major drivers of deforestation in the province between 1990 and 2010 based on the application of remote sensing (RS) technology and geographical information systems (GIS). This analysis will help identify options to prevent deforestation and forest degradation and assess the potential to reduce emissions from deforestation and forest degradation when REDD+ policies and measures are implemented in Lam Dong province.

To achieve the project's objectives, the project focused on two distinct tasks:

**Mapping task:** identification of various land categories and forest types for 1990, 1995, 2000, 2005 and 2010 through remote sensing images and development of forest status maps for Lam Dong for these years at a 1:100,000 scale for the whole province at a 1:50,000 scale for all districts.

**Analysis task:** establishment of forest resource and land uses time series data and a change detection matrix to estimate the area changes between four intervals, 1990 - 1995, 1995 - 2000, 2000 - 2005 and 2005 vGHG emissions from the land use sector in Lam Dong province.

## 1.2 Content

This report provides a description of the technical approaches for mapping the land cover and forest status with remote sensing data and an estimation of the land cover and forest resource change for the time periods 1990 - 1995, 1995 - 2000, 2000 - 2005 and 2005 – 2010. The report is structured as follows:

Section 1 - introduction and the objectives of this project

Section 2 - details on the methodological framework for creating the forest status maps

Section 3 - technical details on actual image pre-processing and classification

Section 4 - details on implementation and collaboration activities

Section 5 - results and discussion

Section 6 - conclusions and recommendations

# 2 Methodological framework for creating forest cover and forest status maps

The methodological framework for creating forest cover and forest status maps is presented in Figure 1.

***Figure 1: Framework for creating forest cover and forest status maps for Lam Dong province.***

## 2.1 Data collection

After discussion with the LEAF project, the Forest Resources and Environment Center worked with the forestry department of Lam Dong province and the Lam Dong Agro-Forestry Company to plan, implement and collaborate on activities as well as collect relevant documents from FIPI and Lam Dong province. The materials collected are outlined in the following sections.

### 2.1.1 Collection of satellite images from 1990 - 2010

Satellite images were collected in 1990, 1995, 2000, 2005 and 2010, at more or less the same time of year as the historical land use/forest cover maps they were being used to validate.

- Landsat images 4-5 TM images for 1990 and 1995

Landsat 4-5 TM images were used for mapping forest status and enhancing map quality for 1990 and 1995. The Landsat images comprised seven bands, including six multispectral and one panchromatic band, and were collected by FIPI within a JICA project with the image code of 124-52.

- Landsat 7 ETM+ images for 2000

Landsat ETM+ images from the year 2000 were used for mapping of forest statuses and for updating and enhancing the year 2000 map quality. The Landsat ETM images consisted of seven bands, including six multispectral and one panchromatic band, and were collected by FIPI within a JICA project with the image code of 124-52.

- SPOT 5 satellite images for 2004 - 2005

SPOT 5 satellite images for 2004 - 2005 were used for mapping of forest statuses in the year 2005 and consisted of 19 mosaics at 1:50,000 scale. All the mosaics were adjusted and composited with natural colors and were provided by the remote sensing center (Ministry of Natural Resources and Environment (MONRE)), under the National Forest Inventory and Monitoring of Forest Resource Changes Program (NFIMAP) in cycle 4 during the 2005 - 2010 period.

- SPOT 5 satellite images for 2009

False color composition SPOT 5 satellite images with a resolution of 2.5 meters, acquired in 2009, were used for mapping of forest statuses in 2010 and for enhancing the quality of the 2010 map. The SPOT 5 images included six scenes which were orthogonally corrected based on the digitized elevation model. Details of these scenes are provided in Table 1 below.

***Table 1: Serial number of SPOT 5 used for mapping of forest status in 2010***

| NO | Serial number of the mosaic | Row/column | Imagery taken date |
|---|---|---|---|
| 1 | 487398 | 279/326 | 4/25/2010 |
| 2 | 487399 | 277/326 | 3/10/2009 |
| 3 | 487400 | 277/326 | 3/10/2009 |
| 4 | 487401 | 278/326 | 3/30/2009 |
| 5 | 487402 | 277/326 | 3/10/2009 |
| 6 | 487403 | 277/326 | 3/10/2009 |

### 2.1.2 Forest status maps during various periods from 1990 – 2010

A range of other GIS products wereas accessed during this study to compare and confirm the satellite imagery outlined in Section 2.1.1. This included:

- Historical forest cover maps were produced by the National Forest Inventory and Monitoring Program (NFIMP) between 1990 and 2010 and were digitized and partly improved by the JICA funded study on "Potential Forests and Land Related to Climate Change and Forests".
- Forest statistics status maps, developed under instruction 286/CT-TTg dated May 2nd, 1997 by the Prime Minister, were collected for 1998 - 2000.
- Forest status maps from the JICA project in collaboration with FIPI for 1990, 1995, 2000, 2005 and 2010.
- Forest status and land use maps from Di Linh and Lam Ha districts for 1990, 1995, 2000, 2005 and 2010, which were developed by FREC in collaboration with the Vietnam UN-REDD Programme during the program's phase 1.
- Forest status and land use maps which were developed from the Forests For Livelihood Improvement In The Central Highlands In Vietnam (FLITCH) project based on SPOT 5 satellite images acquired in 2010.
- Other spatially explicit and current official information in digital format including forest management, three types of forest, protected areas, development areas, roads, towns, rivers, topography, etc.

### 2.1.3 Collection of data in Lam Dong and from other organizations

Data collected to support the analysis of the satellite imagery included:

- Maps, data and reports on the current state of forest resources in 1990, 1995, 2000, 2005 and 2010 from Lam Dong Forest Protection Sub-Department (Sub-FPD), implemented under the National Forest Resource Changes Monitoring and Assessment Program (NFCMAP) by the Forest Protection Department (FPD).
- Maps, data and reports from various reforestation programs and forest development projects during different periods from 1990, 1995, 2000, 2005 and 2010.
- Maps and data from hydropower system development projects in Lam Dong province.
- Data from various permanent cultivation and residence projects.
- Topographical base maps, land allocation maps and land use planning maps.
- Maps and data from sample plots of the FLITCH project.
- Socio-economic data from various periods during 1990, 1995, 2000, 2005 and 2010.
- Documentation, maps and data on forest status and land uses.

## 2.2 Data processing and analysis

### 2.2.1 Assessment of quality of data and maps developed from 1990 - 2010

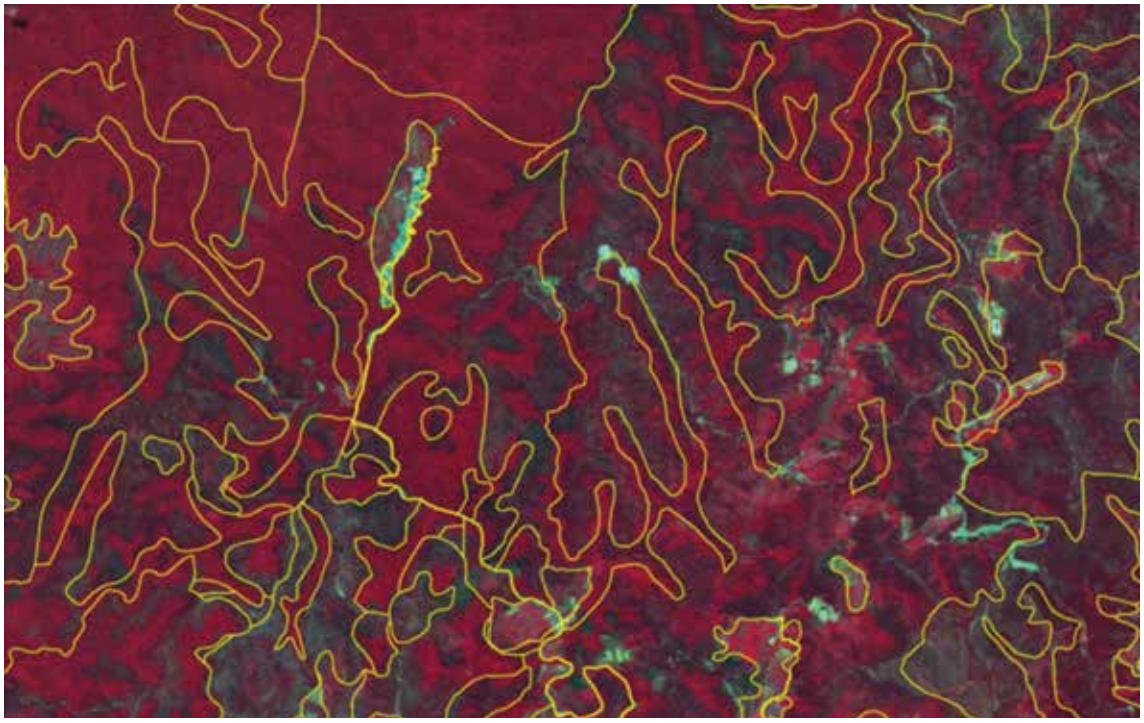
Various different programs and projects created maps on forest status and land use in Lam Dong province between 1990 - 2010 using a variety of data sources and different mapping methods. All maps were therefore evaluated to ensure uniformity in their coordinate system, format, scale, methodology and classification system.

However, there were some issues and inconsistencies which needed to be addressed at the data processing step, including:

- **Spatial resolution:** between 1990 and 2010, a variety of remote sensing images were used from various sources with different spatial resolutions. For example, in the 1990 -1995 period, Landsat images with a spatial resolution of 30m were used and Landsat 7-ETM+ images with a spatial resolution of 15m was used. During 1995-2000, SPOT 4 images with a spatial resolution of 20m were used and between 2005 and 2010, SPOT 5 images with a spatial resolution of 2.5m were used.

- **Coordinate system:** Between 1990 and 2010, various mapping coordinate systems were used with multiple systems of projection, including: UTM – Indian Thailand, HN 72, WGS 84 and VN2000 at scales of 1:100.000 and 1:50.000. Prior to 2000, WGS 84 UTM projection system was predominately used for mapping but, since 2000, VN2000 projection system has been the standard. Thus, the maps using the WGS 84 UTM projection system needed to be converted to the VN 2000 projection system.
- **Forest classification systems:** Forest definitions were different. Before 2004, the classification system was based on Regulation QPN6 – 84 where forest cover was classed as 30% canopy cover, whereas the classification system used during the period from 2008 - 2010 followed Circular 34/TT-BNN which defined forest as having a canopy cover of 10%.
- **Mapping methods** were also different. Field inventory and delineation methods were used in the 1990 - 2000 National Forest Inventory & Statistics (NFI&S) but remote sensing technologies were used in the later NFIMAPs with different image interpretation methods such as visual interpretation on hardcopy images during cycles 1 and 2 and interpretation of digitized images during cycles 3 and 4. Also some mapping projects (such as the JICA Study on Forests and Land Related to Climate Change and Potential Forests in Vietnam) were desk based studies with no ground-truthing. Therefore the accuracy of these maps are limited and require further field analysis.
- **Mapping Scales:** There were differences in scale and format of maps used across the different periods. Regional hardcopy maps were developed for NIFMAP during cycles 1 and 2, whereas digitized provincial maps were developed during cycle 3 and digitized provincial, district and communal maps were developed during cycle 4.

***Figure 2: JICA result on SPOT 5 image in 2010***



## 2.2.2 Development of the classification system

The classification system for different land categories and forest types was as defined under Circular 34/2009/TT-BNN&PTNT issued by MARD.

FREC has collaborated with the LEAF project and the Viet Nam REDD+ Office to come to an agreement on the forest and land classification system to use for interpretation of satellite images for Lam Dong in order to ensure the consistency of various land categories and forest types for intervals between 1990 and 2010. This classification is based on the actual land categories and forest types of Lam Dong province, the properties of satellite images taken at various periods and the possibility of being able to distinguish and separate different strata in Landsat, Landsat ETM+ and SPOT 5 images. The classification system of various land categories and forest types is shown in Table 2.

***Table 2: Classification system of land categories and forest types***

| CODE | LDLR | Types |
|---|---|---|
| 1 | G | Evergreen - Broadleaf forest - Rich |
| 2 | TB | Evergreen - Broadleaf forest - Medium |
| 3 | NG | Evergreen - Broadleaf forest - Poor |
| 3 | PH | Evergreen - Broadleaf forest - Regrowth |
| 5 | RL | Deciduous forest |
| 6 | TN | Bamboo forest |
| 7 | HG | Mixed wood and bamboo forest |
| 8 | LKG | Coniferous forest – Rich |
| 9 | LKTB | Coniferous forest – Medium |
| 10 | LKNG | Coniferous forest – Poor |
| 11 | LKPH | Coniferous forest – Regrowth |
| 12 | RK | Mixed broadleaf and coniferous forest |
| 13 | RT | Plantation forest |
| 14 | DT | Bare land |
| 15 | NN | Agricultural land and other land |
| 16 | MN | Waterbody |
| 17 | DC | Residential area |

### 2.2.3 Development of key interpretation sets

Based on the classification system of land use categories and forest types and characteristic of satellite images taken during various periods from 1990 - 2010, a key interpretation set was developed for each period to support the classification process.

Each key interpretation set was developed based on the following principles: (i) It must be representative of the objects to be interpreted; (ii) It must be representative of different geographical conditions and regions; and (iii) It must visualize different images and image mosaics.

Key interpretation sets for different forest strata needed to prioritize and target national parks, natural conservation areas and protection forest areas. Some areas saw little change between 1990 and 2010 and can be used as a reference point.

The number of key interpretation sets selected for image classification had to be sufficient to accurately determine the threshold for each forest status. The key interpretation set of each forest type required at least 30 key interpretations (30 ground truth points).

Selection of the key interpretation sets to be used for image classification included the following steps:

### Step 1: Selection of ground truth points

- Satellite images which have been pre-processed (geometrically and radiometrically corrected and color synthesized by ERDAS software) were imported into eCognition software.
- Based on the properties of the satellite images (colors, texture, structure, shapes, etc.) combined with expertise, key interpretation sets were selected according to the classification system of land categories and forest types.
- Note that interpretation points had to explicitly and accurately determine coordinates and locations. The key interpretation set had to be consistent with those visualized on satellite images in terms of color, structures, etc. An explicit and accurate description was provided, as outlined in Table 3 below.

### Step 2: Field trip to develop interpretation key sets

- Each interpretation key (ground truth point) of a key interpretation set for a land cover type was checked in the field to ensure that all key interpretations were correct. This process was applied for 2010.
- For 2005, 2000, 1995, 1990, field checks of ground truth points were not conducted. Instead, key interpretation sets were collected from FREC and FIPI databases.

***Table 3: Interpretation keys***

| X coordinate | Y coordinate | Status | Location | Image properties |
|---|---|---|---|---|
| 838060 | 1339193 | G | Lieng Sron commune, Dam Rong district | |
| 831204 | 1333988 | RT | Lieng Sron commune, Dam Rong district | |
| 828182 | 1305177 | GH | Tan Thanh commune, Lam Ha district | |
| 808463 | 1305360 | TN | Loc Lan commune, Bao Lam district | |

## 2.2.4 Development of topographical base map

MapInfo and ArcGIS software were used for developing topographical base maps (contour lines, administrative boundaries, boundaries of compartments and sub-compartments, transportation road networks, hydrology, names of locations, elevation points) using VN2000 projection systems at a 1:100,000 scale for provincial maps and a 1:50,000 scale for district maps, as specified in Circular 973/2001/TT-TCĐC by the Directorate of Land Administration (which is now MONRE). The mapping work required the conversion of the base cadastral maps generated by using Microstation software and developed by Lam Dong Department of Natural Resources and Environment (DONRE) into MAPINFO and ArcGIS format.

## 2.2.5 Image interpretation

**a. Sources of satellite images**

- Landsat satellite TM images taken in 1990 and 1995, comprising seven bands (six multispectral bands and one panchromatic band) and synthesized with natural colors.
- Landsat ETM+ satellite images from the year 2000, which consisted of seven bands (six multispectral bands and one panchromatic band) and were synthesized with natural colors.
- SPOT 5 satellite images from 2004 and 2005, synthesized from three bands, as provided by the Remote Sensing Centre of – the Ministry of Natural Resources and the Environment.
- SPOT 5 satellite images from the year 2010, synthesized with false color and 2.5 m resolution. These were acquired in 2009 and orthogonally corrected based on a digitized elevation model.

**b. Pre-processing of satellite images**

Equipment and software used for processing and enhancing satellite image quality included:

- ERDAS IMAGINE10 software: for processing and enhancing satellite images from different intervals between 1990 and 2010 including: color composition, intensification of spatial resolution, contrast level and geometrical correction according to the base map of the VN2000 projection system.
- eCognition software: for classifying satellite images for indoor mapping of forest status.
- Version 10.5 of MapInfo software: for updating, modifying, editing, layout setting and storing maps.

- ArcGIS software: for updating, modifying, editing, layout setting and storing maps and databases as well as for analyzing and calculating area of forest types.
- Computers with installed professional software: for processing and interpreting satellite images, developing forest status and statistics and land use maps of the province.

The pre-processing steps:

- Geometric correction of satellite images: based on the topographical base map of the VN2000 projection system and using ERDAS/ IMAGINE software, satellite images from different periods were adjusted according to the VN2000 projection system. This work was implemented on Landsat, Landsat ETM+ and SPOT 5 satellite images acquired in 2005.
- Enhancement of image quality: integrated color images need to have their spatial resolution enhanced in order to increase the level of detail. Additionally, contrast levels need to be enhanced so as to increase the recognition of, as well as the difference between, various objects.

Based on image bands collected over time (panchromatic and multi-spectral bands), ERDAS/IMAGINE software was used for pre-processing satellite images. The collected SPOT 5 images for the years 2005 and 2010 were already color composited and rectified at level 3. Therefore, color composition and geometrical correction were also conducted for images collected in the years 1990, 1995 and 2000.

### c. Image classification

The object-oriented classification method using eCognition software was used for satellite image classification.  This process involved two main stages as below:

#### Stage 1: Image segmentation

The image segmentation function of eCognition software was used to segment various objects on the images into separate segments (polygons) based on parameters as defined by the software.

Values of parameters (shape, smoothness and scale) were used to run the segmentation processing for each period from 1990 – 2010. The following threshold values of parameters were used:

- Shape: 0.2 – 0.3
- Smoothness: 0.5 – 0.6
- Scale parameter: 30 - 50

The segmentation resulted in drawn plot boundaries mainly based on

different levels of color and structure. A multi-resolution segmentation algorithm was then used (Figure 3) in which an image was divided into segments based on the values of parameters (shape, smoothness and scale). However, the land use classes of each segment (polygon) were not assigned at this stage, so the segments were classified as undefined objects (Figure 4).

***Figure 3: Algorithm of segmentation SPOT 5***

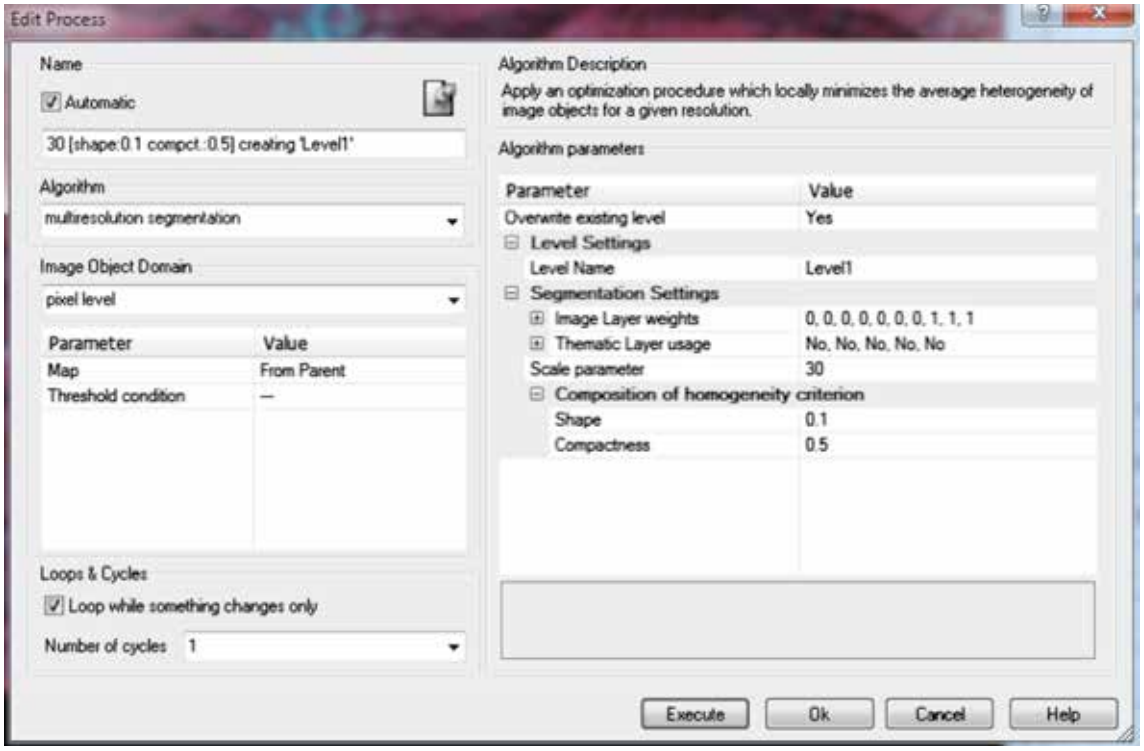



***Figure 4: Result of segmentation for SPOT 5 satellite image***

### Stage 2: Develop and apply classification rule

In this stage, the segments (undefined objects) were characterized and assigned a class name, for example, rich forest, medium forest or water body, by applying a classification rule. Each undefined object group had its own features measured by parameters such as TRRI, NDVI, RVI, EVI, and GVI. Development of these classification rules followed these steps:

#### Step1: Identification of classification parameters

Based on the properties of each type of image (Landsat, Landsat ETM+ and SPOT 5 satellite images) parameters for the classification and development of forest status maps during different periods from 1990 - 2010 were established as follows.

For Landsat images for the years 1990 - 1995, Landsat ETM+ images for 2000 and SPOT 5 images for the year 2010:

Parameters based on satellite image properties included:

- Total ratio reflectance index (TRRI)
  TRRI = (Layer1+Layer2+Lay3+… +Layer n) / (n*255)
- Normalized difference vegetation index (NDVI)
  NDVI = (NIR-RED)/(NIR+RED)
- Ratio vegetation index (RVI)
  RVI=NIR / RED
- Enhancement vegetation index (EVI)
  EVI= 2.5* (NIR-R) / (NIR+6*R-7.5q*B+1)
- Green vegetation index (GVI)
  GVI=1.6225NIR – 2.2978RED + 11.0656

For SPOT 5 satellite images for 2005:

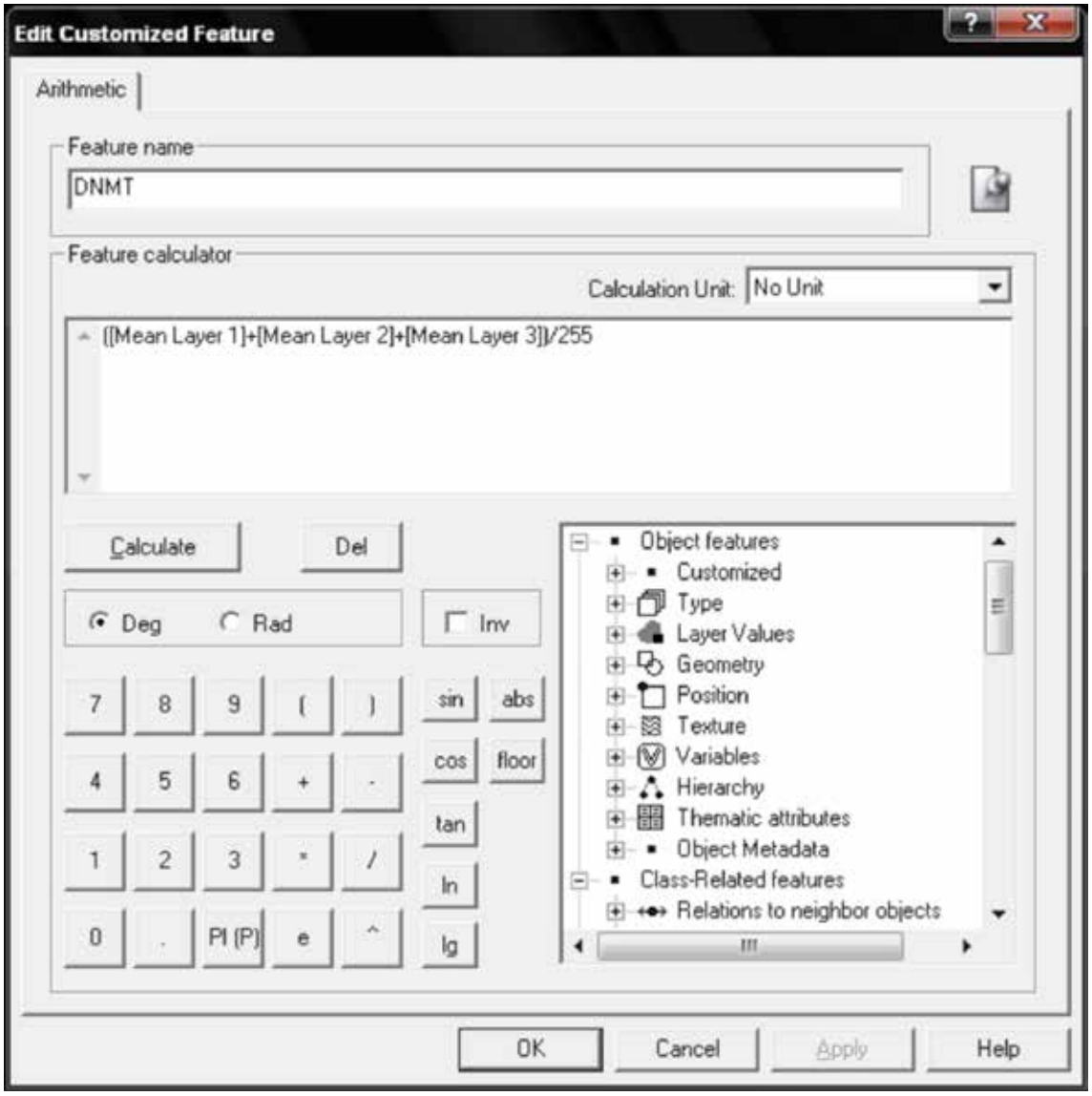
- Total ratio reflectance index (TRRI)
  TRRI = (Layer1+Layer2+Lay3+… +Layer n) / (n*255)

Other parameters which were automatically calculated by the eCognition software included mean values and standard deviations of spectral values of each image band.

Some thematic layers used for classification included transportation networks, river systems and residential areas.

The calculation of parameters for classification in eCognition software is illustrated in Figure 5.

*Figure 5: Tool for calculating parameters for image classification*




However, the work of selecting parameters used for classification depended on the image bands so it was not necessary that all criteria were used for classification of forest and land use classes. Based on the experience of experts, suitable parameters for different kinds of images (as described in the method section) were selected. Some parameters, such as NDVI and TRRI, were used quite frequently.

### Step 2: Preparation of training set and test set

The key interpretation set know as ground truth points of forest types, which were developed as detailed in section 2.2.3, were divided into two groups to develop a training set and a test set. The training set was used for classification and the test set was used to test the results of classification. The layers of the training set and test set were generated in ArcGIS format. The detailed steps for developing the training set and test set were as below:

The ground truth points of the training set were imported into eCognition then overlaid with the segmented layer. The ground truth points of each forest type were then aligned with its matching undefined segment (see pictures in column 6 of Table 3). Next a classification name (from the ground truth point) and corresponding parameters such as TRRI, NDVI, RVI, EVI, GVI were allocated to each undefined segment. These defined segments were saved as the training set to prepare for the next steps.

In this step, the land cover types, as shown in Table 2, were defined, i.e., the parameters in term of spectral values of the land cover types were determined and saved in the training set.

### Step 3: Establishment of classification threshold for rule set of classification

***Table 4: Thresholds of parameters for classification***

| Class name vs parameters | Evergreen - broadleaf forest - Rich | Evergreen broadleaf forest -Medium | Evergreen broadleaf forest Poor | Evergreen Broadleaf forest - Regrowth | Bamboo forest | Mixed wood and bamboo forest | Coniferous forest - Rich | Coniferous forest - Medium | Coniferous forest - Poor | Coniferous forest - Regrowt | Non forested land | Other land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GLDV-Entropy | 3.68 - 4.117 | 3.47 - 4.058 | 3.47 - 4.058 | 2.921 - 3.686 | 2.607 - 3.2156 | 2.725 - 3.47 | 1.86 - 2.7 | 2.15 - 3.0 | 1.8 - 2.5 | 2.3 - 2.9 | 3.17 - 3.62 | 1.49 - 3.372 |
| Mean_Layer1 | 58 - 91 | 25 - 101 | 45 - 102 | 78 - 118 | 126 - 148 | 91 - 126 | 54.5 - 63.5 | 55.06 - 86.65 | 52.8 - 60.4 | 59.4 - 81.07 | 138 - 158 | 132 - 255 |
| Mean_Layer2 | 69 - 114 | 50 - 119 | 75 - 124 | 102 - 137 | 142 - 168 | 116 - 145 | 35.5 - 49.5 | 44.2 - 94.7 | 31.8 - 44.9 | 45 - 77.6 | 135 - 139 | 141 - 245 |
| Mean_Layer3 | 48 - 58 | 18 - 67 | 20 - 67 | 40 -87 | 89 - 116 | 53 - 95 | 70.8 - 98.3 | 56.7 - 99.4 | 64.1 - 94.8 | 81.6 - 97.8 | 113 - 135 | 97 - 255 |
| TRRI | 0.24 - 0.34 | 0.12 - 0.376 | 0.192 - 0.38 | 0.29 - 0.44 | 0.47 - 0.556 | 0.345 - 0.478 | 0.21 - 0.27 | 0.21 - 0.35 | 0.19 - 0.25 | 0.25 - 0.33 | 0.505 - 0.564 | 0.486 - 1 |
| DVI | 11.17 - 23.196 | 16.32 - 31.21 | 11.74 - 38.08 | 14.03 - 29.49 | 14.03 - 28.349 | 16.89 - 28.349 | -44 - (-30.4) | -34 - 10 | -53.7 - (-21.3) | -48 - (-16) | -18.6 - (-3.14) | -26.61 - 18.04 |
| LVI | 64.588 - 86.823 | 31.76 - 96.353 | 46.58 - 97.41 | 72- 114.3 | 121.76 - 146.117 | 86.82 - 123.88 | 56.4 - 72.1 | 57.4 - 99.4 | 52.9 - 66.7 | 66.3 - 88.4 | 133.4 - 150.3 | 126 - 270 |
| BI | 4080 - 10710 | 1530 - 12240 | 4080 - 13005 | 8415 - 16065 | 17850 - 24735 | 10965 - 18360 | 3142.4 - 5576.3 | 2915.4 - 8044.3 | 2645.3 - 5337.3 | 4060 - 7490.1 | 18615 - 22185 | 18615 - 64770 |
| NDVI | 0.082 - 0.137 | 0.082 - 0.341 | 0.05 - 0.294 | 0.058 - 0.145 | 0.0509 - 0.098 | 0.066 - 0.137 | -0.34 - (-0.23) | -0.24 - 0.05 | -0.39 - (-0.19) | - 0.33 - (-0.09) | -0.066 - (-0.0117) | -0.082 - 0.066 |
| Standard_d1 | 24.81 - 36.43 | 17.88 - 37.105 | 11.62 - 36.88 | 8.94 - 23.023 | 6.92 - 14.976 | 8.94 - 20.56 | 3.3 - 8.9 | 5.3 - 14.5 | 2.8 - 7.8 | 5.4 - 12.3 | 27.047 | 0 - 20.78 |
| Standard_d2 | 22.94 - 35.88 | 14.7 - 42.94 | 12.6 - 43.52 | 8.823 - 20.29 | 8.823 - 14.41 | 9.411 - 15.88 | 4.8 - 12.3 | 7.01 - 21.8 | 3.3 - 11.5 | 6.4 - 16.7 | 19.411 - 30 | 6.17 - 20.88 |
| Standard_d3 | 26.6 - 34.63 | 18.03 - 32.06 | 11.7 - 32.63 | 9.73 - 26.9 | 7.15 - 19.46 | 8.58 - 24.047 | 5.1 - 12.6 | 6.1 - 20.3 | 4.6 - 11.02 | 8.04 - 16.5 | 16.604 - 28.62 | 1.145 - 22.32 |
| Brightness | 62 - 87 | 32 - 96 | 49 - 97 | 74 - 113 | 120 - 142 | 88 - 122 | 53.6 - 69.4 | 54.4 - 89.2 | 50 - 64.8 | 63.9 - 84.4 | 129 - 144 | 124 - 255 |

Based on the features of the training set, a threshold range (maximum and minimum values) for each parameter outlined in Table 4 and other statistical values for the spectral bands of each forest type were defined. The determination and calculation of thresholds for classification was based on the features of each spectral band from the satellite images. However, knowledge on the topography and ecological features of Lam Dong for each class were also utilized.

### Step 4: Establishment of the rule set for image classification

The classification threshold of parameters for each forest type developed in step 3 was used to establish the rule set for classification by running the algorithm of the setting rule set in eCognition. The tactic for establishing the rule set was to go from general to detailed, so in the first run of the process the un-classified objects were classified into two main objects: forest land and non-forest land. These were then processed down to the most detailed objects, following the classification system pre-determined for the area. As a result, all the plots in the segmentation step were assigned with class names following the classification system.

***Figure 6: The rule set used for forest classification***

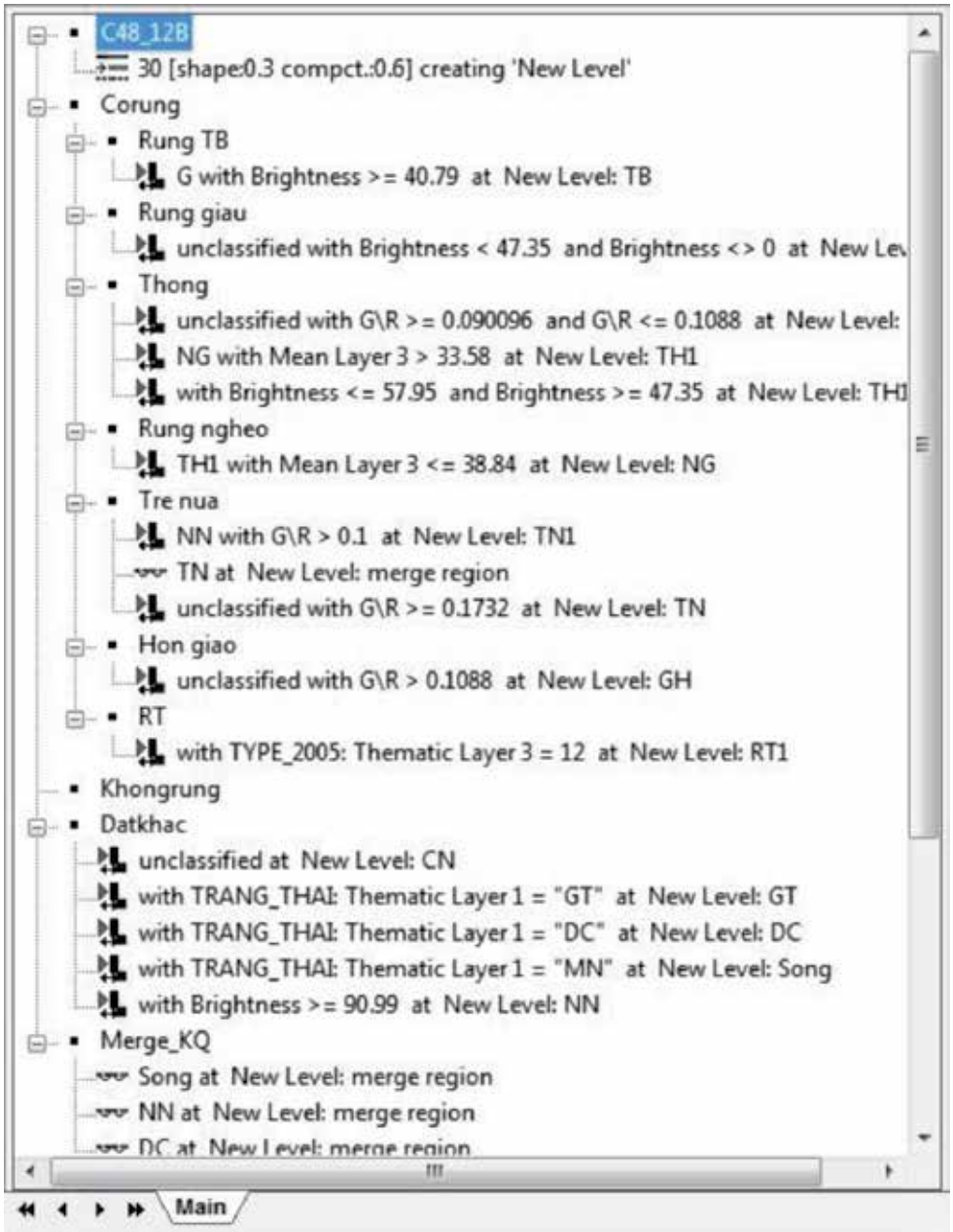


Figure 6 illustrates the rule set for image classification. The first row shows the code of the satellite image that was classified. The second row shows the command of the segmentation steps. For example, row 10: “NG with Mean Layer 3 <= 38.84 at New Level: NG” shows the rule to classify poor forest based on thresholds of the mean brightness values of the satellite image. If the segment has a mean brightness value less than or equal to 47.35 then eCognition will assign this unidentified segment as poor forest. at New Level : NG” shows the rule toclassify the poor forest based on threshold of  the mean of brightness values of the satellite image, that is, the condition to identify the poor forest: if unidentified segment has  mean of bright less value lower than 47.35 eCognition will assign this unidentified segment as poor forest

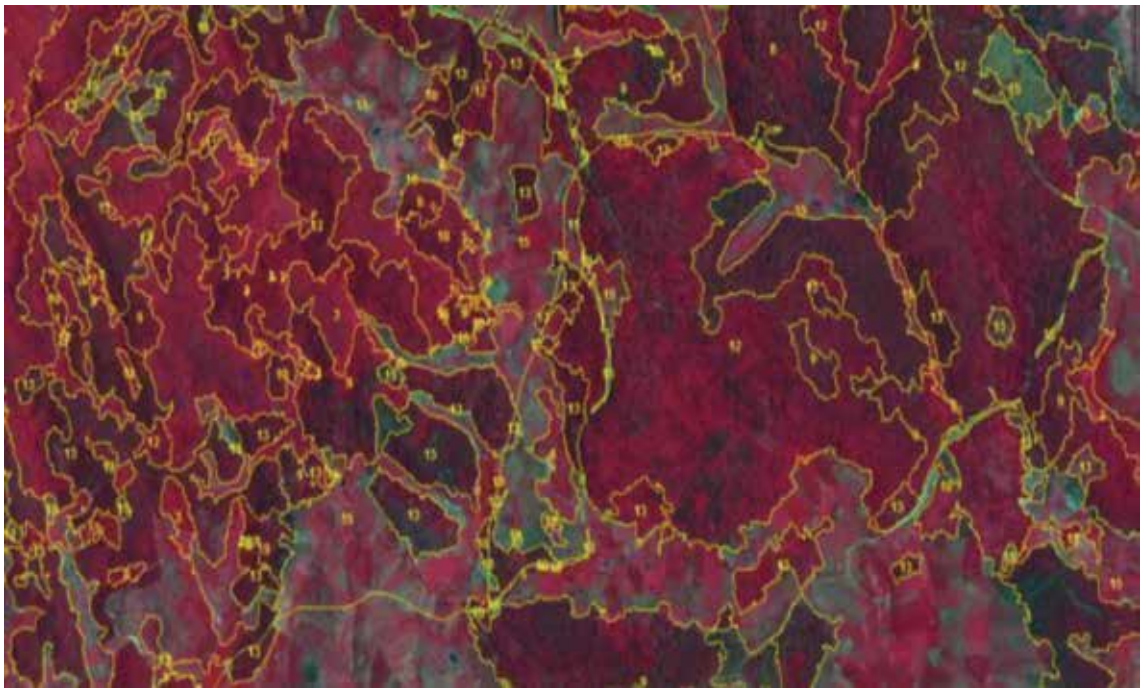
**Step 5: Running the classification and combination of status names**

Applying the rule set established in step 4 (see Figure 6), eCognition classified and labelled all undefined segments by land cover code and type (see Table 2). However, many unclassified contiguous segments were labelled and classified as the same land cover type, which were obviously incorrect. These segments were combined into a collective polygon.

**Step 6:  Generation of land cover maps**

After running the classification using eCognition software, the classified layer was exported to ArcGIS software and saved in vector format after making the forest type boundaries smooth (Figure 7).

***Figure 7: Classification results of forest cover map in 2010***



## 2.3 Accuracy assessments of the maps and enhancement of classification results

### 2.3.1 Accuracy assessment and enhancement of classification results during different periods from 1990 – 2010

Image interpretation experience combined with expert knowledge, and other sources such as collected documentation and maps (including maps from the FLITCH project and NFIMAP sample plots of 2010), were used to check, assess and enhance the automatic classification results in order to modify and re-delineate forest type boundaries caused by inaccurate automatic classification. The method applied in this stage was the visualization method (visual observation of satellite images on the screen and collation with reference documents and maps with the help of MapInfo and ArcGIS software). The maps were then updated and enhanced manually, i.e., interpreters manually and directly delineated images on the screen. This step was conducted as follows:

- In ArcGIS, vector files (from step 6) were overlaid onto the relevant satellite images, maps of FLITCH, the JICA project maps and sample plot maps from NIFMAP 2010. Based on image interpretation experience combined with expert knowledge on the distribution of forest in Lam Dong, some inaccurate classification plots were revised.
- If the accuracy verification showed that the classification was inaccurate, then it was compulsory to re-collect samples, re-calculate thresholds for each status and re-establish the classification rule set and re-run the classification steps.
- Still some segments remained suspicious after being re-classified. These were marked for further verification and modification during field checks.

### 2.3.2. Enhancement of map quality according to changes between different periods

Another possible source of inaccuracy in the study was inaccurate or abnormal land use changes between two time periods. To enhance the accuracy of these land use transitions between different periods, the following tasks were implemented:

ArcGIS software was used to overlay the updated interpretation results for the intervals, 2010 - 2005, 2005 – 2000, 2000 - 1995 and 1995 – 1990. That resulted in forest cover change maps and attribute tables (transition metrics, see Table 5) of these maps for these four time intervals. The transition metric showed some inconsistent transitions and abnormal transitions over the time periods. For example, from 2005 - 2010

some bare land plots changed into rich forest or rich forest changed to deciduous forest (see the figures in red in Table 5). These inconsistent changes, as well as abnormal changes, were marked and then revised manually by experts before conducting the field check. However, only abnormal polygons larger than 0.1 ha were checked and revised. Very small polygons that showed abnormal transition were not revised, and this may have contributed to the abnormal changes shown in the transition matrix (see numbers highlighted in yellow highlight in Table 5).

***Table 5: Example of transition matrix of forest and non-forest land for 2005 - 2010***

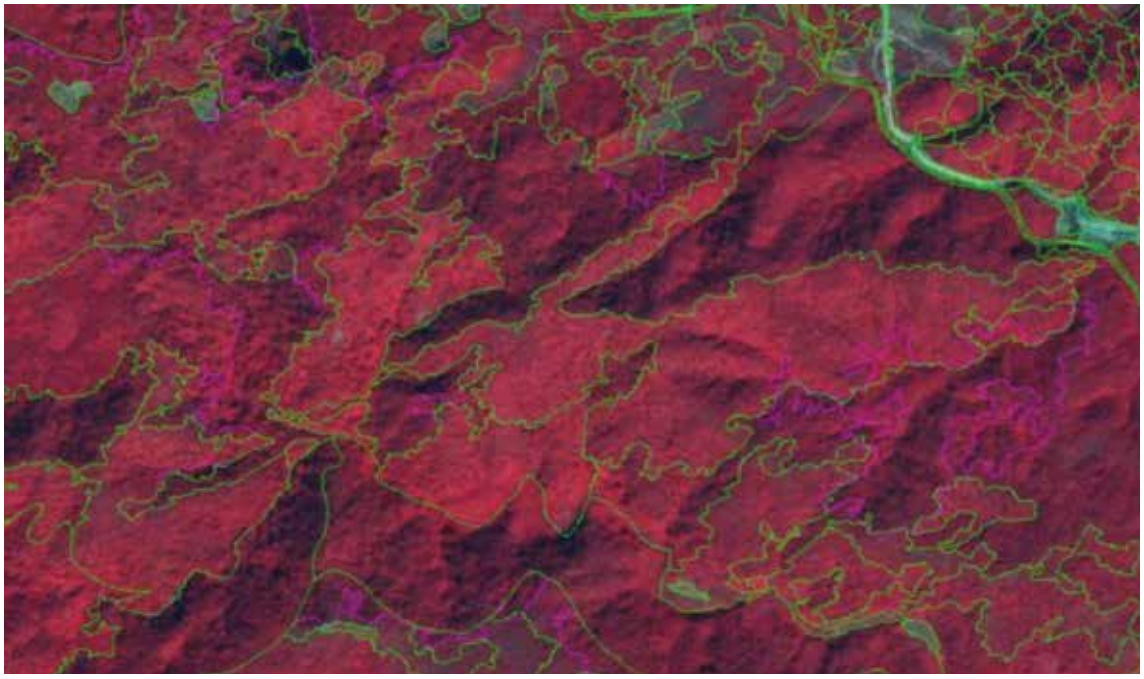
| Category 2010 | Evergreen - broadleaf forest - Rich | Evergreen - broadleaf forest - Medium | Evergreen - broadleaf forest - Poor | Evergreen - broadleaf forest - Regrowth | Deciduous forest | Bamboo forest | Mixed wood & bamboo forest | Coniferous forest - Rich | Coniferous forest - Medium |
|---|---|---|---|---|---|---|---|---|---|
| Category 2005 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Evergreen - Broadleaf forest - Rich | 17390.2 | 8531.7 | 2278.9 | 259.0 | - | 83.5 | 438.3 | 0.9 | 3.2 |
| Evergreen - Broadleaf forest - Medium | 3155.1 | 55526.9 | 9237.2 | 1545.6 | 0.0 | 409.1 | 2438.9 | 5.2 | 8.9 |
| Evergreen - Broadleaf forest - Poor | 45.0 | 7178.6 | 61903.5 | 5695.6 | 36.6 | 1438.9 | 7600.6 | 17.2 | 30.5 |
| Evergreen - Broadleaf forest - Regrowth | 11.8 | 191.0 | 5224.5 | 16394.7 | 0.2 | 552.1 | 3410.5 | 3.2 | 7.6 |
| Deciduous forest | 2 | 1.0 | 22.5 | 0.5 | 15417.8 | - | 32.3 | - | 0.2 |
| Bamboo forest | 9.5 | 65.9 | 139.7 | 723.6 | 0.0 | 37739.1 | 7431.6 | 9.6 | 9.5 |
| Mixed Wood and Bamboo forest | 56.7 | 1553.1 | 7905.1 | 952.5 | 44.2 | 6305.2 | 69327.3 | 14.6 | 17.3 |

The reasons for inaccurate or abnormal land use change transitions include:

- Satellite images were not 100% accurate during the geometric correction process (variations were within the allowable accuracy limits).
- Quality of satellite image processing between the different periods was not consistent. Satellite image resolution for different periods also varied significantly, in particular between 200 and 2005 and 1995 and 2000.
- The automatic classification of satellite images from different periods gave rise to certain errors but these errors were still within the allowable accuracy limits.

Based on the classification results for the different periods between 1990 and 2010, the process of updating and improving the classification results was completed (see Figure 8) following the steps as described above.

***Figure 8: Result of updating and improving lassification results***



## 2.3.2 Fieldwork for updating and enhancing map quality during 2010

The results of the desk based analysis, classification, updating and enhancement of map quality for 2010 were then field truthed to update, supplement and enhance the quality and interpretation of the maps.

Due to the high degree of change in forest cover between 1990 and 2005, and to check the land cover maps for this period, interviews were conducted with forest owners and local people with forest management profiles and paper maps used as reference.

Field truthing also targeted suspicious plots identified during the interpretation process. Local forest staff, such as forest rangers, forest owners and communal officers, were closely involved in this process which included the following steps:

**Step 1: Field mission preparations**

- Field truthing plans were developed and submitted to the provincial project working group, district government and forestry companies for approval.
- Forest status maps for different periods between 1990 and 2010 were printed for each district administrative unit at a 1:25,000 scale.

- Field truthing transects were determined. These transects were evenly distributed over the project sites and stretched across many forest classifications. Transportation and road networks and paths were used to save travel time.
- Templates for recording data during the field truthing process were developed.
- Meetings of field truthing teams were held to agree on content and field truthing techniques.

**Step 2: Field implementation and collaboration with relevant agencies**

**At provincial level**

Meeting with sub-FPD to determine collaboration principles for field work and to collect relevant documentation for the period 1990-2010, such as maps, data and reports of annual forest monitoring programs, in accordance with Directive No 32/2000/CT-BNN-KL issued by MARD, plus relevant socio-economic data.

Meeting with sub-FPD to also collect documentation relating to different forest protection and development programs and projects and plantation design and validation dossiers of various programs and projects in the province during the period 1990 - 2010.

Meeting with DONRE to gather topographical map, maps and reports of land statistics programs, and land use planning and land use conversion reports during the period 1990–2010.

Meeting with the Department of Industry and Trade (DOIT) to collect documentation related to hydro power development, transportation infrastructure and electricity grid development in the province from 1990 - 2010.

Meeting with the Department of Statistics to gather statistical year books from 1990 - 2010.

**At district level**

Meeting with district forest protection division, agriculture and rural development division, functional division and other relevant authorities to collect data and documentation on results of forest monitoring and forest resource changes assessment, land use planning schemes, agro-forestry economic development programs and projects, infrastructure, hydro power and other development projects.

Meeting with forestry organizations, forest owners (state forest enterprises, forestry companies and management units of protection and special-use forests) to gather documentation and data related to forest management, protection and development (reforestation) and changes in forest

resources and trends, and to conduct interviews on forest management between 1990 and 2010.

### At communal level

Conducting surveys and interviews with local government leaders, officers in charge of forestry and communal cadastral officers on the drivers of deforestation, forest degradation, forest area expansion and conversion of various land categories during different periods (surveys targeted communes which experienced major forest and land use changes).

Conducting interviews with forest owners and households on the situation of forest resource changes and utilization of forest and forest land in 1990, 1995, 2000, 2005 and 2010.

### Field truthing

Field truthing was conducted by teams consisting of experts from consulting firms, officers from district forest protection divisions and staff of forestry companies. Additionally, the field truthing team may have had input from officers from district natural resources and environment divisions and communal cadastral officers. The consulting firms were responsible for inputting technical expertise whereas forest rangers and forestry companies played supporting roles.

Field truthing was implemented along pre-determined transects. Along these transects, forest status and land uses were compared and collated between that shown on the maps and what was actually in the field. The field truthing prioritized and targeted some major objects as follows:

- Objects that remained suspicious during the desk-based image interpretation.
- Objects which exposed variations between the image classification and observations made in the field.

Along field truthing transects, field truthing points were verified as follows:

- Exact locations were identified using GPS.
- Exact names of the observed objects were observed and identified.
- Qualitative parameters of the observed objects, such as forest canopy cover, tree height and predominant species were identified.
- Photos were taken of the observed objects. Information such as names of forest status, camera shooting directions, distances and time was recorded.
- Observed results were recorded and verified in the field using a standard template.

- Objects from the desk based interpreted maps were compared and collated with those in the field to directly modify interpretation results on the field truthing maps:
- Names of forest status were modified and corrected if there were variations between objects from the desk based interpreted maps and those in the field.
- Names of the delineated forest status which had not been identified by name during the desk based image interpretation process were corrected.

After being supplemented and modified, all field truthing results were exchanged, discussed and agreed among the field truthing team members. Additionally, interviews with local forest owners and managers were conducted to look for further information about the management, protection, extraction and utilization of forest resources in order to further supplement the modifications to the interpretation of results and assessment of forest resource changes from 1990 - 2010.

***Figure 9: Some photos of site surveys***

Working with forest protection staff of Lam Ha district

Cooperating with local forest ranger to conduct ground truthing

Interviewing in Dung Kno commune of Lac Duong district

Working with forest protection staff of Duc Trong district

Agreeing on preliminary ground truthing with Cat Tien district

Agreeing on preliminary ground truthing with Don Duong district

All field truthing results were communicated to appropriate parties at district level for comment on the current state of forest resources and reasons (or drivers) for forest resource changes from 1990 - 2010.

Forest status maps from 1990 and 2010, listing land categories and forest types by administrative systems at provincial, district and communal levels were uploaded into MapInfo and ArcGIS software and appropriately archived.

## 2.4 Development of final maps

### 2.4.1 Layout setting for final maps

Forest status maps were then edited in MapInfo and ArcGIS software.

- Layout of the final maps followed FIPI's guidelines on the development of forest status and land use maps, which were issued along with Decision 553/KHKT-HTQT/QĐ, dated August 6th, 2008, and comprised information layers as described in Table 6 below.

***Table 6: The other layers for creating the forest land use map***

| | Name of other layer | Format | Description |
|---|---|---|---|
| 1 | (Lam Dong)_tde | Text | Class of map names, map scales, names of coordinate grid |
| 2 | (Lam Dong)_luoi | Line | Class of coordinate grid, map frame |
| 3 | (Lam Dong)_rghc | Line | Class of administrative boundaries |
| 4 | (Lam Dong)_hctext | Text | Class of names of administrative units at different levels |
| 5 | (Lam Dong)_dh1 | Line | Class of major contour lines |
| 6 | (Lam Dong)_dh2 | Line | Class of minor contour lines |
| 7 | (Lam Dong)_dhddc | Point | Class of elevation points |
| 8 | (Lam Dong)_dhtext | Text | Legends of contour line values and elevation points |
| 9 | (Lam Dong)_gth | Line | Class of transportation network |
| 10 | (Lam Dong)_tv1 | Line | Class of hydrological network in the format of lines |
| 11 | (Lam Dong)_tv2 | Polygon | Class of hydrological network in the format of segments |
| 12 | (Lam Dong)_nentxt | Text | Class of location names and other legends on the maps |
| 13 | (Lam Dong)_point | Point | Class of various points of people's committees, heath care stations, schools |
| 14 | (Lam Dong)_rung | Polygon | Class of forest statuses |
| 15 | (Lam Dong)_HCT | Polygon | Class of provinces |
| 16 | (Lam Dong)_HCH | Polygon | Class of districts |
| 17 | (Lam Dong)_HCX | Polygon | Class of communes |

### 2.4.2 Map area

The calculation of area of each forest status was implemented by using MapInfo and ArcGIS software. The areas were calculated at the communal administrative unit then aggregated at the district level to develop district forest status maps (12 districts) and further aggregated to produce a provincial scale map. The process followed the steps shown below:

- The forest status layer for the four time periods between 1990 and 2010 were overlaid with maps of provincial and district administrative boundaries using MapInfo software.
- The area of each forest status was calculated.
- The attribute tables were exported to Microsoft Excel software for processing.
- The area for each land use type was calculated and aggregated to calculate the total area in the commune. There was a slight difference between the calculated area of the commune and the actual natural area of the commune (the official statistical area of the commune as in the 2010 land statistics from MONRE). The calculated area for each forest type in each commune was adjusted in order to equate to the actual area. This was done by multiplying the area of each land use type by an adjustment coefficient (see formula below).

Formula for area calculation:

$$\text{Adjustment coefficient} = \frac{\text{Actual natural area}}{\text{Calculated area}}$$

Corrected area = Calculated area * Adjustment coefficient

### 2.4.3 Outputs

The final output comprised forest cover maps of the province at a scale of 1:100,000 and 12 district maps at a scale of 1:50,000 for the four time periods between 1990 and 2010.

# 3 Implementation and collaboration activities

## 3.1 Implementation arrangements

Collaboration between different technical experts was essential in efficiently working through the methodologies outlined above and in producing a high quality product. Remote sensing and GIS specialists, provincial and district forest protection and development officers, and technical staff of forestry companies and forest owners all worked together in the development of the forest status maps and in the assessment from forest resource changes between 1990 and 2010.

Implementation tasks were assigned to groups based upon their skills and specialist expertise. The groups and their responsibilities were as follows:

**Desk based implementation group:**

- Collect and select relevant documentation, develop base maps and update and develop final maps.
    - This group comprised senior specialists who have sound experience in applying MapInfo and ArcGIS software.
- Analyze, process and interpret satellite images for developing forest status maps during the four different periods between 1990 and 2010 to supplement, update and enhance map quality.
    - Members included senior specialists who had sound remote sensing expertise and experience and were good at applying ERDAS software for image processing and eCognition software for image interpretation.
- Check and evaluate the image interpretation results.
    - Members included senior specialists who had sound remote sensing expertise and experience and were good at recognizing various land categories and forest types and interpreting satellite images. This group was tasked to verify the quality of satellite image interpretation and work out criteria and supplementary methods in order to enhance the image interpretation quality.
- Create databases and analyze and prepare reports.
    - This group included senior specialists who had sound expertise and experience in applying remote sensing and GIS technologies in the analysis, assessment and synthesis for report preparation

**Field work groups:**

Field work groups consisted of specialists who had sound expertise and experience in conducting forest inventory in the field and were capable of forest classification and modification and correction of forest status maps. These specialists also had experience in conducting interviews with local residents for collecting information related to forest status and forest resource changes during the different time periods.

## 3.2 Implementation collaboration

To ensure the quality and enhancement of efficacy during the course of the project implementation process, collaboration between consulting firms, which had sound expertise and experience in remote sensing and GIS technologies for developing forest status and land use maps, and various organizations and local forestry officers was of utmost important.

During the course of implementation, FREC collaborated with Lam Dong Agro-Forestry Consulting Centre, technical staff from forestry companies and forestry officers of districts in Lam Dong province. FREC nominated senior specialists with sound expertise and experience in applying remote sensing and GIS technologies for developing forest status and land use maps. FREC also assigned tasks to senior specialists with sound expertise in assessing forest resource changes and calculating GHG emissions. Forestry companies nominated senior specialists who had sound knowledge of field inventory techniques and were highly experienced in conducting field inventory and data collection.

Group members involved in the field work were assigned with clearly defined responsibilities and tasks as follows:

**FREC specialist responsibilities:**

- Collect documentation, maps and data and prepare documentation, equipment and technical methodology.
- Interpret images and develop forest status maps for the different interval periods of1990, 1995, 2000, 2005 and 2010.
- Overlay forest status maps for different periods between 1990 and 2010.
- Assess map accuracy of the four different periods between 1990 and 2010.
- Combine field truthing outcomes with mapped segmentations to assess accuracy.
- Update and supplement forest status and land use maps.
- Assess forest resource changes and trends during the four different periods between 1990 and 2010.

- Calculate carbon stock and changes in GHG emissions.
- Edit final maps at 1:100,000 scale at the provincial level and at a 1:50,000 scale at the district level..
- Process and analyze data and prepare reports.

**Local expert responsibilities:**

- Collect various maps of forest resource status and reforestation areas under different programs and projects during 1990, 1995, 2000, 2005 and 2010.
- Collect various forest resource planning maps, hydropower system planning maps, maps of permanent cultivation and residence maps during 1990, 1995, 2000, 2005 and 2010.
- Gather reports and data on sample plot systems which were established and assessed in Lam Dong province under various programs and projects.
- Collect data and maps of hydro power projects in Lam Dong province.
- Assess the collected documentation.
- Collaborate with FREC to carry out field inventory. Identify drivers of forest resource changes during different periods from 1990 - 2010.

# 4 Conclusions and recommendations

## 4.1 Conclusions

Satellite images and GIS technology have been be used to develop forest cover maps in Lam Dong province for four different time periods between 1990 and 2010. During the study, there was close cooperation between FREC, the Agro-Forestry Consultancy Company, local agencies and organizations such as the Forest Protection Department, forestry companies and communal forestry officers.

The forest mapping and calculation of area of forest and land use change in four different time periods (1990-1995, 1995-2000, 2000-2005 and 2005-2010) was conducted very objectively. The outputs were as follows.

**Maps:**

- A forest cover map of the province at a scale of 1:100,000 and 12 district maps at a scale of 1:50,000 for 1990, 1995, 2000, 2005 and 2010.
- Forest cover change maps of the province at the scale 1:100,000 and those of the 12 districts and cities at the scale 1:50,000 for four different periods (1990-1995, 1995-2000, 2000-2005 and 2005-2010).

**Data:**

- Data on forest resources for 1990, 1995, 2000, 2005 and 2010 were aggregated from the commune level to the district and province levels.
- Data on forest resource changes were divided by district and province for four different periods (1990-1995, 1995-2000, 2000-2005 and 2005-2010).

**Forest area change in Lam Dong province between 1990 and 2010 was as follows:**

- Year 2010: The total forest land area was 565,317 ha; the forest coverage was 57.8%.
- Year 2005: The total forest land area was 600,099 ha; the forest coverage was 61.4%.
- Year 2000: The total forest land area was 623,399 ha; the forest coverage was 63.8%.
- Year 1995: The total forest land area was 646,379 ha; the forest coverage was 66.1%.
- Year 1990: The total forest land area was 700,363 ha; the forest coverage was 71.6%.

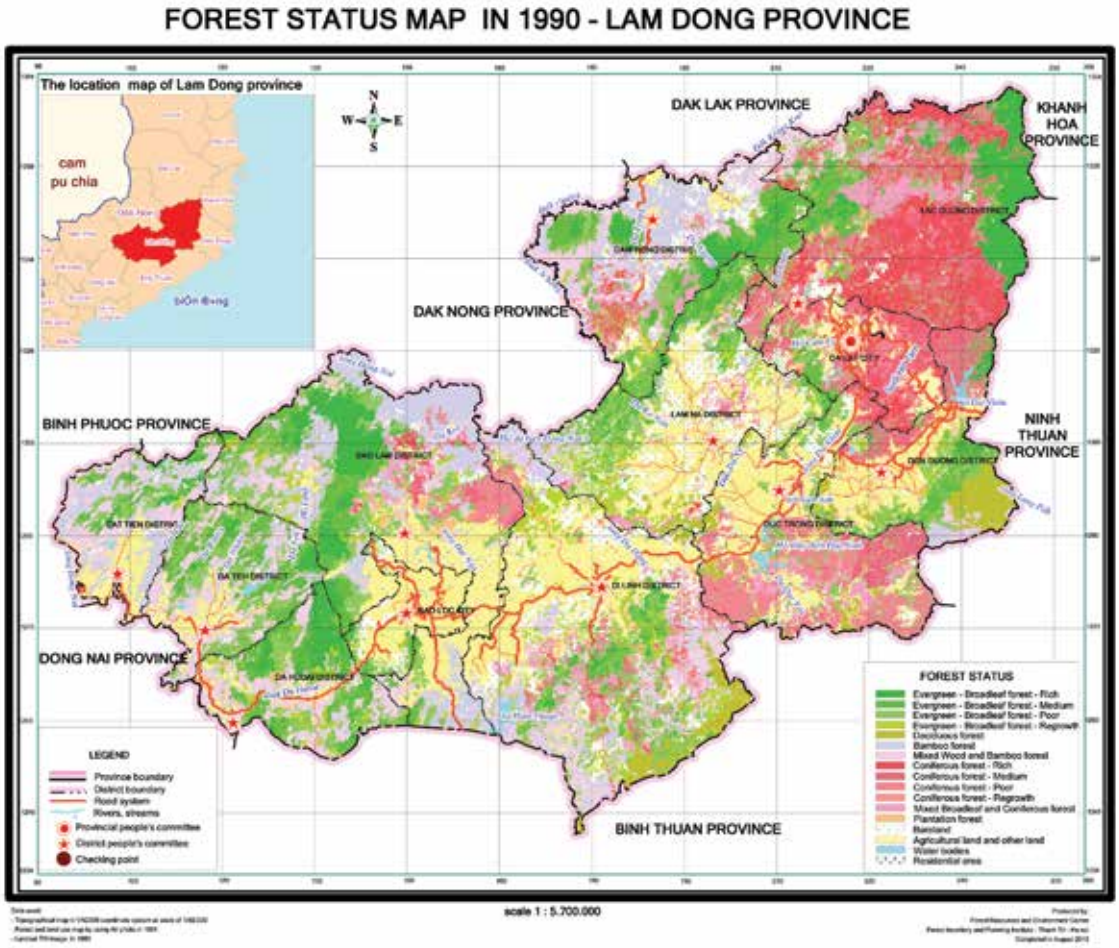
## 4.2 Challenges

The map of current and historical status of forest resources in Lam Dong province was developed based on satellite images for 1990, 1995, 2000, 2005 and 2010. However, different periods used different types of satellite images with different resolution. For example, Landsat images used in 1990 and 1995 had a resolution of 30m, Landsat ETM+ images used in 2000 had a resolution of 15m and SPOT-5 images used in 2005 and 2010 had resolution of 2.5m. Therefore, when overlaying the resultant forest cover maps for assessing the changes between two time periods, there were many plots that had very small areas. According to analysis, these small areas experienced illogical changes.

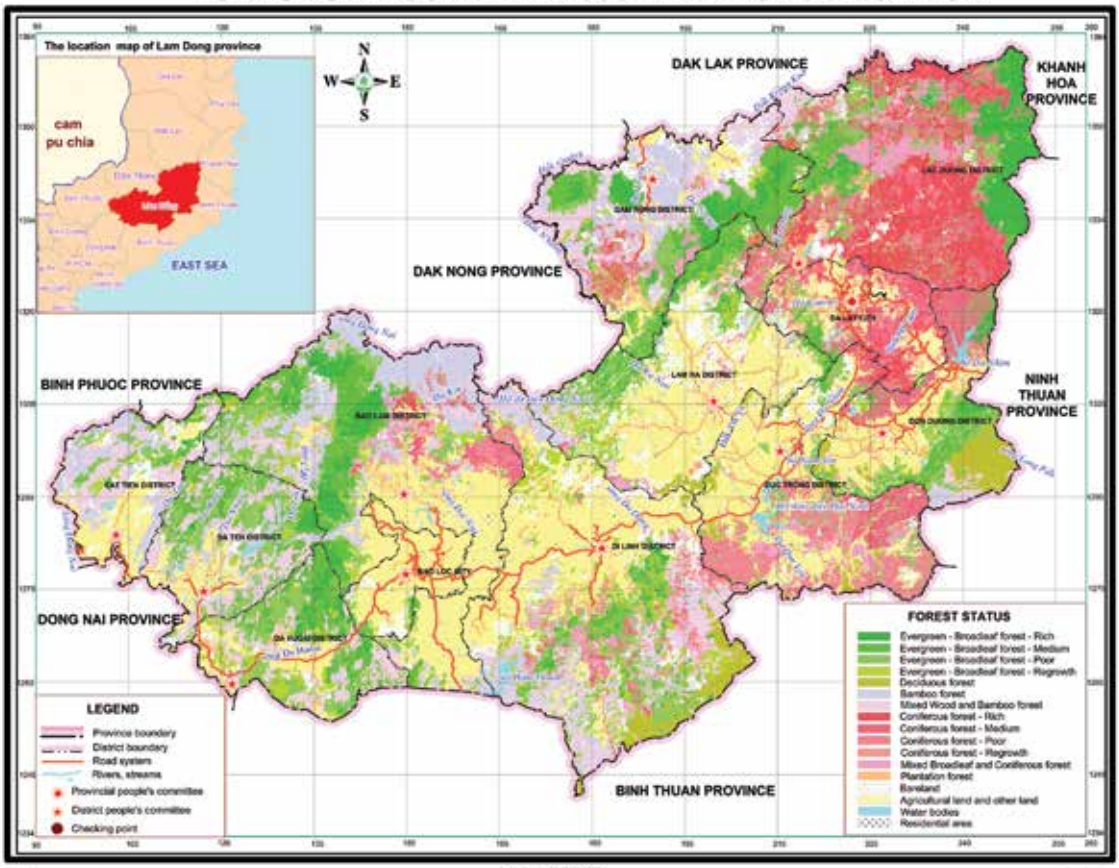
## 4.3 Recommendations

To ensure effective and realistic management and monitoring of forest areas in the near future, it is necessary to develop an updated forest cover map for 2013 – 2014 using high-resolution satellite images and GIS technology. The map should be developed based on the forest ownership boundaries, the boundaries of the three forest types and the boundaries of compartments to facilitate forestry as well as socio-economic development management and planning.

# APPENDIX:
# Forest status map in Lam Dong from 1990 to 2010

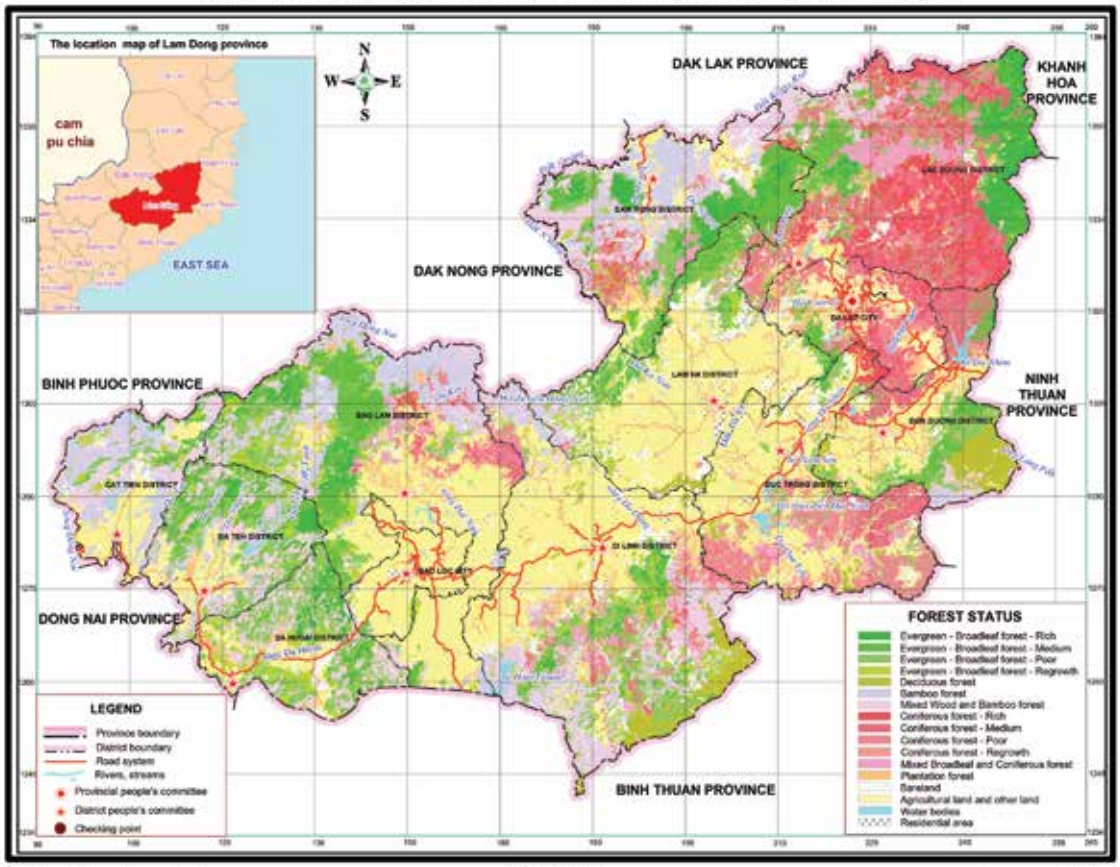


## FOREST STATUS MAP IN 1995 - LAM DONG PROVINCE



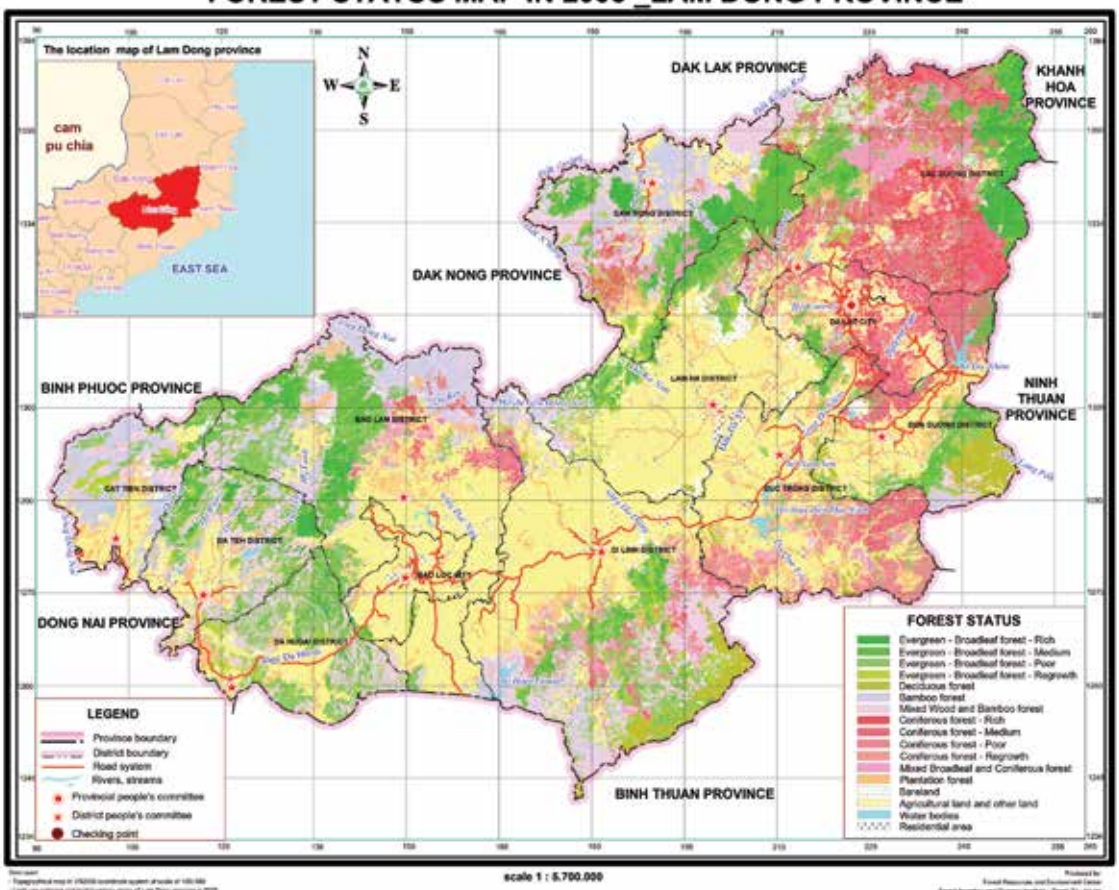

scale 1 : 5.700.000

## FOREST STATUS MAP IN 2000 - LAM DONG PROVINCE



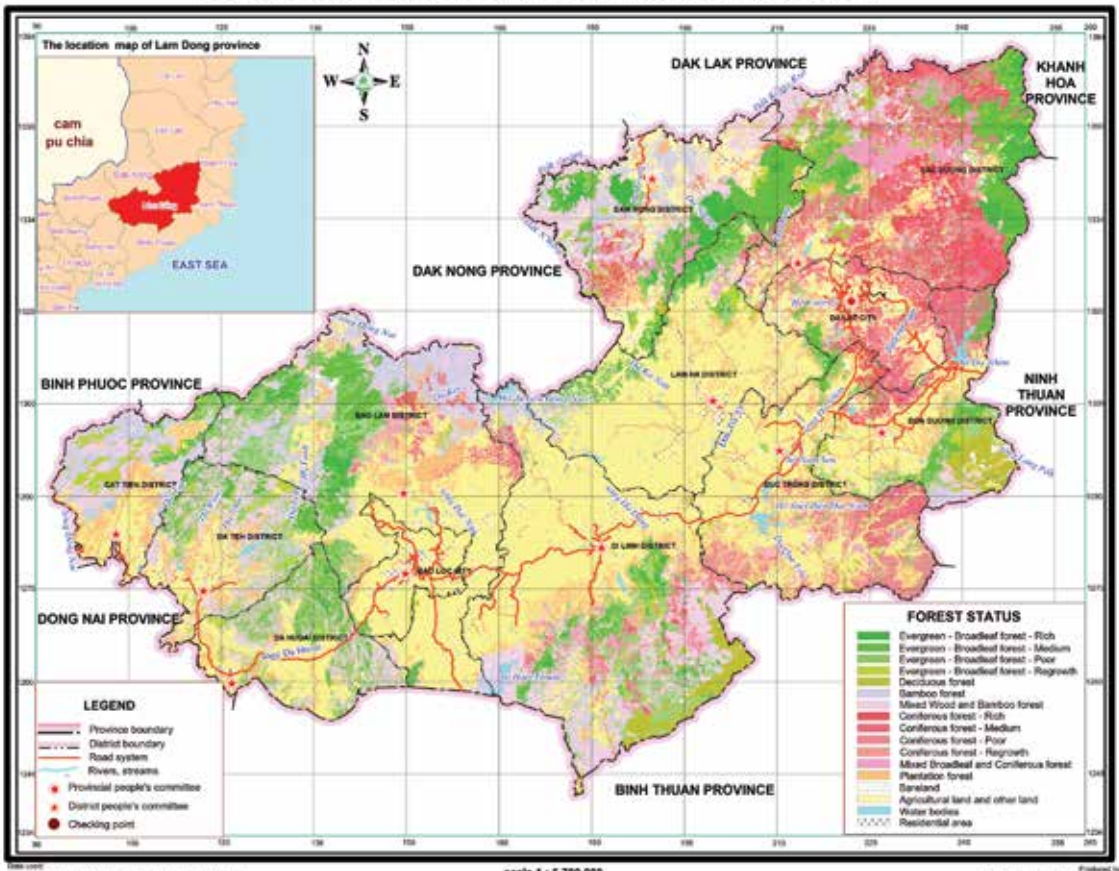

scale 1 : 5.700.000

## FOREST STATUS MAP IN 2005 _LAM DONG PROVINCE




scale 1 : 5.700.000

## FOREST STATUS IN 2010 LAM DONG PROVINCE




scale 1 : 5.700.000

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