UN-REDD
P R O G R A M M E

Papua New Guinea National Experts Workshop:
Land Cover Change Mapping.

Description of the activities
By Michele Downie

Index

Participants:

National Experts from PNG

Gewa Gamoga

Frederick Ohmana

Mericha Masta

Siola Popei

International Experts

Danilo Mollicone

Michele Downie

Catherine Bodart

Przemek Zelazowski

Stefano Giaccio

Emanuele Tajariol

Inge Jonckheere

1   Introduction

This document describes the work undertaken during the visit of a national PNG team to FAO HQ, Rome, Italy, from the 21th of November to the 2nd of December 2011.

The workshop described in this document is part of the capacity building activities related to the Start-Up Phase of the UN-REDD Programme. The topics dealt with during the workshop concerned the satellite land monitoring system (SLMS), as part of the national MRV system. The aim was to develop a classification system using TerraAmazon software as a tool to undertake thematic classification and database implementation.

This experience builds on the experience gained from the visit of the DRC national team in Rome from the 3rd to the 11th of November 2011. These two countries were selected as pilot countries for the Start-up Phase. Both workshops represented the initial stage of the mapping activities for these two UN-REDD countries.

The following chapters introduce and describe the preliminary classification that has been adopted for the main typologies of change. Class types were discussed and described individually during the work by the team. These classes can be subjected to future modifications and improvements in the coming months, while implementing the Monitoring System in PNG.

The annex B to this document describes the conceptual model which is characterised by all the features required to edit the vector layers and to implement a robust geo-database (in particular: rules and topological relationships among classes), as well as some photokeys based on Landsat and high resolution images taken during the discussion about classes.
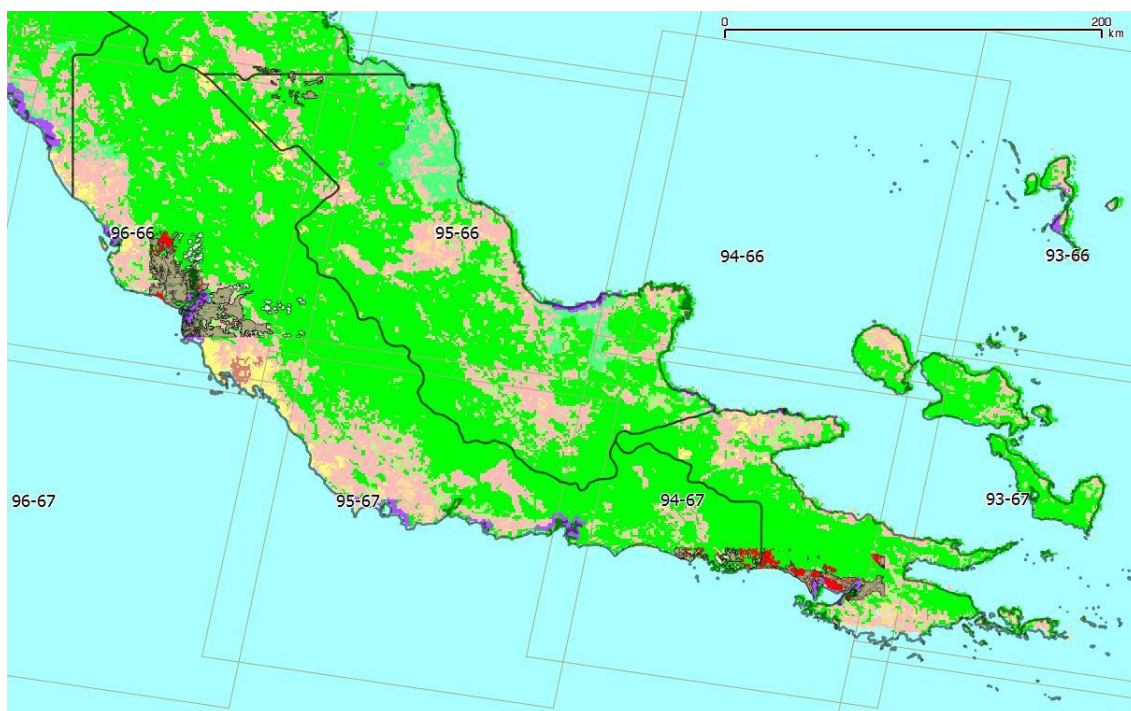
Figure 1: Two selected test areas in Central and Milne Bay regions. Back ground image is GLC (JRC Land Cover) and Landsat tiles.

The main objectives of this document are:

  ⚔ To support the definition of class features in PNG.

  ⚔ To supply standards for consistent work among different experts (multidisciplinary) and over

time (monitoring).

⅄ To document and learn lessons from the experience for future related UN-REDD activities.

⅄ To assess the potential of Landsat imagery in terms of provision of useful information on land cover and land change.

2   Satellite imagery sources

2.1   **Landsat images**

Photo-interpretation and data extraction activities are based on Landsat Images. PNG's land surface covers approximately 470,000 km^2 and is represented in 66 image tiles: 25 of these include wide inland areas while the others represent mostly the ocean with some islands and archipelagos of various sizes. Landsat images were selected and downloaded from the United States Geological Survey (USGS) web portal at the following address:

http://glovis.usgs.gov/
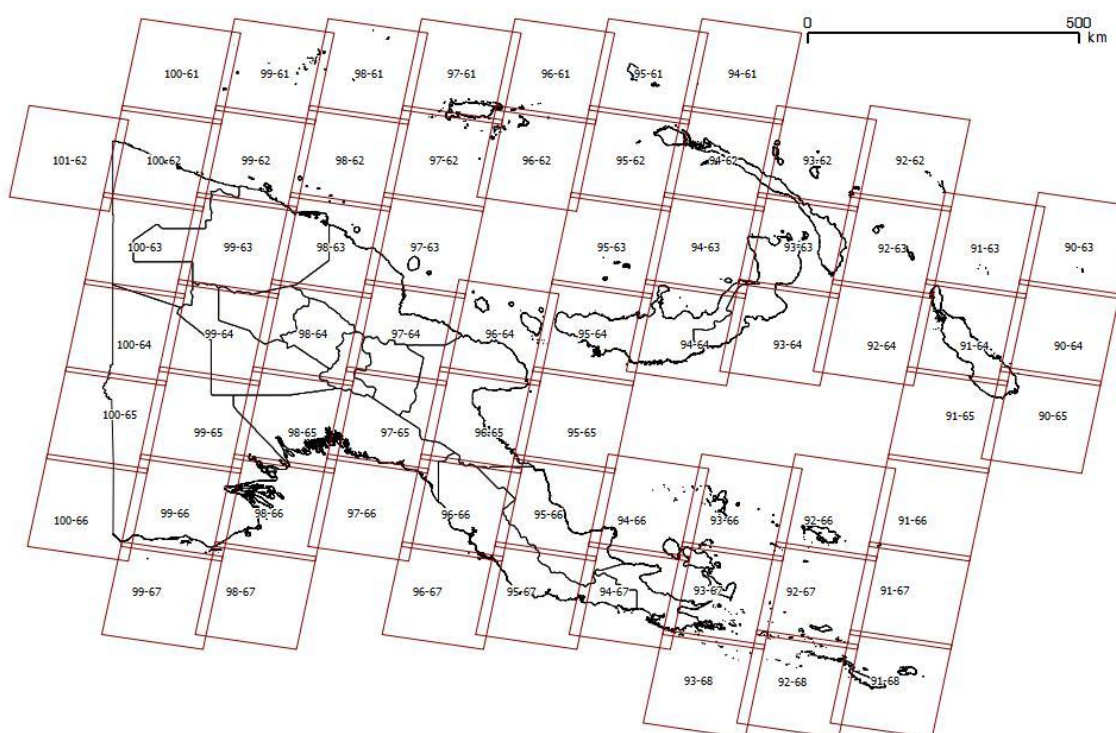
Figure 2: Landsat Tiling Index.

The main problem concerning the PNG satellite image representation is the extremely wet weather causing widespread cloud cover for most of the year over the majority of the country.

Another relevant issue is the difficulty in accessing good quality Landsat data collected after the 14th of July 2003, the reason being that in this year ETM+ images are affected by the "SLC-OFF" data gaps. As a consequence, most of the images available for several tiles that were generated by Landsat 7 in the years since 2003 are black striped, with gaps covering around 30-40% of the image area. This problem occurs primarily over the archipelago to the east of the country. There are districts such as West New Britain, East New Britain and New Ireland which only have available Enhanced Thematic Mapper (ETM) images which are affected by Scan Line Corrector (SLC)-OFF.

Moreover topography influences the concentration of clouds, causing permanent cloudiness in some areas.

A solution to this problem is displaying at least two mosaiced images of two dates close one to another.

In general, in order to get satellite representation with no more than 15% of the surface covered by

clouds it is necessary to select images (more than one for each tile) in a range of 2-4 years, varying from place to place and according to local climate.

Images collected are filed and indexed together with metadata stating the quality screening based on cloud cover, the distribution of clouds, presence of atmospheric haze and SLC conditions.

2.2   TropForest dataset

Further data was provided by archive of the European Space Agency's (ESA) **TropForest** project. TropForest is an ESA scientific Project and FAO its Principal Investigator (PI) that is the one who leads the activities. These projects can access to data products for "Category 1 use" (that is free – or at very low cost – for research and application development use). The principal goal of this project is to support the 2010 global forest assessment performed by the Joint Research Center (JRC) of the European Commission and the Food and Agriculture Organization (FAO) of the United Nations. Other beneficiary programmes are JRC TREES-3 and FAO UN-REDD. Unlike Landsat images, this data cannot be freely downloaded from a web portal, and original data can only be used in the context of UN-REDD activities.

TropForest data comprises a set of image frames located at the nodes of a one degree graticule. Frames are sized 20 by 20 kilometres. The sensors are: Kompsat (at present five frames), AVNIR (at present 20) and Deimos (at present 14). The first two in particular have been demonstrated to be very useful to see detail not only of different vegetation types but also of the types of change,
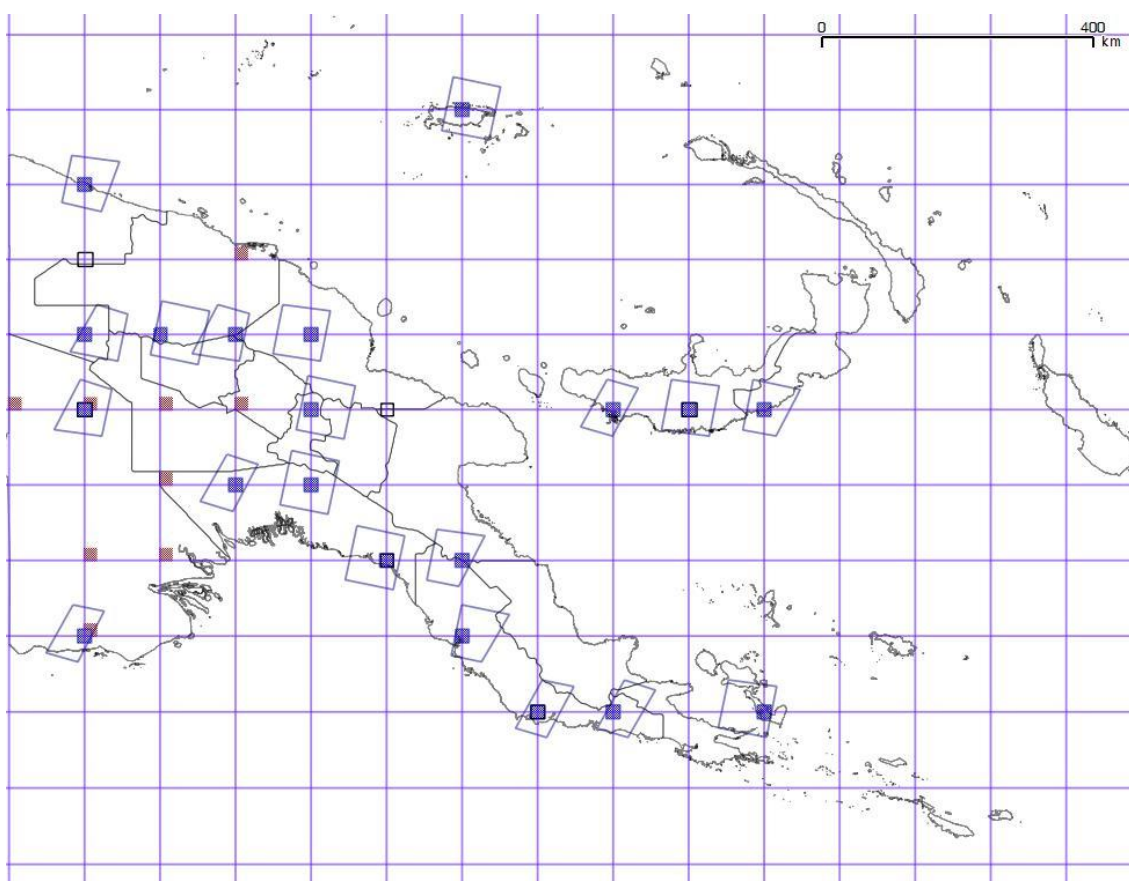

Figure 3: TropForest dataset index.

improving the accuracy of mapping with Landsat images.

In the above figure, the blue squares are AVNIR images, red squares are Deimos and black boundaries are Kompsat. AVNIR 20 x 20 frames were delivered together with the whole image tiles which are represented by large polygons.

3   Additional information

Additional information has been integrated as ancillary data.

The most important ancillary data are two thematic maps representing forests and land use in PNG. These maps, which are described in the following paragraphs, can be used to categorize the land use and land use change classes and to guide the interpretation of the images.

In order to facilitate their usage they have been scanned, geo-referenced and digitised using GIS. They can be displayed alongside Landsat and other images for comparison. Both maps form national wall-to-wall coverage at a scale of 1:1,000,000. It is important to note that the shapes of features in these maps are approximated.

3.1   **Forests Resources of Papua New Guinea**

Edition – Commonwealth Scientific and Industrial Research Organization Australia.

Vegetation classes describe physiognomy and prevalent life forms. Some useful information about flora, landforms and accessibility are included. Understanding vegetation types in the images can support research and analysis of logging areas by focusing the attention on the areas where it has the highest probability of occurring.

In the case of forest degradation, a classifier indicating the percentage of cover of disturbed forest is added to the label in the map.

The legend describes the following classes:

LOW ALTITUDE FORESTS ON PLAINS AND FANS

> Large To Medium Crowned Forests
>
> Open Forests
>
> Small Crowned Forests
>
> Terminalia Brasii Forests

LOW ALTITUDE FORESTS ON UPLANDS

> Large Crowned Forests
>
> Medium Crowned Forests
>
> Small Crowned Forests

LOWER MONTANE FORESTS

> Small Crowned Forests
>
> Small Crowned Forests With Conifers

DRY SEASONAL FORESTS

> Dry Evergreen Forests

ESTUARINE COMMUNITIES

> Mangrove

3.2   Agricultural Land Use of Papua New Guinea

Edition – Commonwealth Scientific and Industrial Research Organization Australia.

This map shows several kinds of agricultural activities. The most interesting feature is the "Classification and mapping of land use intensity". These classes describe the Land Use Mapping Areas (LMA) and are based on a mosaic of "Current Gardens", "Regrow/Fallow and "Primary and/or Advanced Secondary Forest". These three land cover types can be present in a LMA with different proportions and are directly linked with forest degradation and deforestation.

Cultivated lands are classified as follows:

LU0	Very high intensity with tree crops	sec.veg. = 7 5+	curr.use = >20
LU1	Very high intensity	sec.veg. = 75+	curr.use = 10-20
LU2	High intensity	sec.veg. = 50+	curr.use = 5-10
LU3	Moderate intensity	sec.veg. = 20-50	curr.use = 1-5
LU4	Low intensity	sec.veg. = 20-50	curr.use = <1
LU5	Very low intensity	sec.veg. = 10-20	curr.use = <1
LU6	Extremely low intensity	sec.veg. = 10	curr.use = <1

The remaining classes are still important, as they describe natural or semi-natural vegetation types, which are not included in the forest map. One of particular note is "Savanna woodland". This class refers to open woody vegetation >3 meters tall, with a scattered distribution. It is considered to be anthropogenic in origin and irregularly burned. This class includes, among others, degraded areas where natural regeneration could lead to forest. Furthermore this class can include areas that could be classified as forest, but which are not easily detectable due to the geometric resolution of Landsat images.

Uncultivated Land classes are:

LU7   Grassland

LU8   Sago palm with or without emergent trees

LU9   Subalpine grassland

LU10   Alpine grassland

LU11   Savanna woodland

LUU   Larger urban areas

4   Mapping activities

4.1   Methodological approach of the team

The work was subdivided into two parts: a preparatory phase and a mapping phase.

During the first week the PNG team was introduced to the information and images which had been collected. Then a series of discussions were held to coordinate and appoint tasks. The first topic that was discussed is the experience previously gained in the implementation of the TerraAmazon conceptual model during the workshop with DRC team.

This was followed by a detailed discussion on land use and land use change types. During this discussion the group inspected all available geo-information including Landsat and TropForest data: AVNIR and Kompsat.

Google Earth, which offers very detailed images, was also used. The global accessibility and user-friendliness of this tool make it a good reference point for knowledge sharing among people with varying levels of experience.

Lastly the preliminary design of the **conceptual model** was discussed in order to edit a change map for the period 1990-2000. The conceptual model primarily comprises crucial features, such as **layers** and **rules** (described in annex B) that manage spatial relationships between different layers.

During the second week the team started the mapping of two Hot Spots areas and editing a postgres database. The purpose of these activities was to test the classes and the conceptual model. The editing and classification of the vector layers was performed by the team in a network, producing a unique database in a server/client environment. The database was then exported and delivered to the national team.

Considering that the activity is based solely on interpretation of remote sensing imagery, land use characterizations is inferred from land cover. In this document the terms land use and land cover are essentially equivalent.

4.2   Selection of hot spots, images and cartographic standards

A preliminary analysis of Landsat images covering different parts of the country was undertaken to assess general land cover and land cover change patterns. This task was an opportunity for the team to select two areas according to the following criteria: high quality of satellite images, presence of different kinds of change types, high density of population and easy detection of fast anthropogenic deforestation/degradation processes.

The areas selected were:

- ⚲ Orangery Bay, the extreme South-East coastal area around the boundary between Central and Milne Bay, 30 kilometres west of Alotau.
- ⚲ Redscar Bay, 30 kilometres north of Port Moresby.

The group agreed on the need to adopt a common approach for editing, in order to improve the consistency of a single interpreter (internal consistency) and the consistency among the team members (external consistency). In light of Landsat imagery accuracy, a cartographic representation scale of 1:100,000/1:75,000 was assumed. Visualization and detection of the thematic features was independent of map scale. The polygon editing exercise was performed at 1:30,000/1:40,000. When an improved understanding of the area change sizes and fragmentation had been garnered, a minimum mapping unit is defined. The coordinate reference system used was as follows:

- ⚲ Projection: geographic;

   ⚑ Map units: decimal degree;

   ⚑ Datum\spheroid: WGS84;

   ⚑ Hemisphere: south.

4.3 Discussion of land use, land use change and the potential capacity of available satellite images to support mapping activities – classes and legend preparation

The adopted legend was discussed based on several examples showing different features concerning land use and its dynamics. Such examples were collected by the team during a preliminary assessment of available images covering the country. This activity was supported by using Google Earth. The mapping activity does not foresee any wall-to-wall land use or land cover at any level of accuracy or map scale. The interpretation work flow is based on the editing of two time periods. Interpretation for each time period is undertaken using images from approximately the same date. The reason for this choice is to allow interpreters to focus their attention on one single scenario at a time (according to TerraAmazon a scenario is the extent of an image with its date reported). The detection of change is performed comparing the map of the previous period with images of the new period. In this way consistency is facilitated and it is possible to proceed with the interpretation systematically.

Hereinafter a "period" will refer to 10 years. The length is based on the work done so far.

This approach highlights the need to create an initial mask of **non forest** and **degraded forest**. These two kinds of land cover are detected on the image without prior knowledge of land cover dynamics in the past. For the purposes of the monitoring system it is assumed to be time 0, which is set at 1990. The classes used at time 0 are characterised by the same causes as described for the different types of change used in the second map that will be described later. But in this case they have been interpreted by experts without knowing if/when change has occurred.

The "second period" map shows land use change since 1990. In contrast to the first map, this time new non-forest or degraded areas are defined as the change that has occurred between the two periods. The classes used for the second period are "action terms" as they express an act or action. The second period map is composed of two groups of classes for negative change and classes for positive change. In general the first category can be mapped outside the non forest mask, while the second is inside it.

The causes of change reflect the principal drivers of forest cover change in PNG: "Selective Logging", "Subsistence Agriculture", "Forest Fires" and "Plantations". Each one of these factors was discussed and included in one or more classes. A single driver of change can be associated with different classes, depending on its intensity. For example ,"burned areas" and "subsistence agriculture" can be linked to **deforestation** and/or **degradation**.
Positive forest cover changes, resulting in an enhancement of carbon stocks, were described on the basis of preliminary observations and the knowledge of the PNG team. These classes are **afforestation** and **reforestation**. The first term differs from the second one by the length of the period the land undergoes without forest: afforestation refers to longer periods. The third type of positive change is **forest restoration**. This class is different from reforestation in terms of intensity, in the same way as degradation is different from deforestation. The class describes the change that leads from degraded forest to forest.

During the analysis of the images and test areas, various kinds of open forest were observed, some related to degradation and some not. The coastal area of Central Region, for instance, is widely covered by open woodland. This kind of land cover is reported as uncultivated land in the land use map. It can be confused with other kinds of open vegetation due to anthropogenic causes, such as the cutting of firewood or timber, or forest burning by hunters. These kinds of land uses result in degradation. Moreover this class cannot always be differentiated from savanna or other non-forest classes.

During the final discussion of the results, the team noted that it would be advisable to add a new class to refer to a positive change of non forest areas, where semi-natural vegetation is developing. This class would describe vegetation at an initial phase of regeneration.

Mask map at time 1:

This map depicts the land use as it is without any consideration on previous changes.

Class	Description

NON_FOREST	**Natural savanna and grassland** (which are not effective change)
	
	 Urban/Settlements
	
	 Burned areas without trees
	
	 Clear fell
	
	 Other Land use
	    oil palm
	    coconut
	    continuous herbaceous fields

DEGRADED_FOREST	**Burned area with trees** **Selective logging** Detectable in the images by the presence of a network of forestry/skid roads within the forest. Discontinuity and gaps in the canopy around roads can be visible and mappable. Where it is not visible a buffer of 500 meters is mapped around roads. **Other Land use** Scattered herbaceous fields; a mosaic comprised of fields (gardens), fallow areas covered by anthropogenic vegetation at different levels of development and patches of natural or secondary forest.

Change map at time 2:

This map shows areas that have changed between the two periods, based on the differences in respective images.

Negative change		
From class	**To class**	**Description**

FOREST
 DEGRADED_FOREST
	DEFORESTATION	**Burned areas without trees**
		
		 Clear fell
		
		 Other Land use
		    Oil palm
		    Coconut
		    Continuous herbaceous fields

FOREST	**DEGRADATION**	**Burned area with trees** **Selective logging** Detectable in the images by the presence of a

		network of forestry/skid roads within the forest. Discontinuity and gaps in the canopy around roads can be visible and mappable. Where it is not visible it a buffer of 500 meters is mapped around roads. **Temporary un-stocked lands** This kind of land use is included in larger areas with planned forest cutting. It is characterised by tree plots of different ages and well delimited on the ground. Due to Landsat detection capability it refers to the first two or three years of tree growth. Examples: Teak Rubber tree **Other Land use** Scattered herbaceous fields. A mosaic composed of fields (gardens), fallow areas covered by anthropogenic vegetation at different levels of development and patches of natural or secondary forest.
Positive change		
From class	**To class**	**Description**
NON_FOREST	AFFORESTATION	**Tree plantation after a long period without forest** according to the following sequence: Period 1 = non_forest Period 2 = non_forest Period 3 = forest
DEGRADED _FOREST	FOREST_RESTORATION	**Natural recovery** In general refers to selective logging areas or scattered fields in anthropogenic vegetation which have been abandoned, leading to a return of secondary forest.
NON_FOREST	REFORESTATION	**Forest regrowth or tree plantation after a short/medium period without forest** according the following sequence: Period 1 = forest Period 2 = non_forest Period 3 = forest Examples forest restoration are: Teak Rubber tree

4.4   Description of the classes

For the purposes of this document, and considering the preliminary stage of this work, classes are deliberately described adopting general definitions based on meanings shared by the main institutions, and taking into account the document FCCC/CP/2001/L.11/Rev.1 "Matters Relating To Land-Use, Land-Use Change And Forestry", that was adopted by the Kyoto Protocol.

The characterisation of classes proposed in this document stresses the difference between two kinds of features:

 - **Thematic features**: which describe the class in terms of land use or land cover physiognomy.

⋏ **Topological features**: which indicate the spatial relationships between classes in terms of contiguity and overlap.

The two kinds of features are implicit in the conceptual model, but are here emphasised to ensure a clear understanding of the methodology under development. The second type is critical for the development of the conceptual model in TerraAmazon and is explained in further detail in Annex B.

4.4.1 Non_Forest

This class represents all areas that are not classified as forest.

In general **forest** is defined as a portion of land covered with trees and plants; most definitions of forest include the following three parameters:

⋏ Minimum size of the area between 1 and 0.05 hectares.

⋏ Woody plant life forms, the height of which in general exceeds 5 meters, but in some cases may be less, e.g. up to 3 meters.

⋏ Crown cover of at least 10%.

So far the Minimum Mapping Unit (MMU) was not considered because the surface tersholde mentioned above are too small to be detected by Landsat images. Canopy cover of small
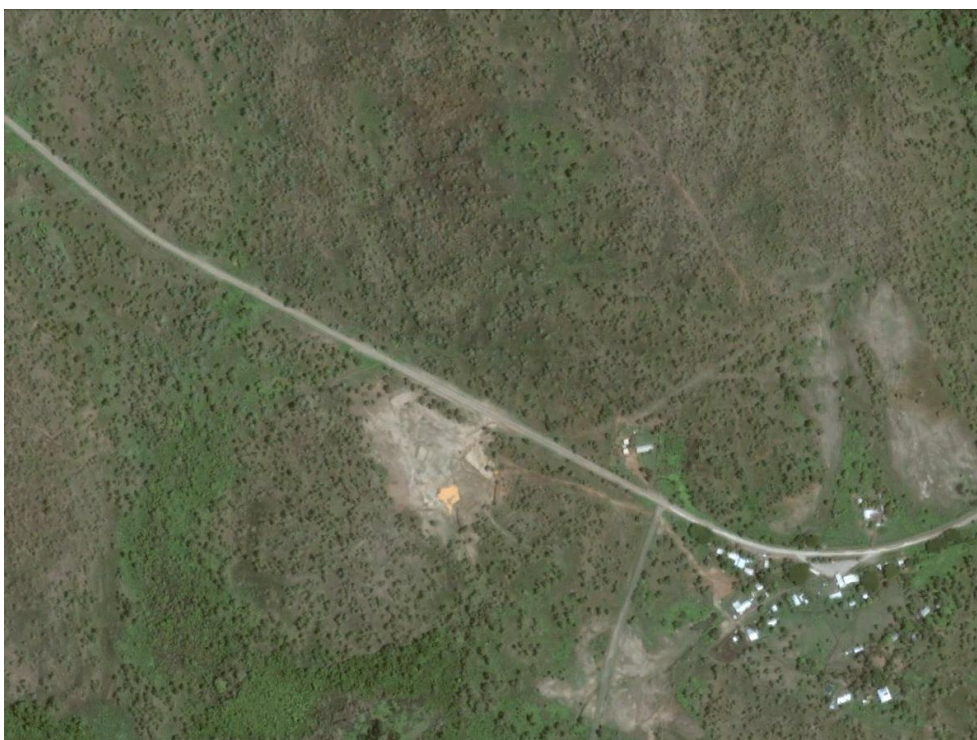
Figure 4: From Google Earth. Close to Port Moresby. Very open woodland can be natural or due to anthropogenic activities.

patches of trees in the grassland is combined with the general percentage of crown cover in the mosaic of grassland and fragmented forest, considering it as a whole. When the effective crown cover percentage is close to 10%, using Landsat images to choose between forest and non-forest can be critical, due to the low geometric resolution, which hamper the detection of trees when they are scattered and/or small. This problem can be sometime compensated in case of intense vegetative activity of trees with a high level of "greenness" and eventually by image

enhancement.

The **non_forest** class includes natural vegetation such as grassland and savanna, cultivated land (including any other anthropogenic activities) and the felling of trees as in case of oil palm plantations.

Main drivers of deforestation are the following:

Subsistence agriculture comprising small fields when they reach maximum density. It is a mosaic of different land cover types as described by the land use map: "actual" fields or gardens, regrowth or fallow and natural or semi-natural forest. Semi-natural forest can be present with degraded trees, distributed in scattered plots which are too small to be mapped and with low percentage of canopy cover.

Woody crops such as oil palm and tea or intensive herbaceous crops which are easily detectable due to their planting patterns (squared horizontal distribution of crowns). The distinction between tree crops and tree plantations associated with forest, such as teak or rubber trees, is more complex. Nevertheless, given that tree plantations are large, small in number and their locations well-known by local experts, these can be readily identified and classified accordingly.

Clear fell is simple to detect and map. It is the complete removal of forest stands. This often precedes the plantation of oil palm or commercial tree species such as teak or rubber. Sometimes this process follows a period of selective logging in order to extract the highest-value timber prior to clearing. Eventually it may become a temporary un-stocked plot in a managed forest, but in this case it is classified as degraded_forest.

Fire is another anthropogenic driver. It can occur in different kinds of vegetation and with different effects. During the review of the Landsat images, burned areas were observed in open woodland or vegetation with scattered trees along the coastal areas in Central Region. This kind of vegetation results from anthropogenic activities, including firewood extraction. In these areas degradation is a permanent condition that is difficult to sort into a specific class. At present burned areas have been observed even in mountain forest areas of the South-East, including: Central, Chimbu, Eastern Highlands, Gulf, Milne Bay, Morobe and Northern. Even in these locations the frequency of fire is irregular, caused by hunters to chase out wildlife. In general it is a matter of surface fire in very open woodland, although an irregular and scattered spreading into adjacent forest was noted when comparing images of different periods (1990, 2000 and 2010).

4.4.2   Degraded_Forest

Forest degradation is the process of lowering the quality of forest land without a change from forest to non-forest. This definition is quite ambiguous and changes from case by case according to the processes affecting it.

The work group decided to base the meaning of degradation on local land use knowledge. It decided to refer to degradation as a generic loss of biomass detectable from Landsat images.

There are two driving factors leading to degradation: selective logging and subsistence agriculture.

Selective logging is carried out on logging concessions by private entities for an extended period. This form of degradation implies primary or natural forest located on alluvial plains or rolling hills. Detection is based on the presence of a complex network of forestry tracks and roads that, where there are slopes, develop on ridges. Logging is carried out along roads and in set up areas, which are administrative plots used to plan logging in defined years. They are used to avoid cutting adjacent areas in consecutive years. Normally skid tracks, load landing plots and discontinuity of the canopy affect the texture of the image. When these features are not visible according to the knowledge of national experts, it is reasonable to apply a 500 m buffer around forestry roads.

Subsistence agriculture is a gradual process that can lead from forest to degraded forest but in high density areas it can persist until the complete change to a non-forest class. This kind of agriculture is characterised by fields smaller than one hectare, but minimum percentage of surface

covered by the fields in the natural background was not defined so far. Density can be also expressed by the medium distance between fields.

Temporarily un-stocked land these are plots of non-forest or very young trees (such as young plantations or stump shoots) mixed with other plots with intermediate growth stands, where forest is clearly visible. In terms of land cover they appear to be bare soil due to the low resolution of Landsat images. The difference is that these areas are subjected to cutting cycles.

Figure 5: From Google Earth. Close to port Moresby. Discontinuity of the canopy due to selective logging along forestry roads.

4.4.3   Deforestation

Deforestation is the conversion of forested to non-forested land. Deforestation can involve the cutting and burning of trees to provide land for agricultural purposes or clearing for residential and industrial uses. In general land is considered non-forest where tree coverage is less than 10% (for developing countries). This feature is useful considering the limits in the detection potential offered by Landsat TM. The satellite does not allow a clear detection of woody or small trees when canopy cover is less than 10-15%. Driving factors are the same as described for non_forest class:

  ⚐ Burned areas without trees;

  ⚐ Continuous small field – subsistence agriculture;

  ⚐ Clear fell;

  ⚐ Woody crops/plantations and intensive herbaceous crops.

The class cannot be mapped inside areas previously classified as non_forest since it would not define a change, but it can be located where forest is already mapped as degraded.
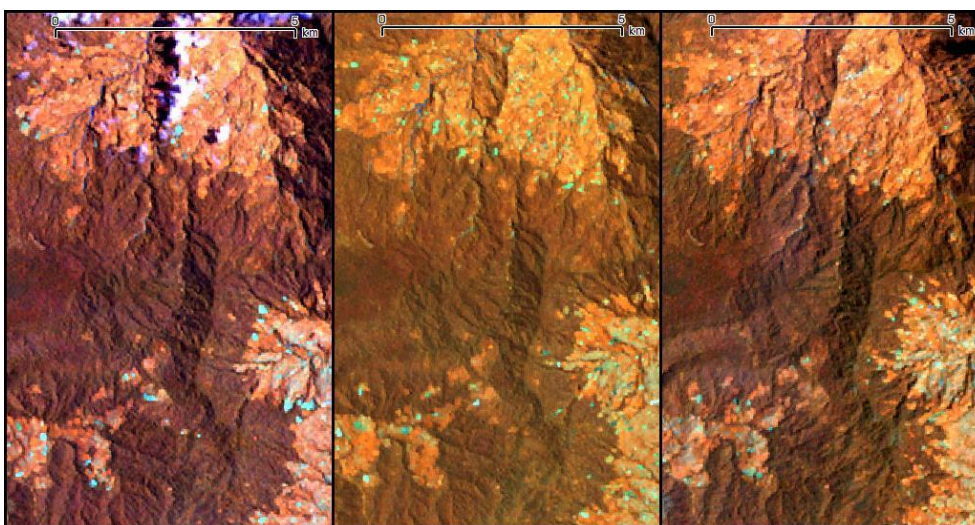
Figure 6: Madang District: Vegetation: Small Crowned Forest. This sequence of three time periods (1994, 2000 and 2009) shows that expansion of subsistence agriculture degradation is a temporary transition from forest to non-forest. This change is very gradual and scattered.
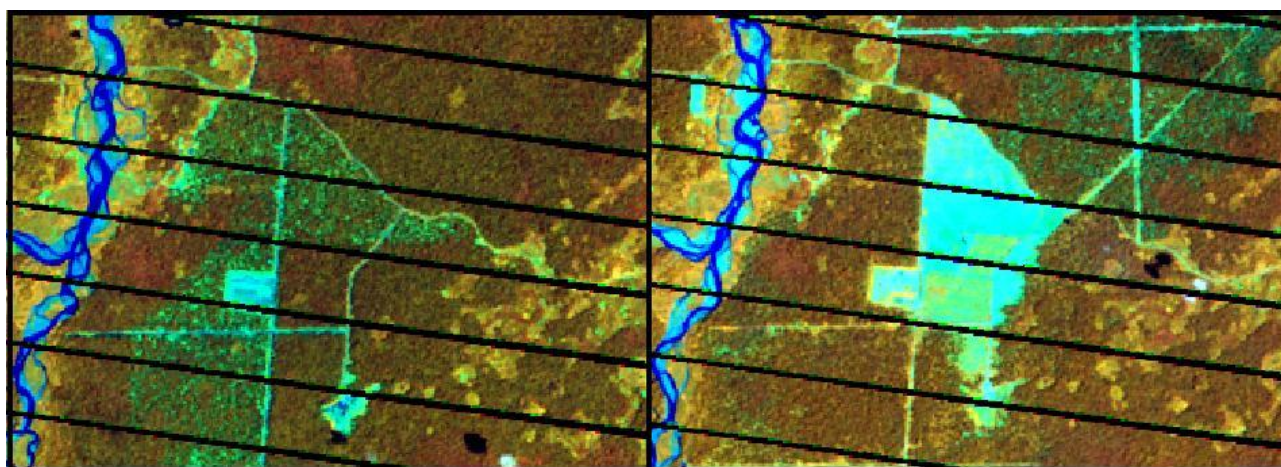
Figure 7: Sandaun District. Vegetation: Large to Medium Crowned Forest and Open Forest. The clear fell is preceded by intense selective logging. Untouched canopy and logging can be discerned by texture. Years: 2009 and 2011.

4.4.4   Degradation

This class corresponds to the characteristics outlined in the class degraded_forest, and it refers to the change that occurs within the studied time period. The drivers are:

- Burned areas with trees;
- Selective logging;
- Temporarily un-stocked land;
- Clustered or scattered subsistence agriculture (small fields).

The class cannot be mapped inside areas already classified as degraded_forest since it would not define a change, it cannot be mapped inside non_forest as it doesn't have any thematic
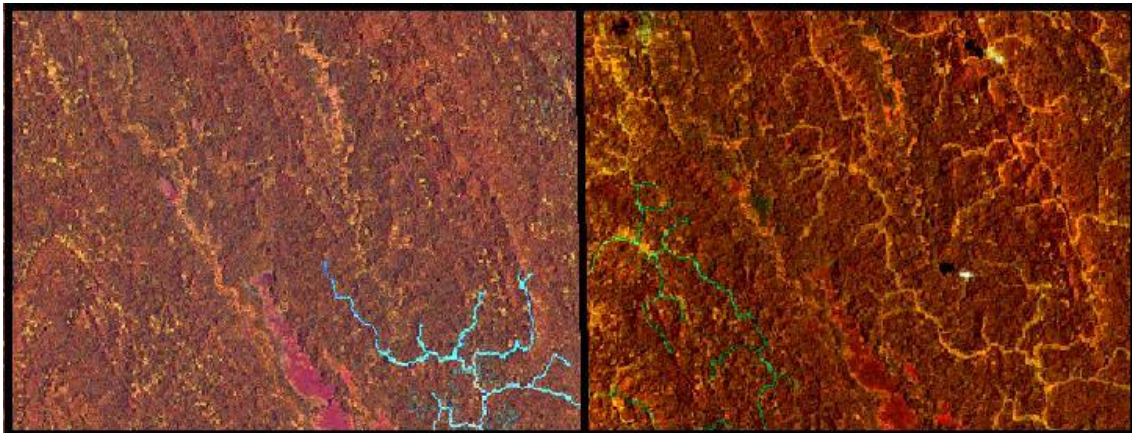
Figure 1: Gulf District, close to Okolo Bay. Vegetation: mosaic with Medium Crowned Forest and Open Forest. Expansion of selective logging. Years: 2001 and 2010.

meaning.
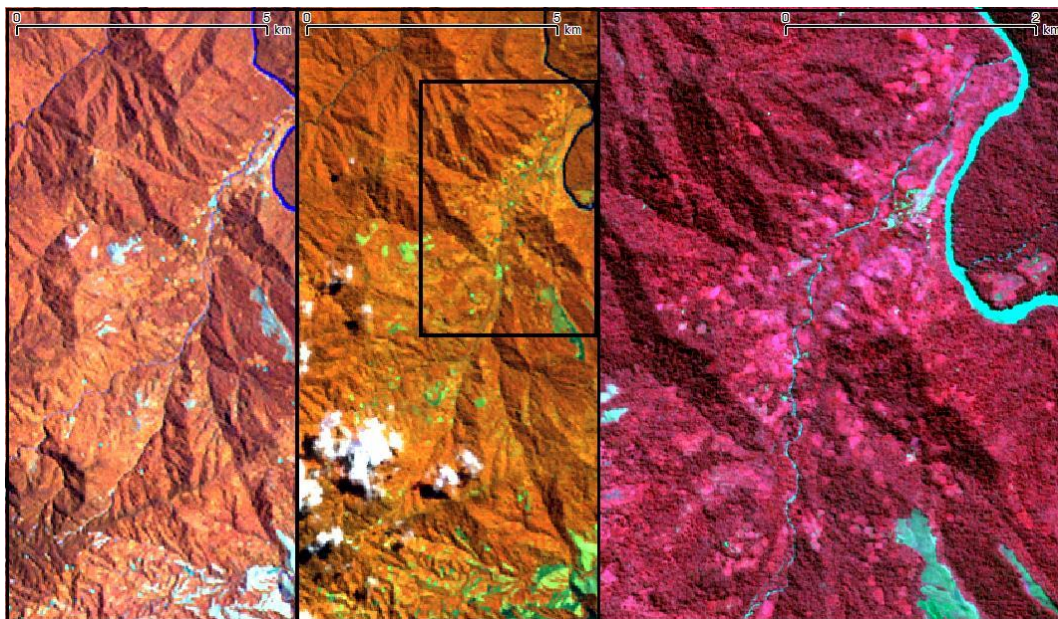
Figure 2: Enga District. Vegetation: Small Crowned Forest and Medium Crowned Forest. Expanding fields in the valley. Years: 1994 and 2010. The AVNIR on the right (2010) shows details of field cluster patterns and canopy texture.

4.4.5   Afforestation

Afforestation is defined as the establishment of trees on an area (or the direct human-induced conversion to forest) that has lacked forest cover for an extended period of time or has never been forested. This kind of change in PNG is quite rare. The action is:

⅄   Tree plantation.

It can only be located in areas previously classified as non_forest. The absence of forest needs to be ascertained for at least two consecutive periods (i.e. 20 years).

4.4.6   *Forest_Restoration*

Forest restoration is the natural regeneration of degraded forest, i.e. restocking a site with self-grown trees resulting from self-seeding or vegetative means. Restoration can be expressed by values such as increase in biomass, which is detectable by remote sensing and other values such as biodiversity, which remote sensing cannot detect. According to the experience done it refers to two of the drivers mentioned for degradation: selective logging and subsistence agriculture:

⅄   Regain canopy continuity (image texture is smoothed)

The class can only occur within areas previously classified as degraded_forest.

4.4.7   *Reforestation*

Reforestation is the planting of forests on lands that have previously contained forests but that have been converted to some other use. Considering historical dominance of forests and the dynamism of change and drivers in PNG, it is much more common than afforestation. The typical case is plantations of rubber or teak in areas where natural forest has been cleared. Similarly to afforestation, the corresponding action is:

⅄   Tree plantation.

As with afforestation, it can only be located in areas previously classified as non_forest, but the absence of forest cannot be longer than one period (i.e. 10 years).
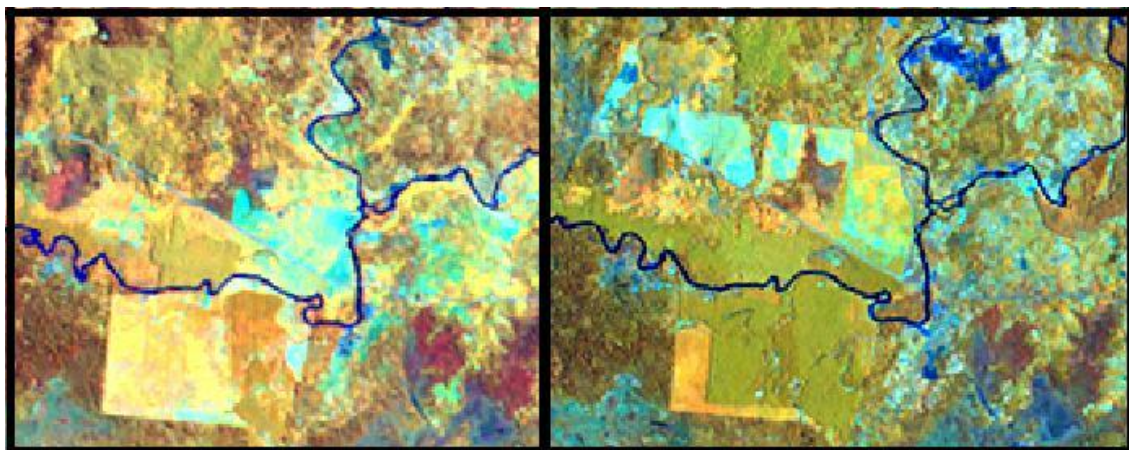
Figure 3: District: Central. Years: 1990 and 2001. Clear fell of large plots is followed by plantation of rubber trees.

4.4.8   **Clouds and shadow**

Clouds and shadow result in no value or null data, since they remove the classified areas from statistic computation. Considering that clouds and shadow can hamper the change verification if present in any of the two periods, only one vector layer was generated for the two periods, 1990 and 2000. The updates for new periods will use a new layer to edit the clouds in images of the previous period.

The classification of clouds can be done manually on the screen or automatically.

5 **Annex A**: Reference samples observed during the workshop during the discussion on the legend and classes description

5.1 **Deforestation: clear fell and other land use**

Milne Bay District. Oil Palm plantations are characterized by rectangular plots of a few hectares
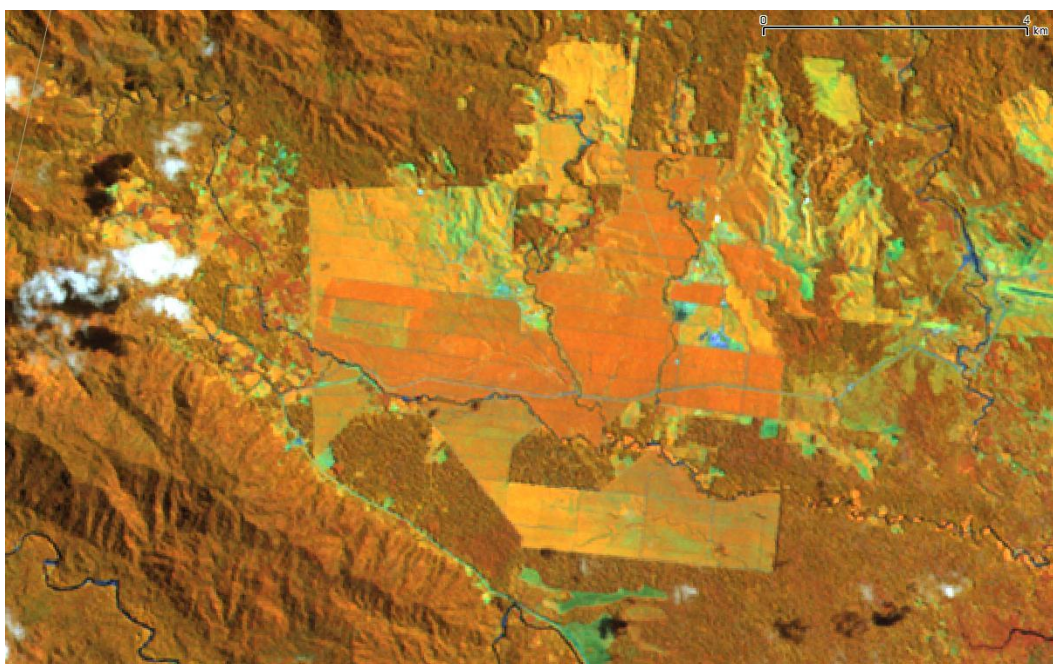
Figure 4: Landsat path 94 row 67 date 1990-08-21.

separated by roads. Clear fell is typically associated with oil palm plantations and subsistence agriculture that expands in parallel.

5.2   Deforestation: burned areas without trees

Milne Bay District. Vegetation: Small Crowned Forest and Medium Crowned Forest.

In the following sequence it is possible to see the gradual retreat of the forest, which occurs irregularly along the borders.
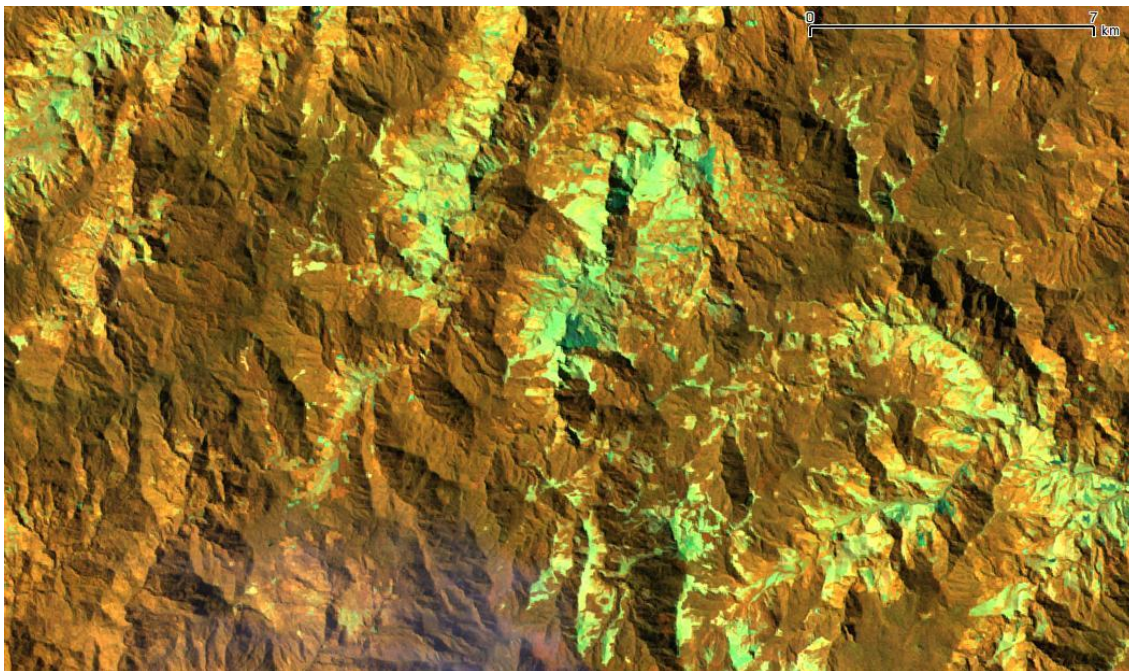
Figure 12: Landsat path 94 row 67 date 1990-08-21.
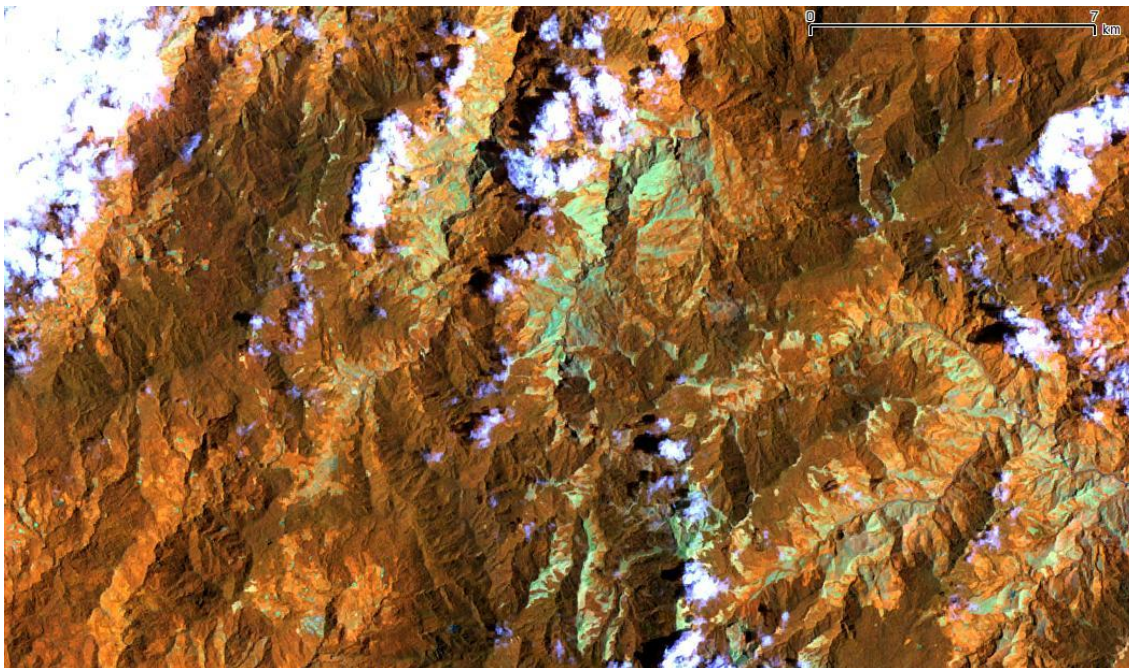
Figure 13 Landsat path 94 row 67 date 2001-01-31.
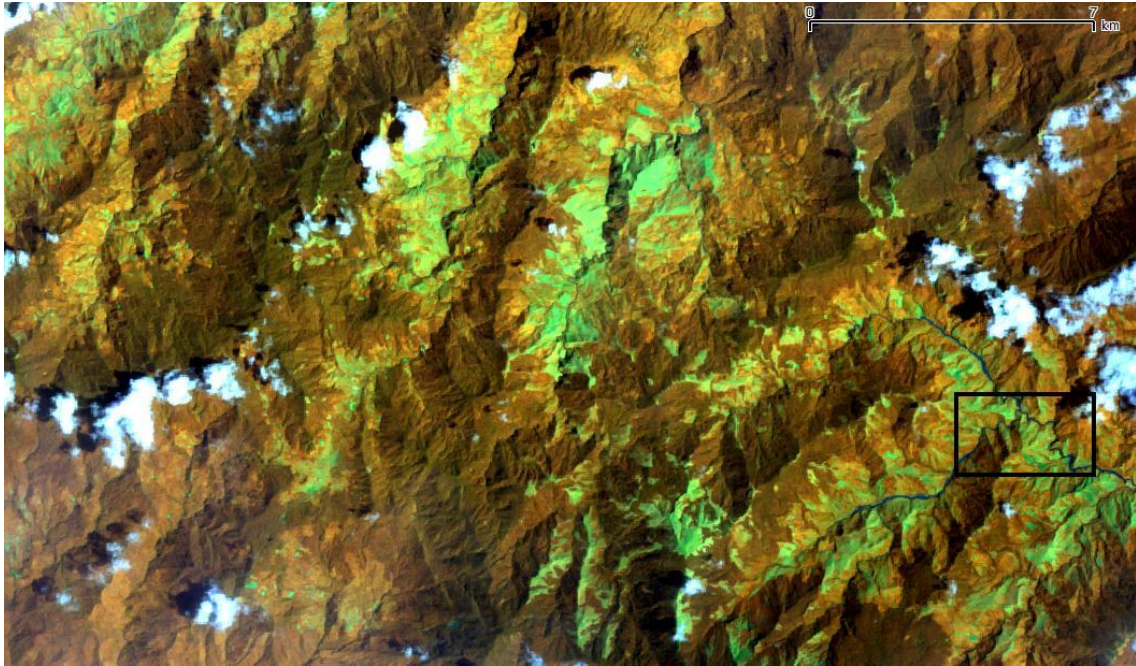
Figure 14 Landsat path 94 row 67 date 2008-12-28.

The following image confirms the absence of trees in the herbaceous cover.

Figure 15: From Google Earth.

5.3   Degradation: selective logging

West New Britain District. Vegetation: Medium Crowned Forest.
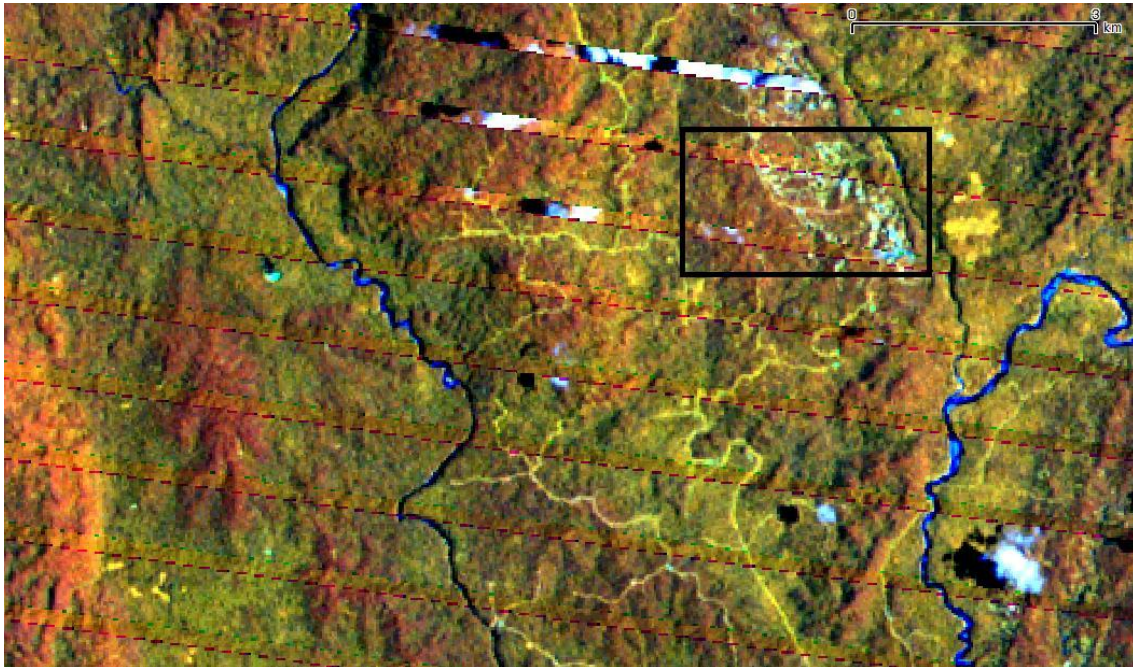
Figure 16: Landsat ETM row 094 path 064 date 2010/10/07 and Landsat ETM row 094 path 064 date 2010/01/28 composite 453.

Inside the box of the following image is visible a more intense logging activity.
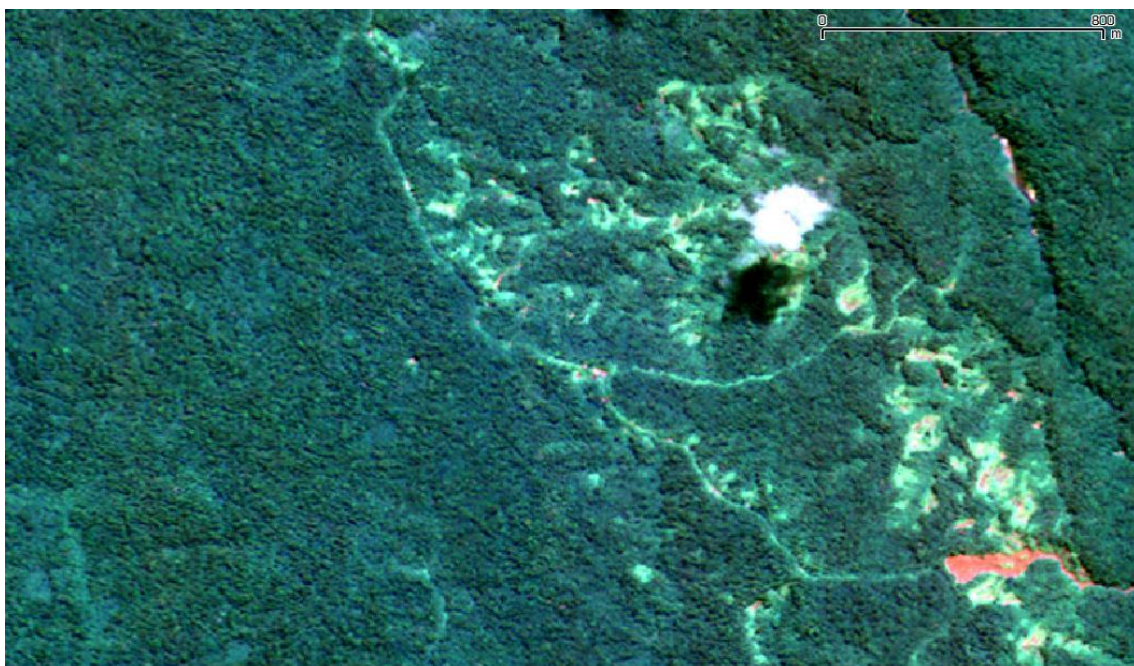
Figure 17: Kompsat from TropForest S06-E150 date 2010/04/17 composite 123

Kompsat sensor allows to distinguish density and distribution of tree crown and to recognise the

gaps due to the fall of the single trees.

The AVNIR in the image shows that this sensor can highlight the selective logging with a sharpen texture.
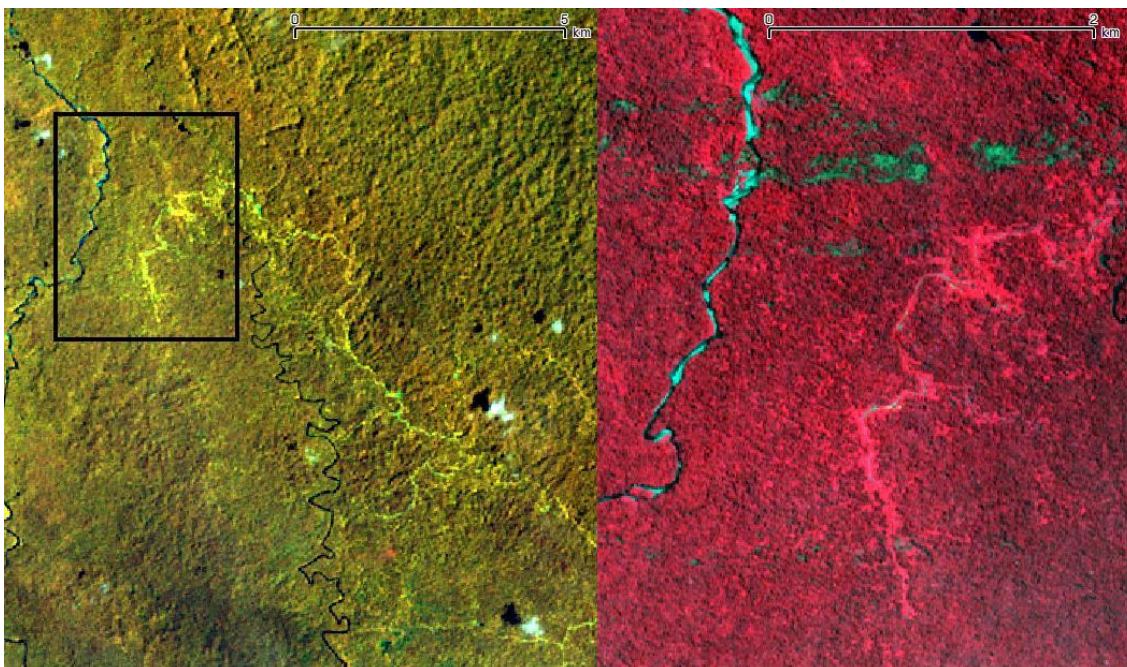
Figure 18: Landsat ETM row 098 path 065 date 2010/01/13 composite 453 and AVNIR AVNS07E144 2010/03/27 composite 432

5.4   Degradation: Subsistence agriculture

Central District. Vegetation: Large to Medium Crowned Forest.

In the following example, are showed three phases of forest retreat, passing gradually from degraded areas with forest mixed with small logging plots to open areas.
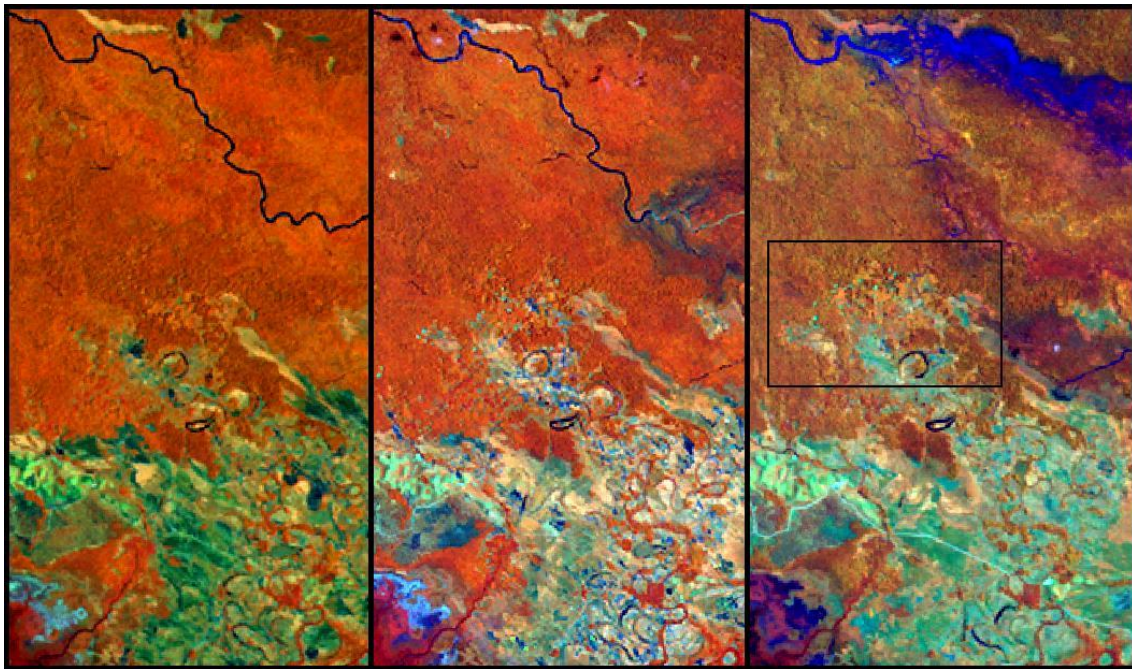
Figure 19: Landsat Path 094 row 67 dates 1991/10/22 - 2001/12/28 - 2009/03/10 composite 453.

This Kompsat image provides details of the front of the cutting area.
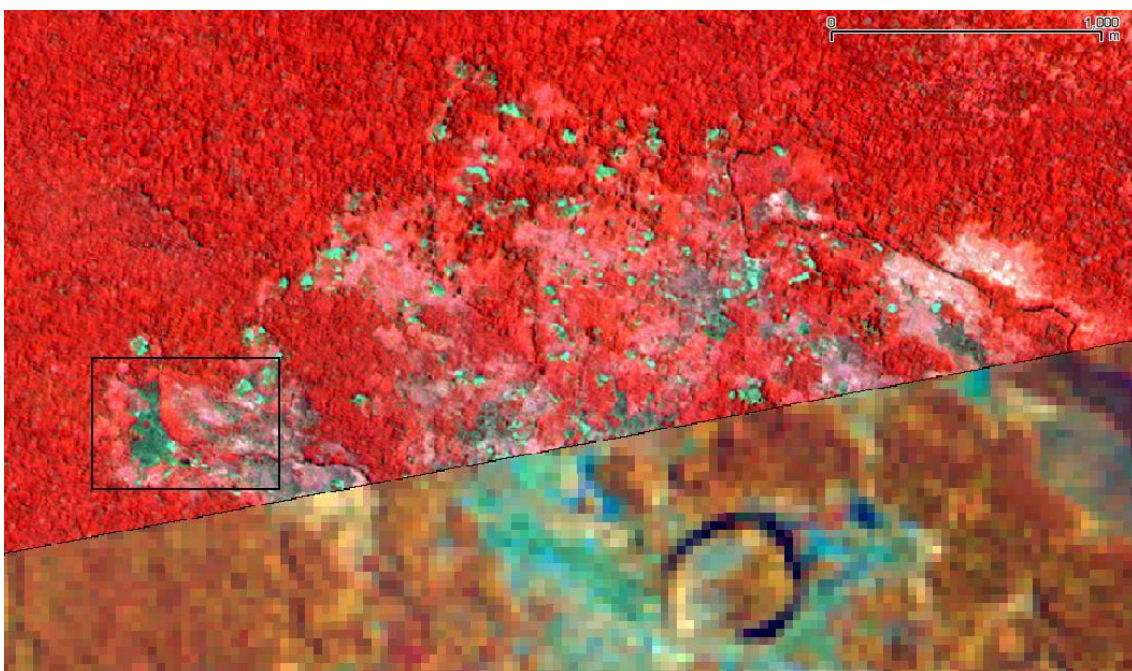
Figure 6: Kompsat S10 E148 KOM date 2010/10/03 composite 432.

More details about the mosaic of different land covers that replace natural forest can be added from this high resolution image in Google Earth.

Figure 7: From Google Earth image dated 10/13/2005.

East New Britain District. Vegetation: Small Crowned Forest.

In the forest map, the area is described as degraded: disturbed from 50% to 90% of forest cover.

The following image shows the cropland extension in 1989. Dense forest is still present in plots inside the agricultural area. Field grass and shrubs mosaic produce a homogeneous surface with sharp

Figure 8: Landsat path 094 row 64 date 1989/06/07 composite 453.

boundaries.
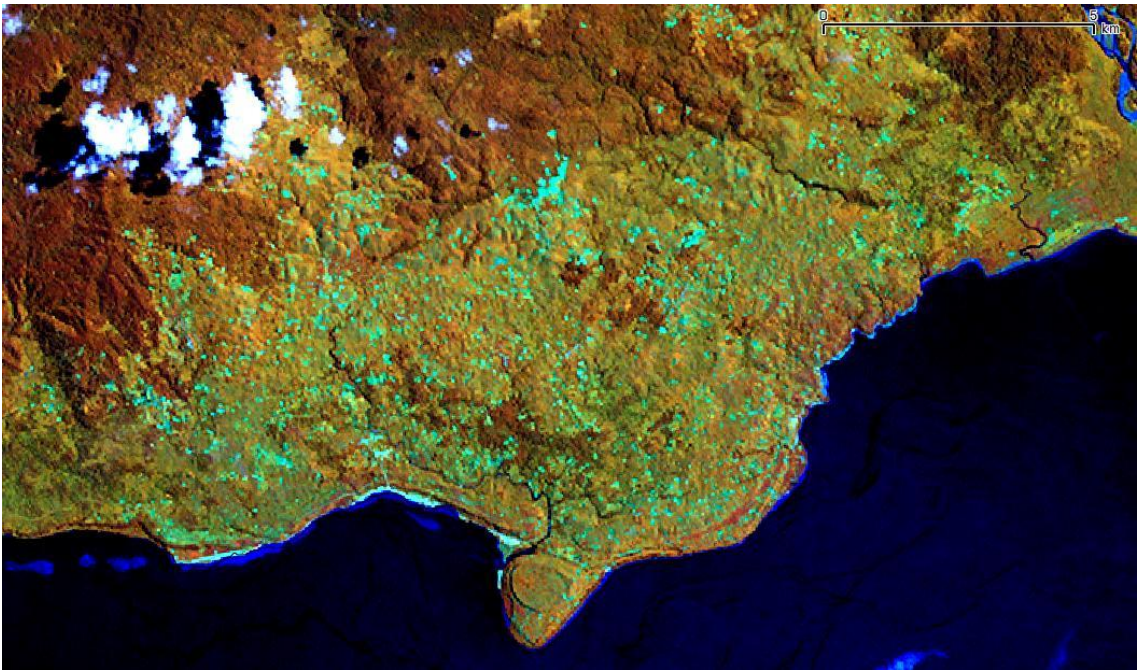
Figure 9: Landsat path 094 row 64 date 2000/04/02 composite 453.

In 2000 crops are developing causing forest retreat.

The next image shows the present situation. Unfortunately it is not easy to find a good quality image for this frame. It has been employed a couple of LSC-OFF Landsat ETM partially covered by clouds.
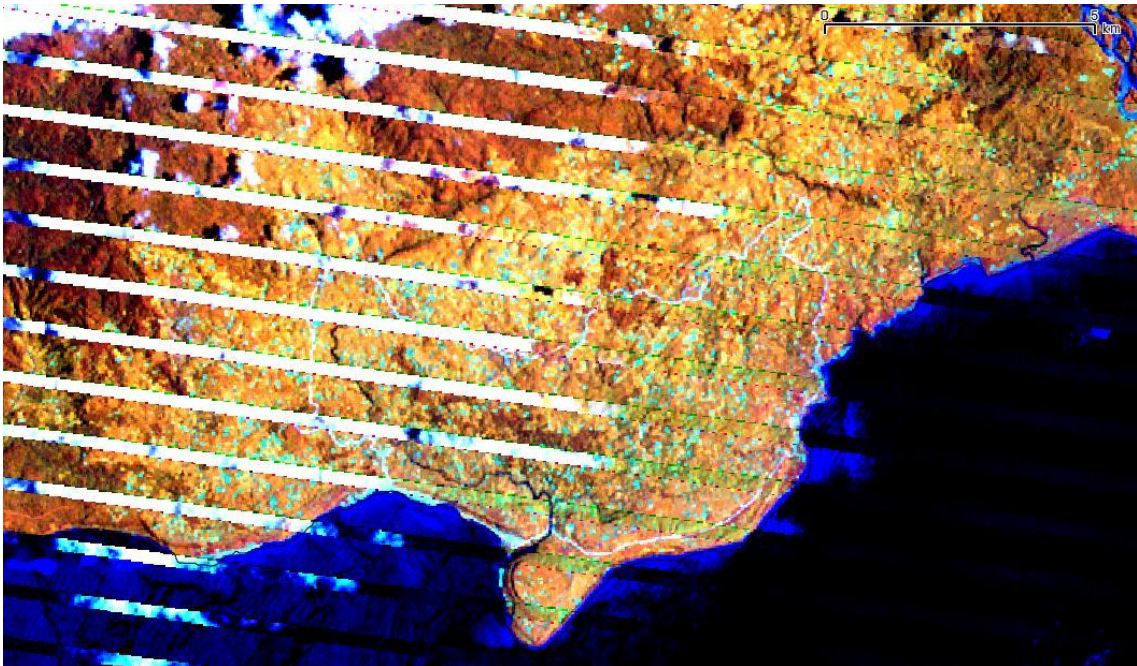
Figure 10: Landsat path 094 row 64 date above10/10/07 below 2011/01/28 composite 453.

Enga District. Vegetation: Small Crowned Forest and Medium Crowned Forest

In this case it is possible to observe the progressive expansion of agriculture area, at first constituted by small scattered fields then larger clusters, and finally a large continuous area. The small fields increase from scattered to clustered and then to continuous. The separation among forest, degraded forest and non_forest is difficult.
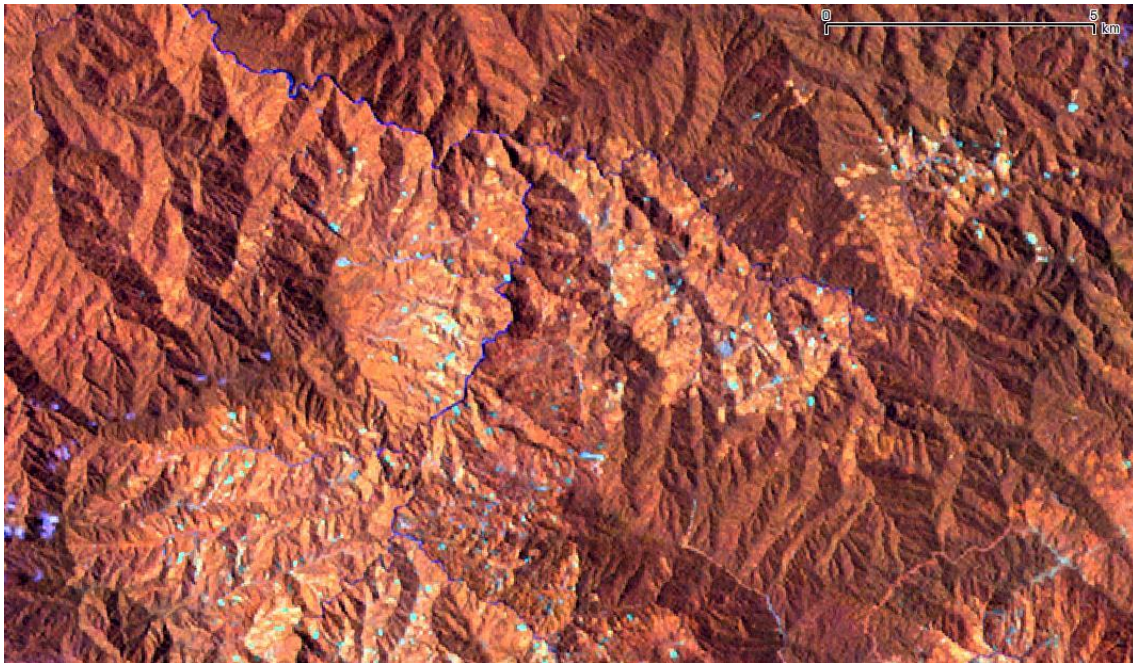
Figure 11: Landsat path 098row 64 date 1994/09/13 composite 453.
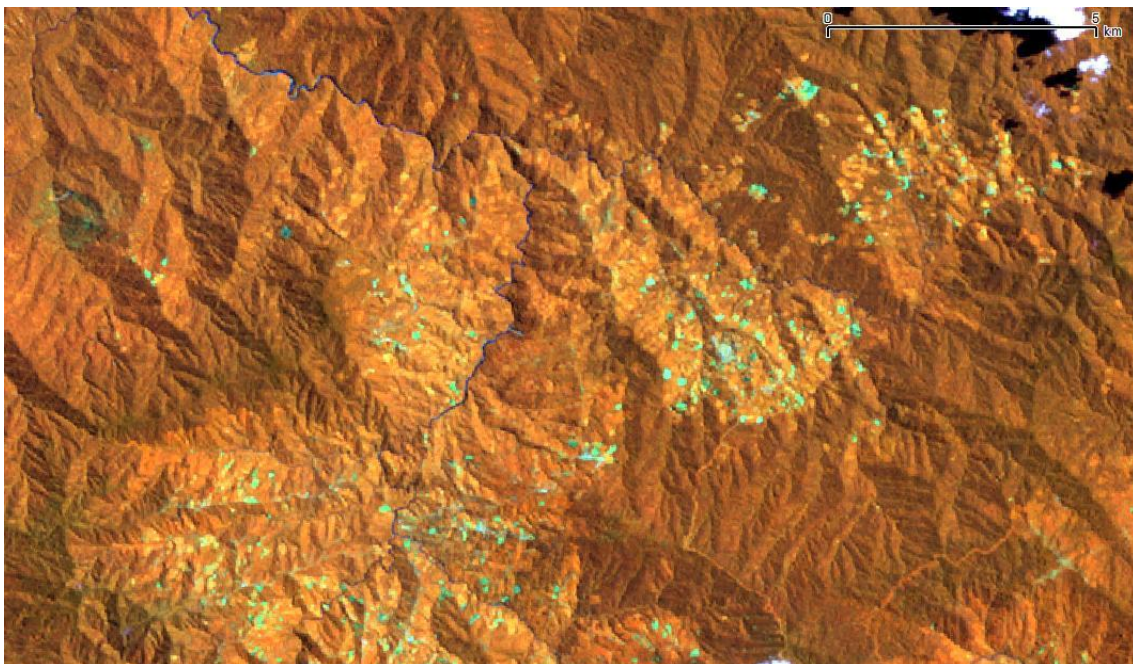
Figure 12: Landsat path 098row 64 date 2000/09/06 composite 453.
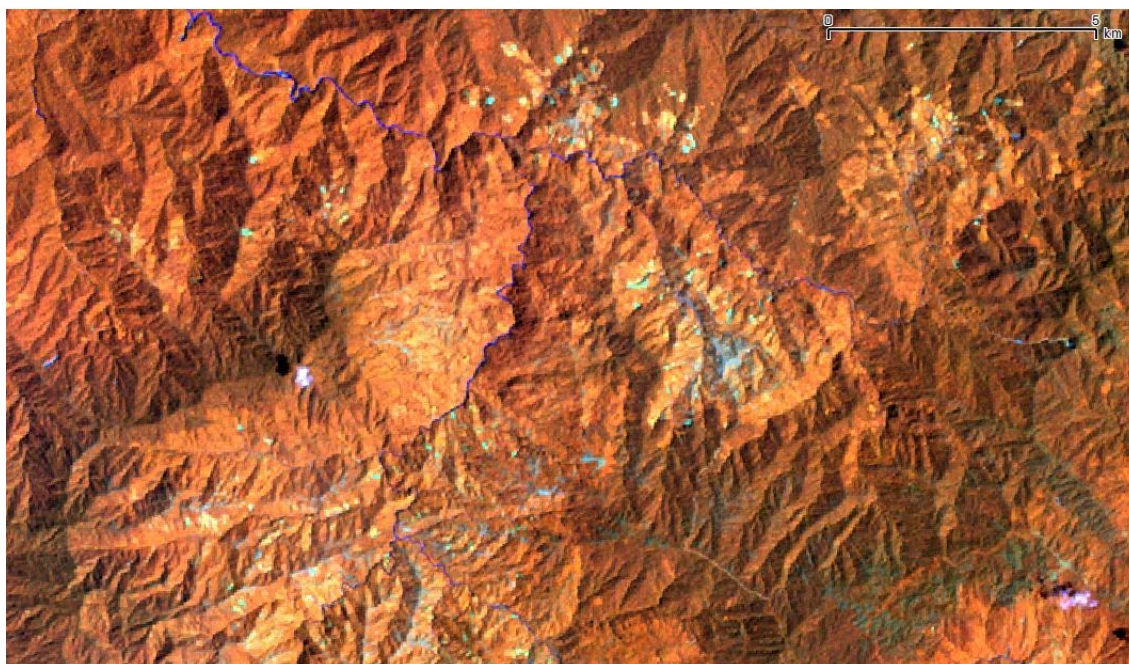
Figure 13: Landsat path 098 row 64 date 2009/01/26 composite 453.

Madang District. Vegetation: Small Crowned Forest and Medium Crowned Forest.

Both mentioned vegetation classes are described at different levels of disturbance in the forest map: from 20% to 40% of forest cover.

This example depicts a landscape characterized by a mosaic of forest and small fields. These fields are exploited for some years, then abandoned to fallow vegetation re-growth, while a new plot is cleared for cropping. This land use change is extremely difficult to detect and assess, and unfortunately it can be very dynamic requiring a regular update.
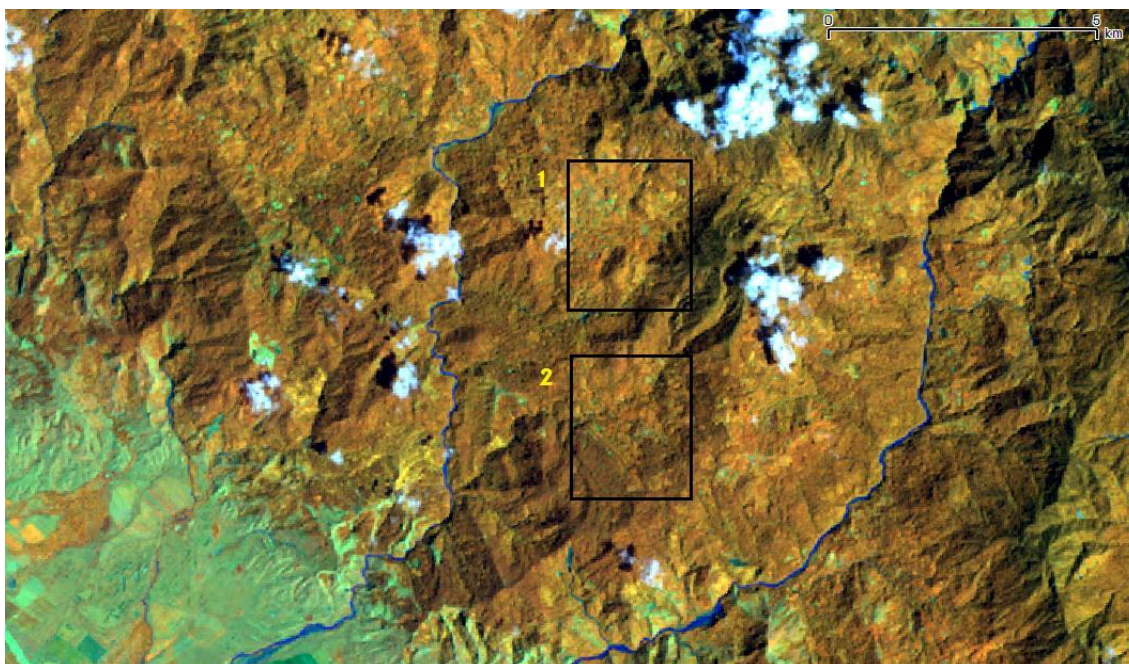
Figure 14: Landsat path 097 row 64 date 2009/01/03 composite 453.

The two boxes on the previous image are covered by the following Kompsat image. Again it is

possible to assess canopy distribution, field patterns and other natural semi-natural vegetation
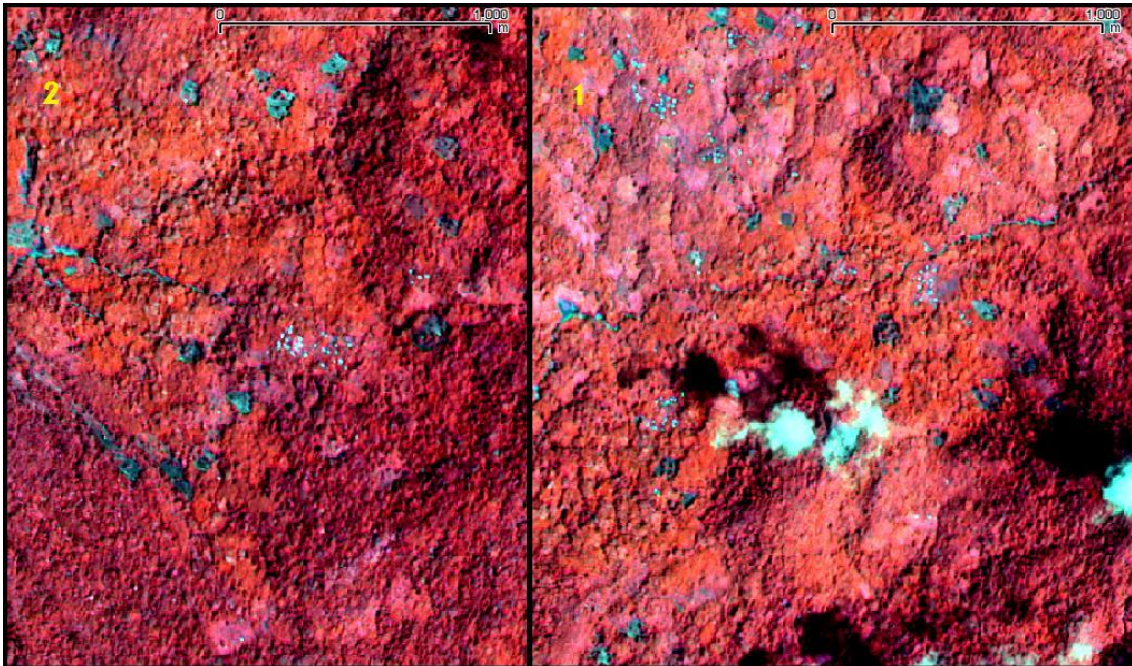
Figure 15: Kompsat KOM S06 E146 date 2010/11/09 composite 432.

texture.

5.5   Degradation: burned areas with trees

Northern District. Vegetation: several kinds of Low Altitude on Plains and Fans and on Uplands Forests. Can be disturbed to 80%.

The forest map indicates burned open woody/tree areas as degraded Large to Medium Forest or degraded Open Forest or even no forested area. The surrounding area is often represented as Small Crowned Forest with natural canopy closure of 60-80%. In this case the open canopy doesn't seem to be due to degradation.

Forest fire may sometimes burn only the surface litter and undergrowth. In the example below, burned areas are in open forest, where a thick layer of grass is present.
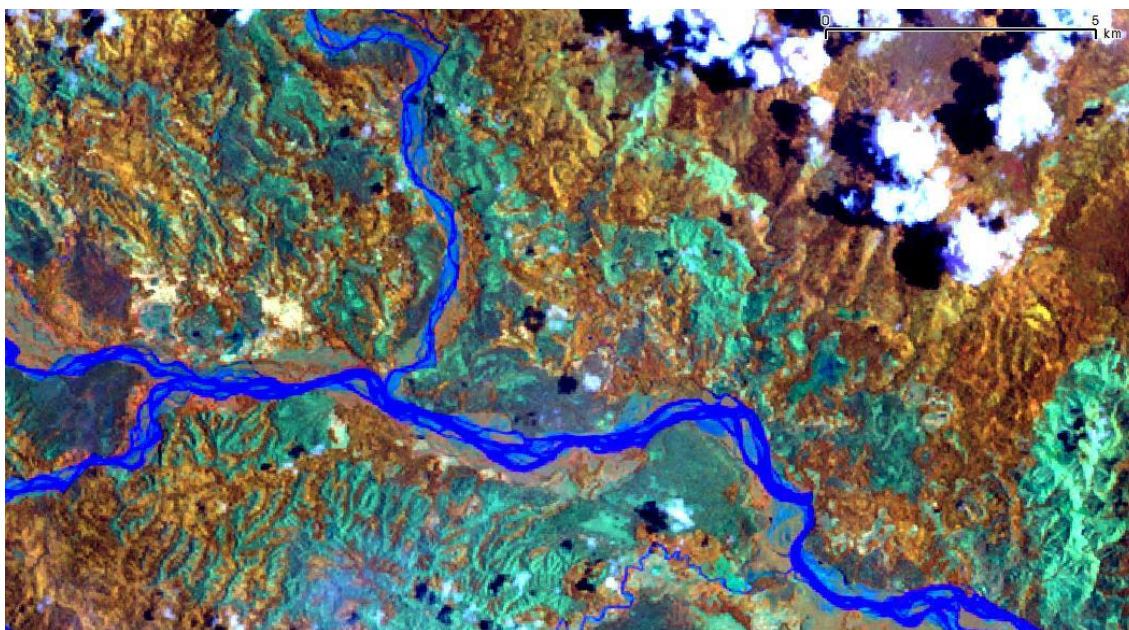
Figure 16: Landsat path 095 row 67 date 2009/03/10 composite 453.

This land cover is difficult to classify since it can be forest if tree coverage is more than 10%, but it can be degraded or non_forest if the percentage is less.

It is very difficult to verify if a reduction of the percentage of coverage has occurred during the assessed period.
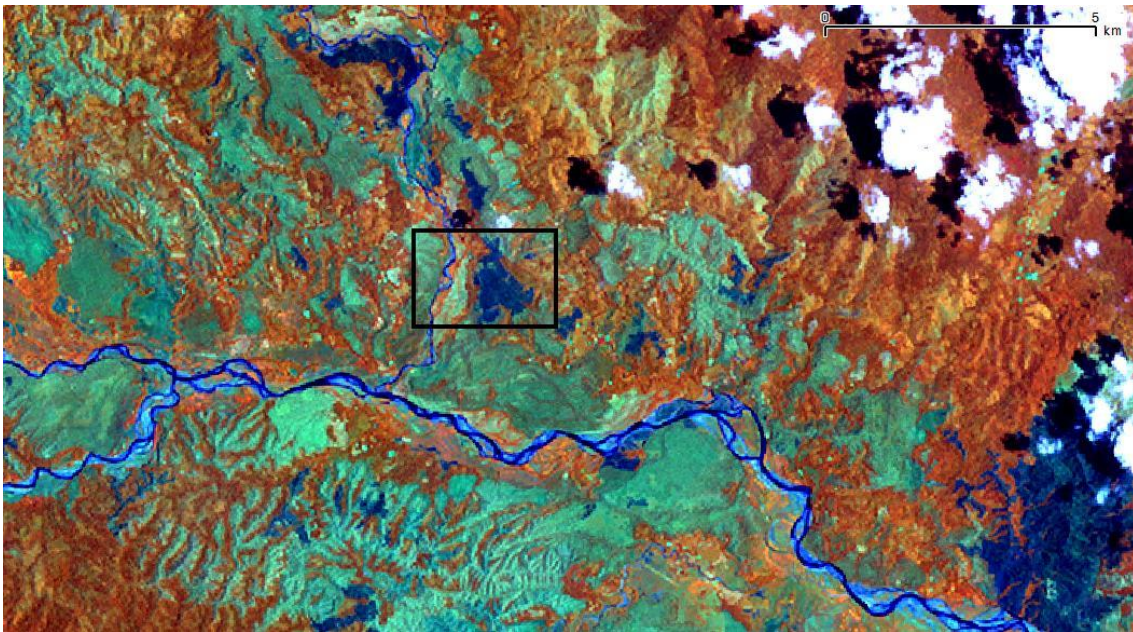
Figure 17: Landsat path 095 row 67 date 2001/10/22 composite 453.

According to this high resolution image collected from Google Earth, this kind of degradation can be assumed to occur with surface fire, as some biomass and litter are destroyed so that forest recovery is hampered.

Figure 18: From Google Earth.

The box showing the location of this very high resolution image is located in the Landsat dated 2001, since the year of this image is 12/01/2002. One year after the fire the trees seem to be still alive.

5.6   Degradation: temporary un-stock lands

This example shows a teak plantation. A very recent cutting area is visible in the year 2010. Unfortunately Landsat does not show clearly the parcels of trees of different ages typical of a
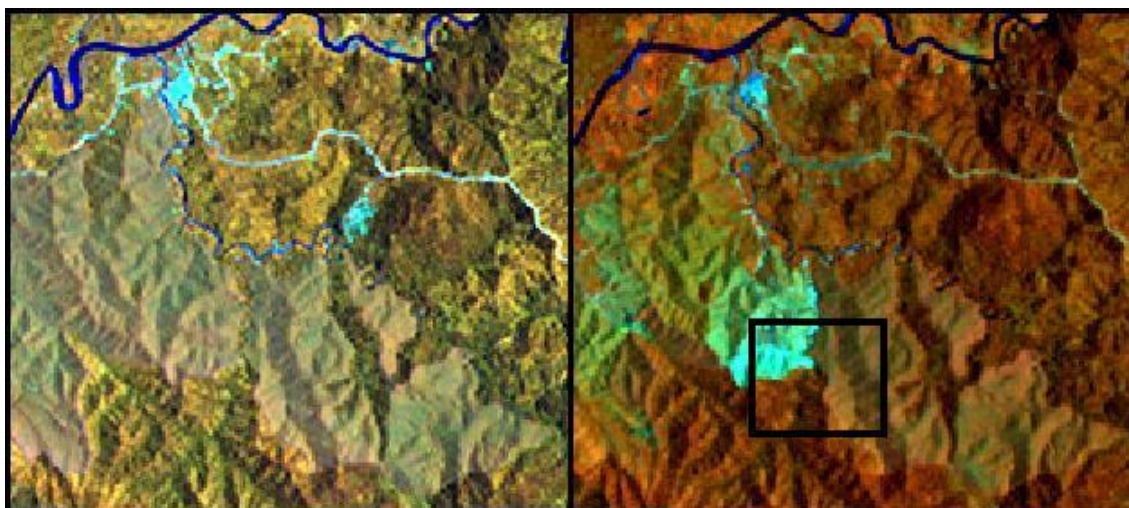
Figure 19: Landsat path 096 row 66 date 2001/03/03 and 2010/02/16.

managed rotation.

Different parcels are visible using this very high resolution image from Google Earth.

In the top-left the past clear cut that occurred one year before is still visible (Google Earth is dated 2011).

On the right there is an old parcel of teak.

In the centre-bottom there is an area that has recently been cleared.

In the left-bottom there is natural forest.

5.7   Reforestation: rubber trees plantation

Central District.

The following two images show deforestation, reforestation and some selective logging.

One peculiarity of this zone is that forestry roads are developing on top of watersheds.
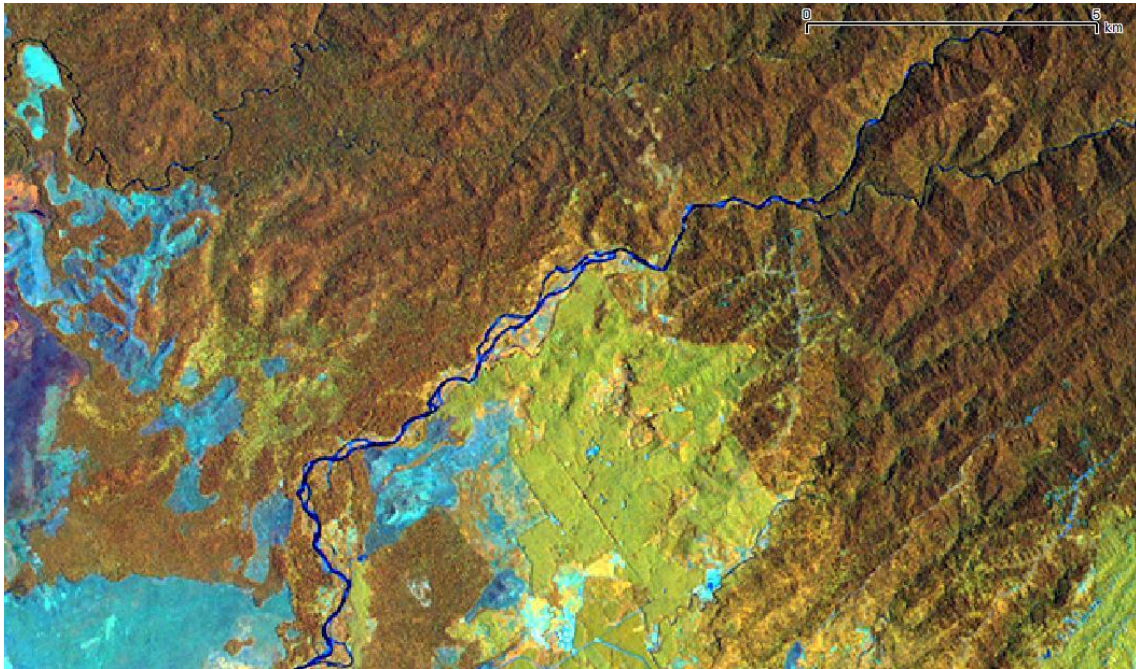
Figure 20: Landsat Path 096 row 66 date 2001/03/03 composite 453.

New plantations of rubber (in 2010) can be classified as reforestation. The AVNIR sample shown by
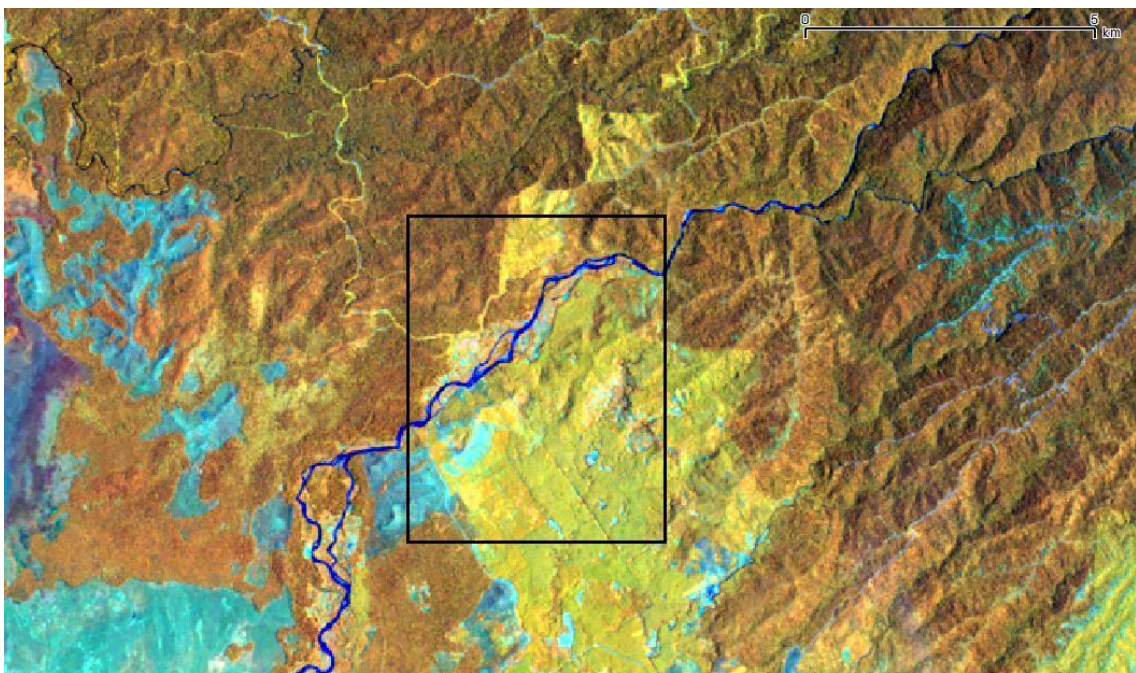

Image 21: Landsat Path 096 row 66 date 2010/02/16 composite 453.

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the box confirms the presence of new plantations.

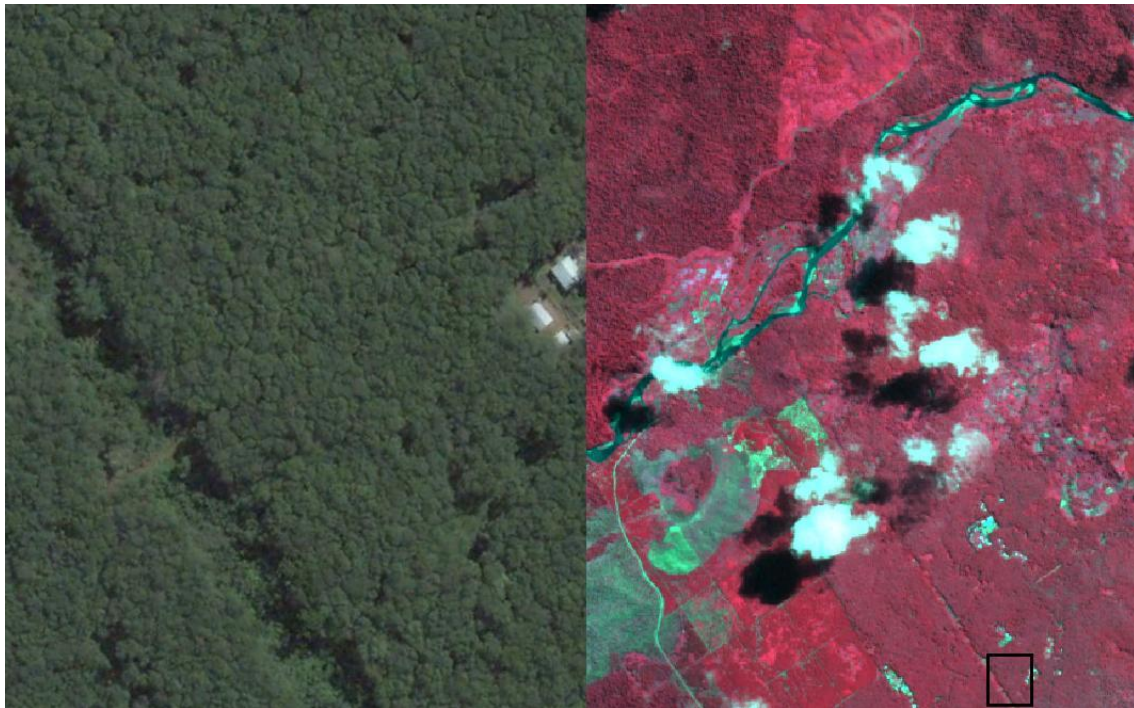The Google Earth image shows clearly the canopy structure.

Figure 22: AVNIR AVN-S09-E147 date 2010/04/15 composite 432 and Google Earth.

6 **Annex B**: Design of the conceptual model in TerraAmazon

6.1 **Rules and rule-sets**

An important purpose of this document is to allow the reproduction of the database made with TerraAmazon presented here.

The implementation of the conceptual model was influenced by the decision to begin the mapping project in pilot countries (DRC and PNG) focusing – initially – on area change only. The definition of the vector layers to be generated and the combination of rules to employ were adapted to the classes described in the previous chapter.

The main question of the model developed concerns how the classes – that are described in terms of land use – are topologically related to each other, and how they are related to the features of the ground of previous periods in order to describe the change that occurred over the previous period.

At the core of this issue are the rules created in TerraAmazon and the rule-sets which determine the classification process.

During the development of the model it was noted that geometries belonging to each class are characterised by different topological behaviours (according to the semantic meaning). These behaviours can be expressed as the need to stay inside or outside pre-existing polygons, or as the indifference to these. This led to the decision to generate a spatial layer for each class (one for deforestation, another for degradation etc.). In other words, considering that PostgreSQL is an Object Oriented environment, each polygon can be considered an "instance" of one class (the kind of change), characterised by one specific set of properties and rules.

In order to have a clear understanding of the model, a detailed explanation of the rules used for the generation of the layers is provided here. This will set out the parameters and dependencies adopted during the design and implementation of the database with TerraAmazon.

More details concerning the parameters and dependencies of the conceptual model are in **annex B**. Each layer representing a class is generated as an "output" resulting from a classification process. The process performs two actions: assigns a predefined class name and generates new polygons in the output layer using the geometry selected from the draft vector layer. One or more rules (rule-set) define the "spatial operations" that edited polygons in the draft layer will be submitted to during the classification, and the layer that will be used for such operation: the "rule layer". Spatial operations can be "intersection", "difference" and "clean", which are well explained in the official manuals at FUNCATE web page.

Despite rules in the rule-set looking similar, they have different effects with different aims. The distinction between these effects allows a better understanding and employment of the rules.

In general we consider three groups of rules, acting at different levels, which are described in the following sections.

6.2 **1ˢᵗ group RULE: concerning one single output layer**

Each polygon of any layer must not overlap with other polygons in the same layer.

With these rules the operation is always "stay outside". The operation in TerraAmazon is **difference.**

The output layer is always the rule layer too.

The purpose is a matter of mere topological contiguity: the statistics derived from the map would fit the surface of administrative or other kinds of area subdivisions. Plus, it becomes possible to edit new contiguous areas by drawing overlapping polygons in the draft layer, which are perfectly appended avoiding gaps.
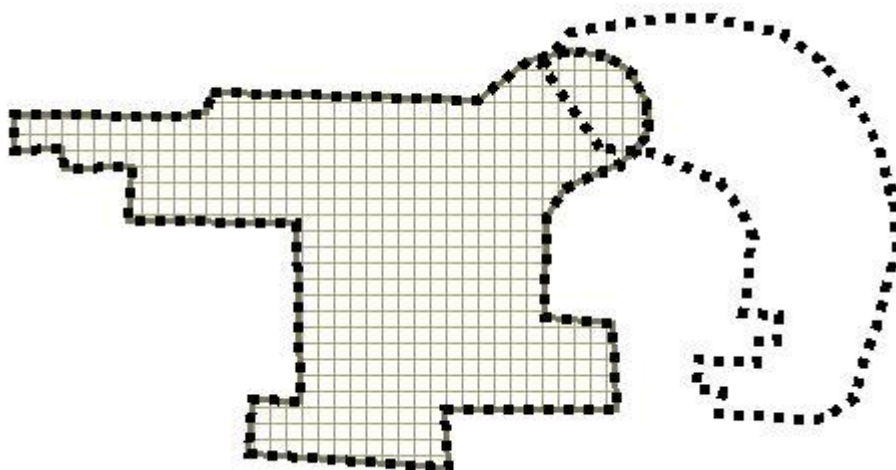
*Figure 24: Two draft polygons was drown. The one on the left was classified as **non_forest**. The other, on the right, is still to classify and overlaps the first.*
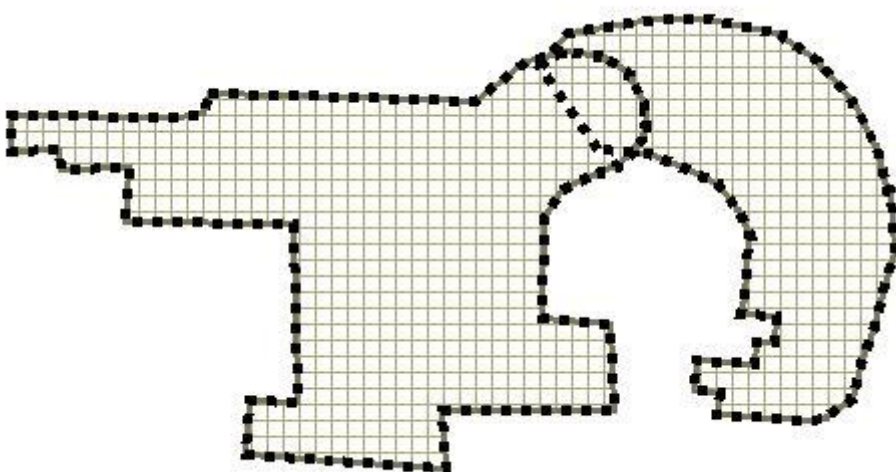

*Figure 23: Now the second draft polygon has been classified as **non_forest** too. The boundary between the two (in dark grey) shows that the second classified polygon is appended to the first and the overlap area was removed.*

In order to simplify the description, all the rules which make use of the operation **clean** are associated with this group. The clean role is necessary for editing since it allows the editor to delete polygons already classified.

By this operation the rule layer is the output layer and as with the difference rule is necessary for all the output layers.

6.3   2nd group RULE: concerning output layers in one single project

The polygons of one layer must not overlap polygons in layers referred to the same period.

As with the previous group of rules the operation is always "stay outside". The operation in

TerraAmazon is **difference.**

The rule layer is not the output layer, but as with the previous group, always belongs to the same project in TerraAmazon and therefore applies to the same year.

This group has two purposes. One is the same as with the previous group: avoiding counting of the same surface more than once. The second reason is thematic: to avoid assigning two or more classes to the same land in the same period as it doesn't have any thematic meaning.
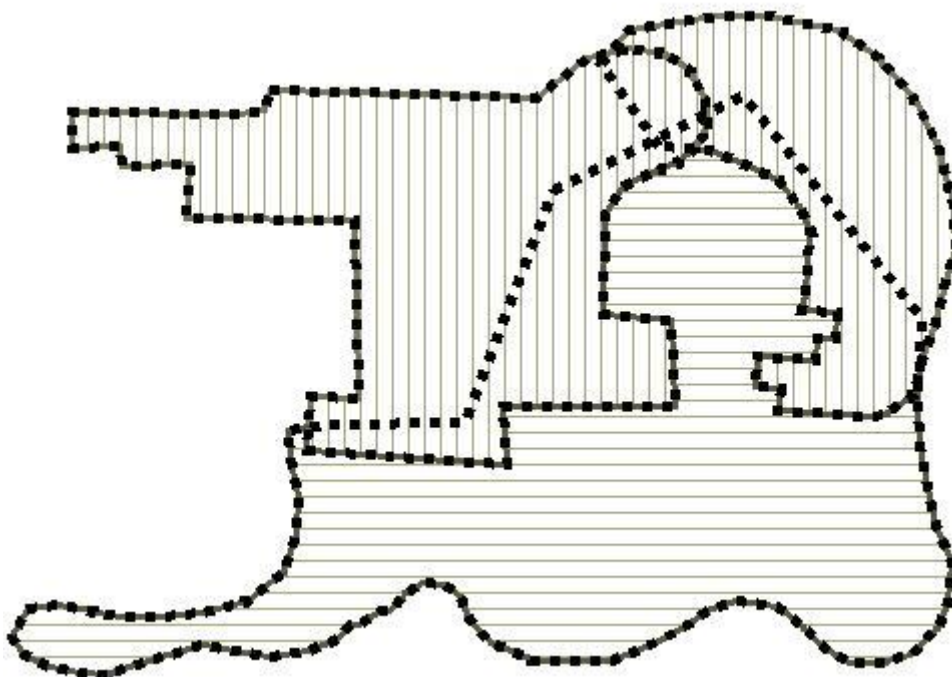

*Figure 25: A new draft polygon has been drawn and classified as **degraded_forest**. According to the sequence of the generated polygons the last one belongs to a different layer and does not overlap any of the pre-existing polygons.*

6.4   3rd group RULE: concerning output layers of two different projects

The polygons of one layer may overlap, or not, polygons in layers referred to in previous periods.

In this case the operation can be "stay outside" as well as "stay inside". It is also possible that two layers of two different projects are not related by any rules. The operation in TerraAmazon can be **difference** or **intersection**.

The rule layer is not the output layer, and the two never belong to the same project in TerraAmazon because the rule layer refers to a previous period.

The purpose of this group is thematic. These rules are used to improve the integrity and robustness of the system that is typical in a relational database. They force the editor to respect the topological relationships among classes belonging to different periods. The relationships fit the "from-to" process or actions described by the kind of change the class refers to.
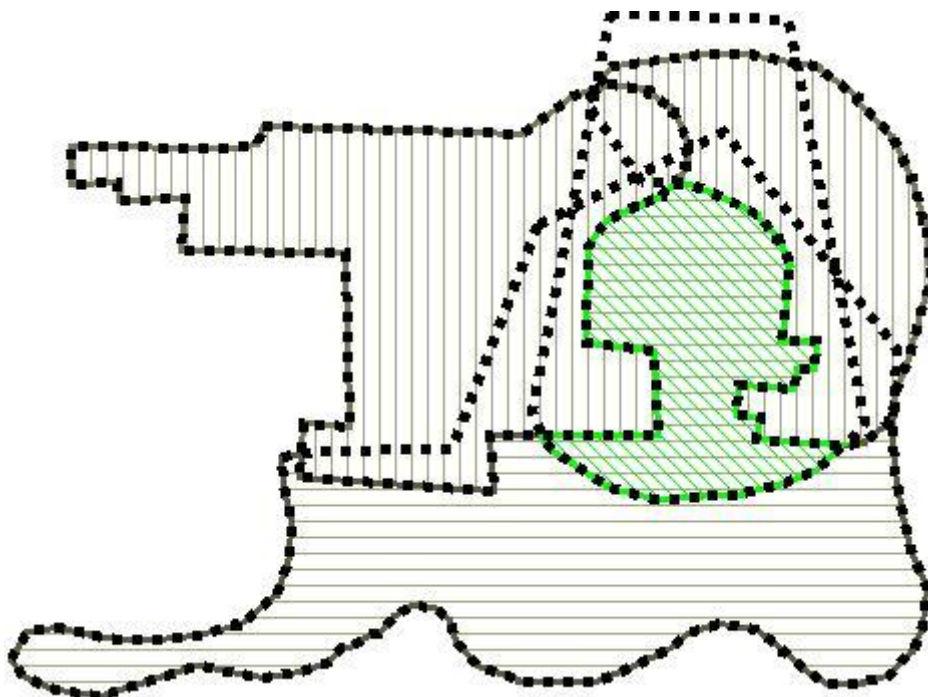
*Figure 27: Editing a subsequent period, a new draft polygon was classified as **forest_restoration**. Note that only the area classified in the previous period as **degraded_forest** has been generated.*
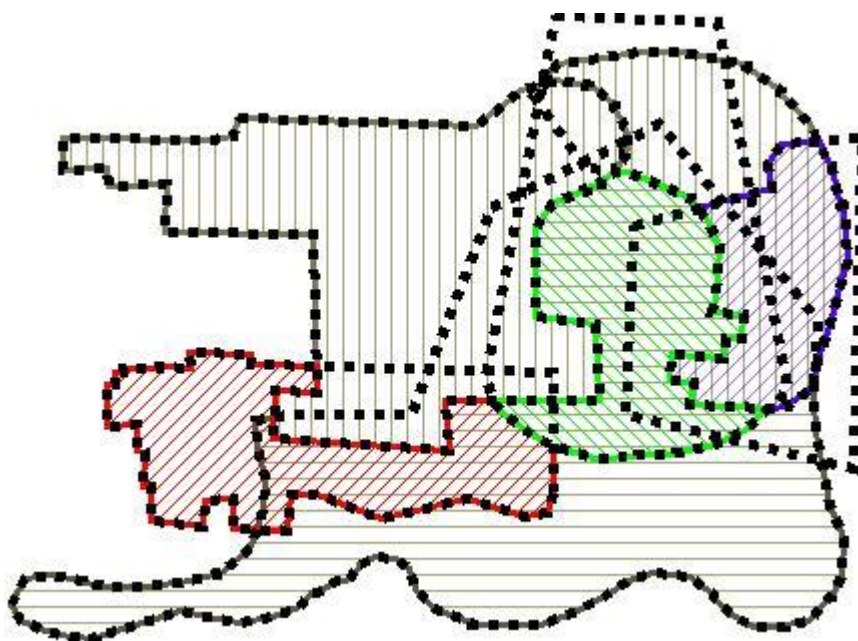

*Figure 26: Eventually the last two draft polygons have been edited for the second period. The polygon on the left was classified as **deforestation.** It does not overlap the **forest_restoration** because it belongs the same period, and it does not overlap the **non_forest** area, because it is not a change. But it can stay within **degraded_forest**, or out of the mask (**forest**). The other polygon (on the right) is **reforestation**, which can stay within **non_forest** mask only.*
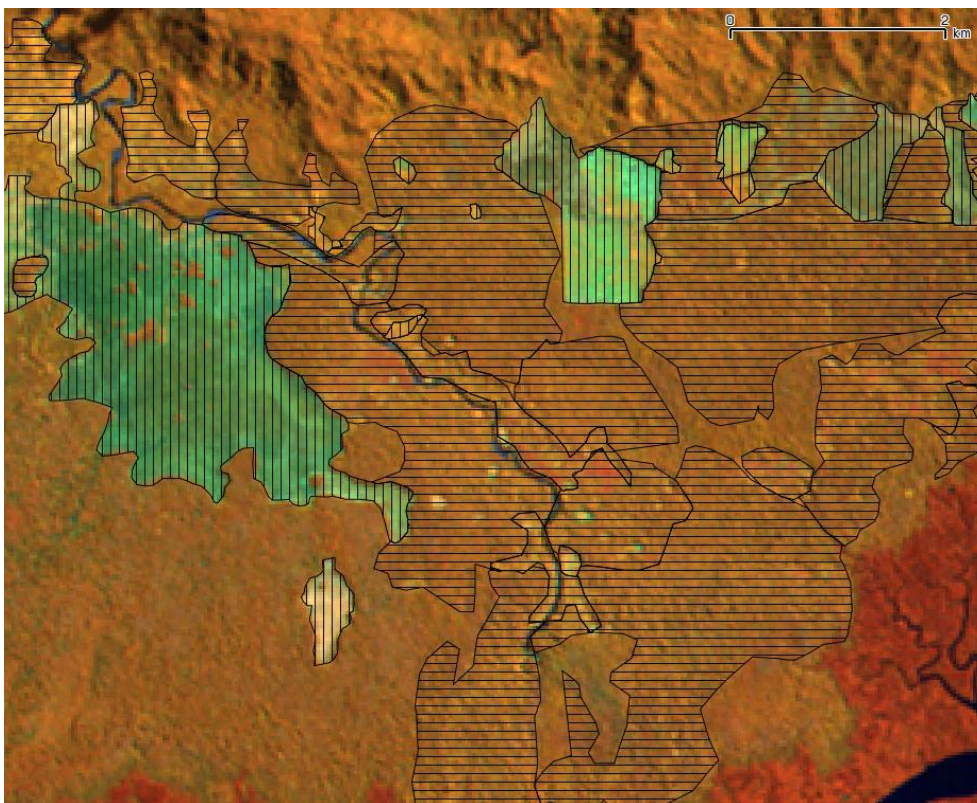
Figure 29: Milne Bay, close to Daudau. This is an example of interpretation performed during the workshop. This image is dated 1990: vertical lines are non_forest, horizontal lines are degraded_forest. Polygons have been freely added according to the improved understanding of the land cover.
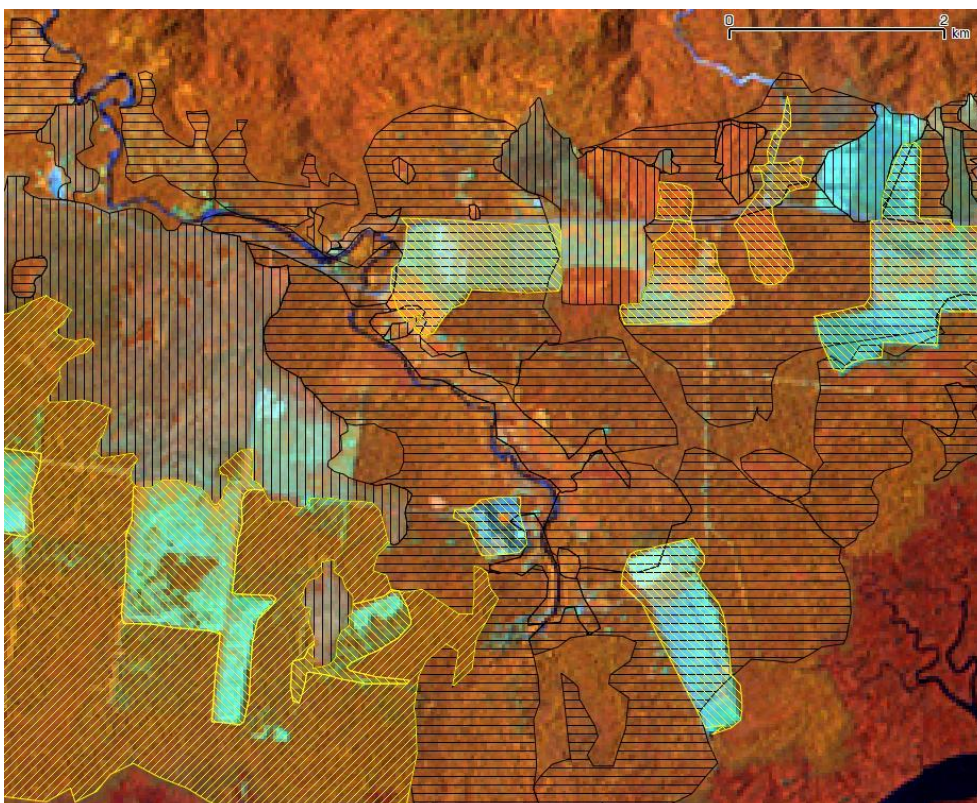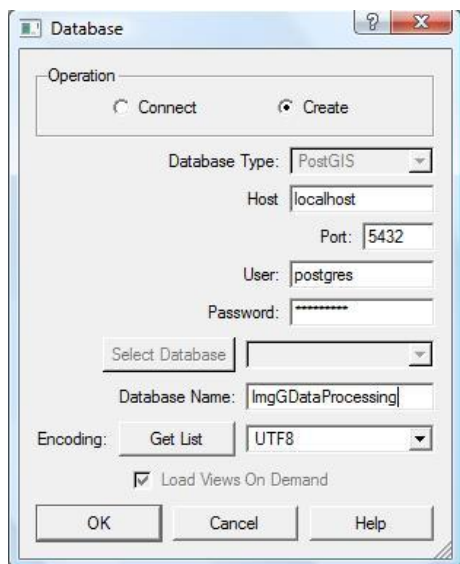

Figure 28: This image is dated 2010. Forward diagonals are deforestation, backward diagonals are degradation. It is possible to observe some topological relationships among classes.
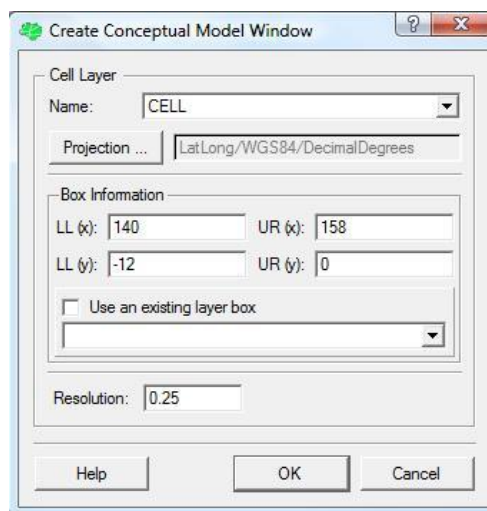
6.5   parameters used for the implementation of the conceptual model in TerraAmazon

6.5.1   Create database

Name: PNG_change

Encoding: UTF8

6.5.2   Create cell layer: CELL

Layer: CELL

Projection: Lat-Long / WGS84 / Decimal Degrees / south

Box: LL(x) = 140, LL(y) = -12, UR(x) = 158, UR(y) = 0

Resolution: 0.25, 0.25

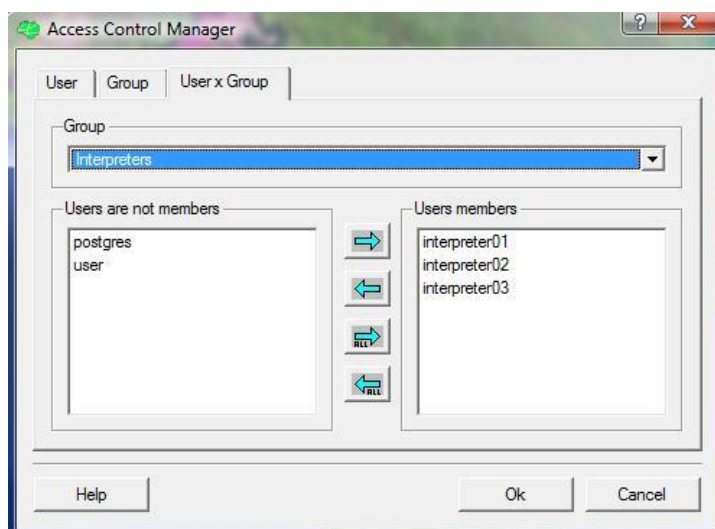### 6.5.3   Create groups:

Group: Interpreters

privilege: operator

6.5.4   Create users:
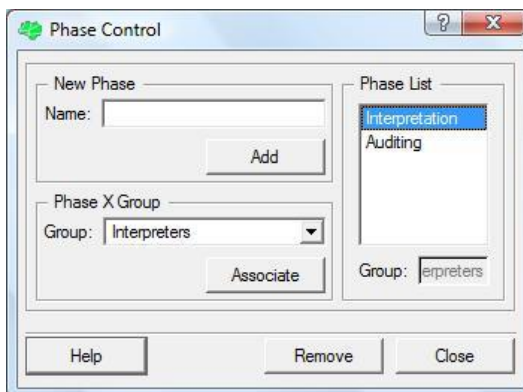
User: Interpreter

Password: xxxxxxxxxxx
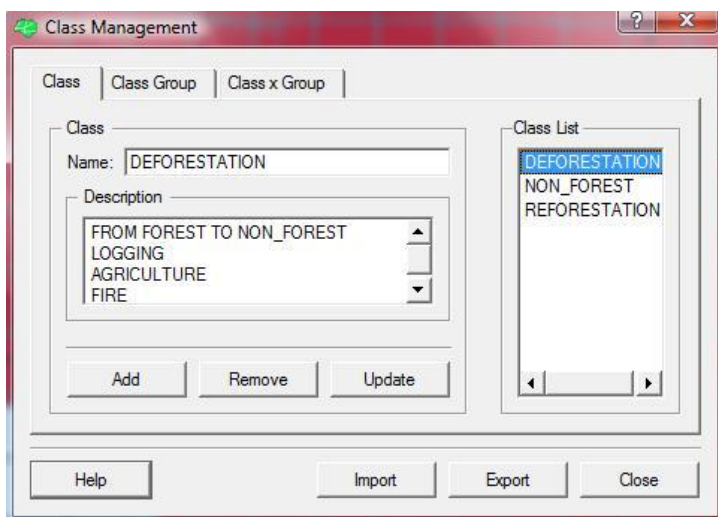
User member: of Interpreters

6.5.5 Create phase

New phase: Interpretation

Associated group: Interpreters

6.5.6 Create class:

NON_FOREST

DEGRADED_FOREST

DEFORESTATION

DEGRADATION

AFFORESTATION

FOREST_RESTORATION

REFORESTATION
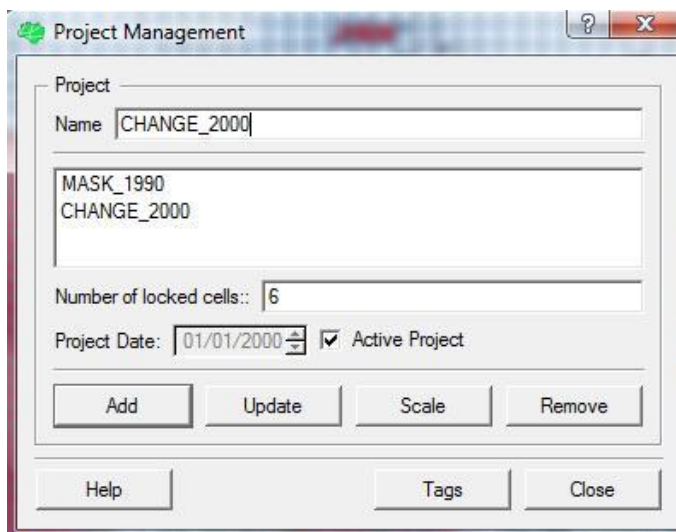
CLOUDS_SHADOW

6.5.7 Create project

Mask_1990

Change_2000

Number of locked cells: 6

6.5.8 Create layers:

Names:

Non_forest

Degraded_forest

Deforestation

Degradation

Afforestation

Forest_restoration

Reforestation

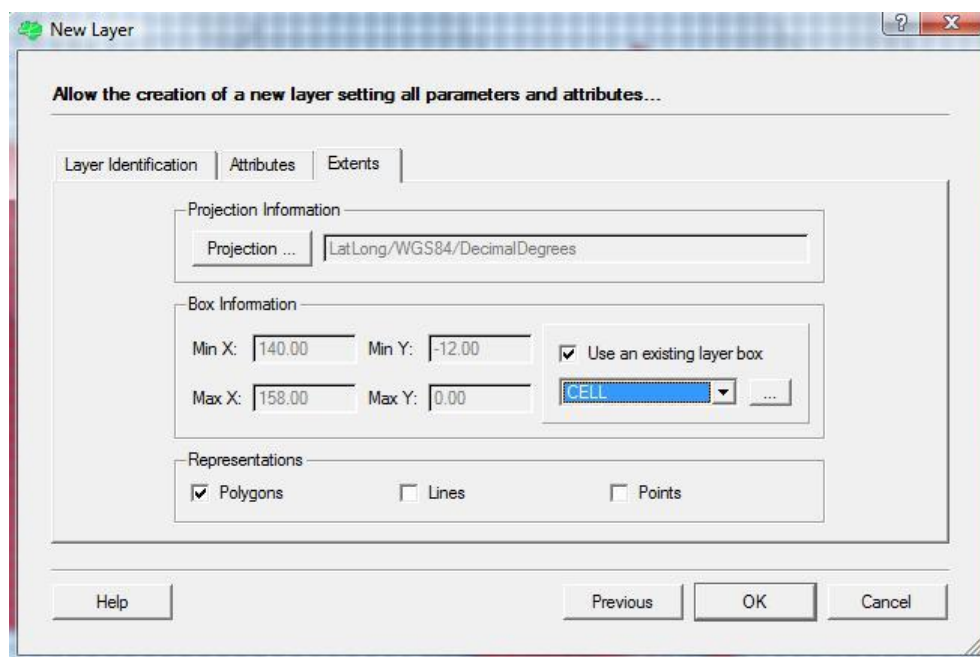
projection:

lat-long

Decimal Degree

WGS84

South-East

Use an existing layer box (checked):   CELL

Representations: Polygons

6.5.9 Create rules

Cell column: cell_oid

6.5.10 Operation: difference

DIFF_NON_FOREST layer: non_forest

DIFF_DEGRADED_FOREST layer: degraded_forest

DIFF_DEFORESTATION layer: deforestation

DIFF_DEGRADATION layer: degradation

DIFF_REFORESTATION layer: reforestation

DIFF_AFFORESTATION layer: afforestation

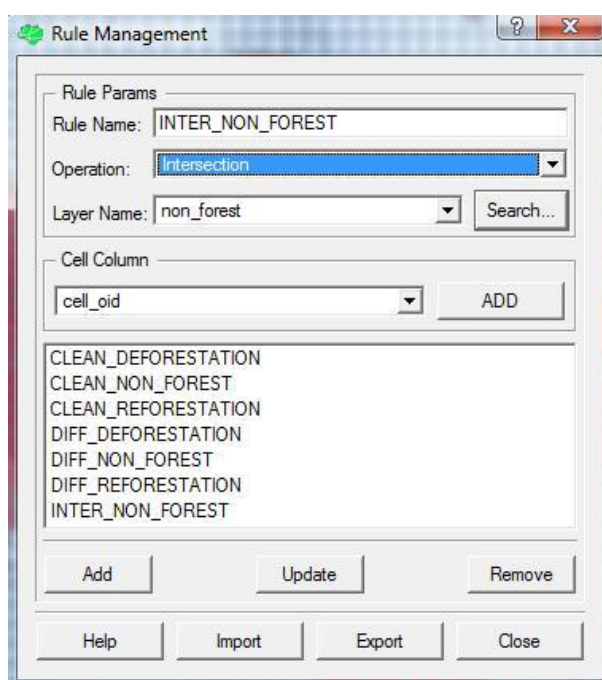DIFF_FOREST_RESTORATION layer: forest_restoration

DIFF_CLOUDS layer: clouds_shadow

6.5.11 Operation: clean

CLEAN_NON_FOREST layer: non_forest

CLEAN_DEGRADED_FOREST layer: degraded_forest

CLEAN_DEFORESTATION layer: deforestation

CLEAN_DEGRADATION layer: degradation

CLEAN_REFORESTATION layer: reforestation

CLEAN_AFFORESTATION layer: afforestation

CLEAN_FOREST_RESTORATION layer: forest_restoration

CLEAN_CLOUDS layer: clouds_shadow

6.5.12 Operation: intersection

INTER_NON_FOREST layer: non_forest

INTER_DEGRADAD_FOREST layer: degraded_forest

6.5.13 Rules control

Note: for each output layer only strictly necessary rules have been employed. For instance in case of **degradation**, it is established that it has to stay outside of the **non_forest** mask. As a consequence the risk of overlap is with **deforestation** only, so it is not necessary to use rules to avoid overlaps with **afforestation, forest_restoration** or **reforestation.**

In order to verify the required rules it is possible to check the following table:

Change	From	To
Deforestation	Forest – Degraded_forest (mask)	Non_forest (mask)
Degradation	Forest	Degraded_forest (mask)
Afforestation	Non_forest (mask)	Forest
Forest_restoration	Degraded_forest (mask)	Forest
Reforestation	Non_forest (mask)	Forest

In this model the **clouds_shadow** layer is the same for both projects. Only one rules-set is available for one output layer. The output clouds_shadow is present in both of the projects, but any modification in one of the two will affect even the other project.

CELL_COLUMN: CELL_OID

CLASS_COLUMN: CLASS_NAME

6.5.14 PROJECT: MASK_1990

SET OF RULES 01:

OUTPUT_LAYER: **NON_FOREST**

CLASSES: NON_FOREST

group 1

RULE: DIFF_NON_FOREST

RULE: CLEAN_NON_FOREST

group 2

RULE: DIFF_DEGRADED_FOREST

RULE: DIFF_CLOUDS

SET OF RULES 02:

OUTPUT_LAYER: **DEGRADED_FOREST**

CLASSES: DEGRADED_FOREST

group 1

RULE: DIFF_DEGRADED_FOREST

RULE: CLEAN_DEGRADED_FOREST

group 2

RULE: DIFF_NON_FOREST

RULE: DIFF_CLOUDS

SET OF RULES 03:

OUTPUT_LAYER: **CLOUDS_SHADOW**

CLASSES: CLOUDS_SHADOW

group 1

RULE: DIFF_CLOUDS

RULE: CLEAN_CLOUDS

group 2 (the following rules are necessary in the project CHANGE_1990)

RULE: DIFF_REFORESTATION

RULE: DIFF_FOREST_RESTORATION

RULE: DIFF_AFFORESTATION

RULE: DIFF_DEGRADATION

RULE: DIFF_DEFORESTATION

group 2/3

RULE: DIFF_DEGRADED_FOREST

RULE: DIFF_NON_FOREST

6.5.15   PROJECT: CHANGE_2000

SET OF RULES 04:

OUTPUT_LAYER: **DEFORESTATION**

CLASSES: DEFORESTATION
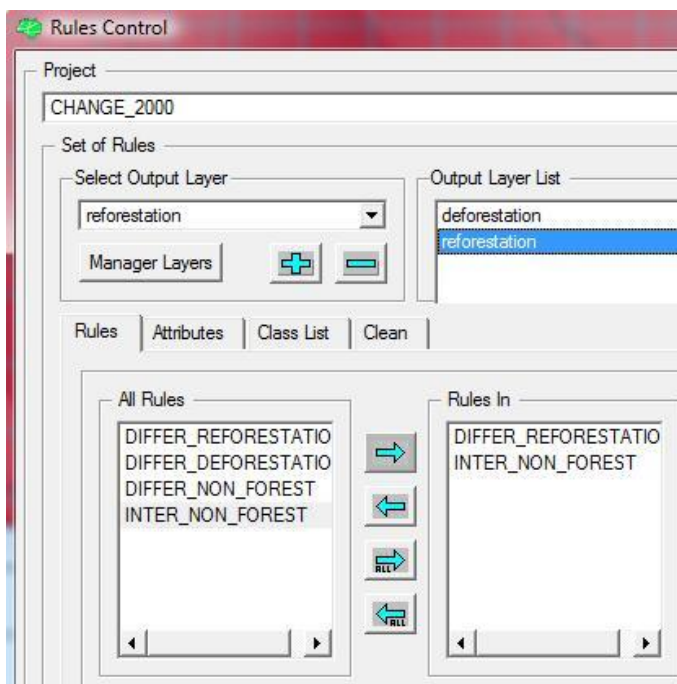
group 1

RULE: DIFF_DEFORESTATION

RULE: CLEAN_DEFORESTATION

group 2

RULE: DIFF_FOREST_RESTORATION

RULE: DIFF_DEGRADATION

group 3

RULE: DIFF_NON_FOREST

RULE: DIFF_CLOUDS

SET OF RULES 05:

OUTPUT_LAYER: **DEGRADATION**

CLASSES: DEGRADATION

group 1

RULE: DIFF_DEGRADATION

RULE: CLEAN_DEGRADATION

group 2

RULE: DIFF_DEFORESTATION

group 3

RULE: DIFF_NON_FOREST

RULE: DIFF_DEGRADED_FOREST

RULE: DIFF_CLOUDS

SET OF RULES 06:

OUTPUT_LAYER: **AFFORESTATION**

CLASSES: AFFORESTATION

group 1

RULE: DIFF_AFFORESTATION

RULE: CLEAN_AFFORESTATION

group 2

RULE: DIFF_REFORESTATION

group 3

RULE: INTER_NON_FOREST

RULE: DIFF_CLOUDS

SET OF RULES 07:

OUTPUT_LAYER: **REFORESTATION**

CLASSES: REFORESTATION

group 1

RULE: DIFF_REFORESTATION

RULE: CLEAN_REFORESTATION

group 2

RULE: DIFF_AFFORESTATION

group 3

RULE: INTER_NON_FOREST

RULE: DIFF_CLOUDS

SET OF RULES 08:

OUTPUT_LAYER: **FOREST_RESTORATION**

CLASSES: FOREST_RESTORATION

group 1

RULE: DIFF_FOREST_RESTORATION

RULE: CLEAN_FOREST_RESTORATION

group 2

RULE: DIFF_DEFORESTATION

group 3

RULE: INTER_DEGRADAD_FOREST

RULE: DIFF_CLOUDS

6.5.16   *Interest Areas Information:*

Area Information is defined by a shapefile containing only one rectangular polygon, covering the whole country.

The administrator can use the same polygon for each project setting the reference date of the period. For instance, for the mask (Mask_1990) it is 1990 although the available dataset is dated from 1988 to 1993.
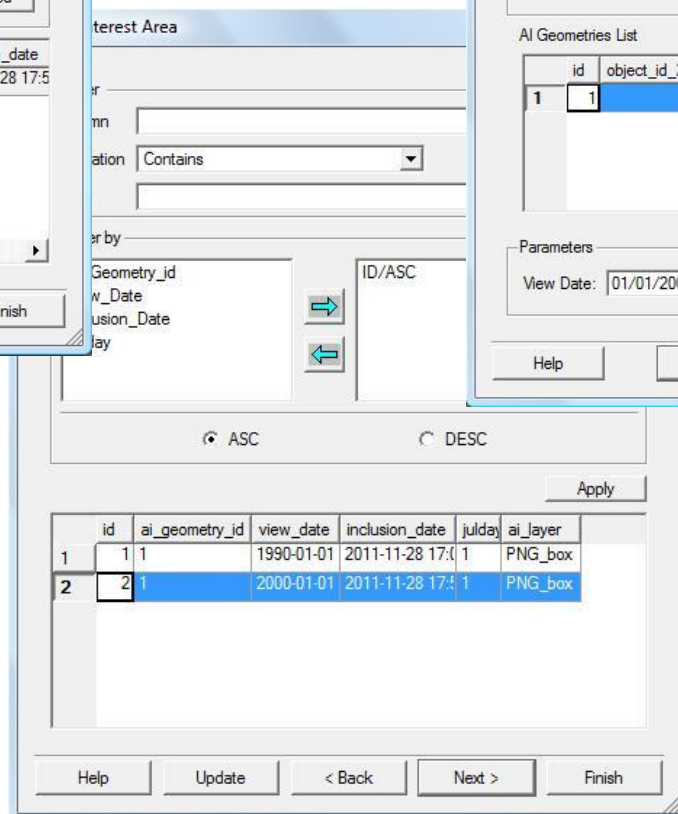
In general it would be better to follow the approach advised at INPE, which for each
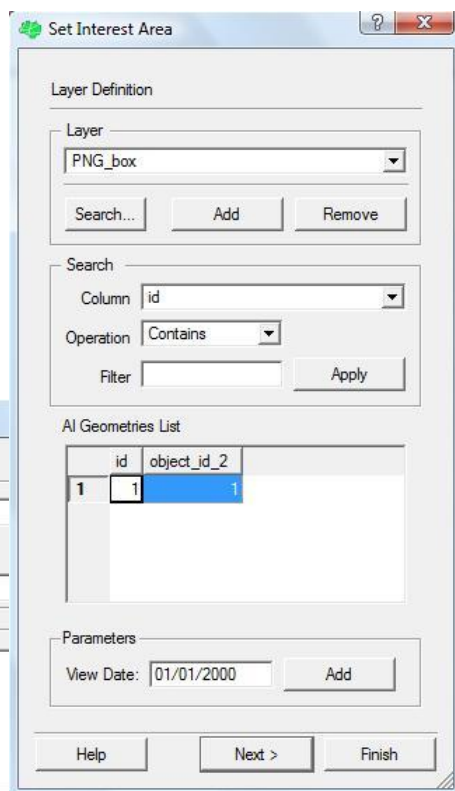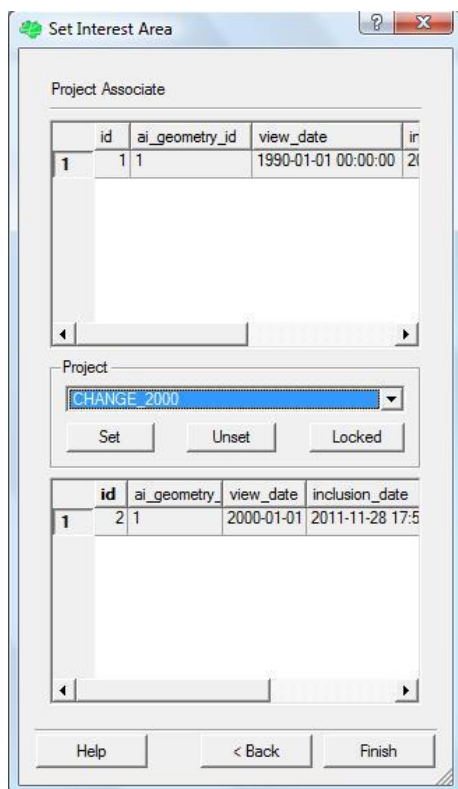
Landsat image used makes use of the corresponding tile polygon and acquisition date.

LAYER:
    PNG_box
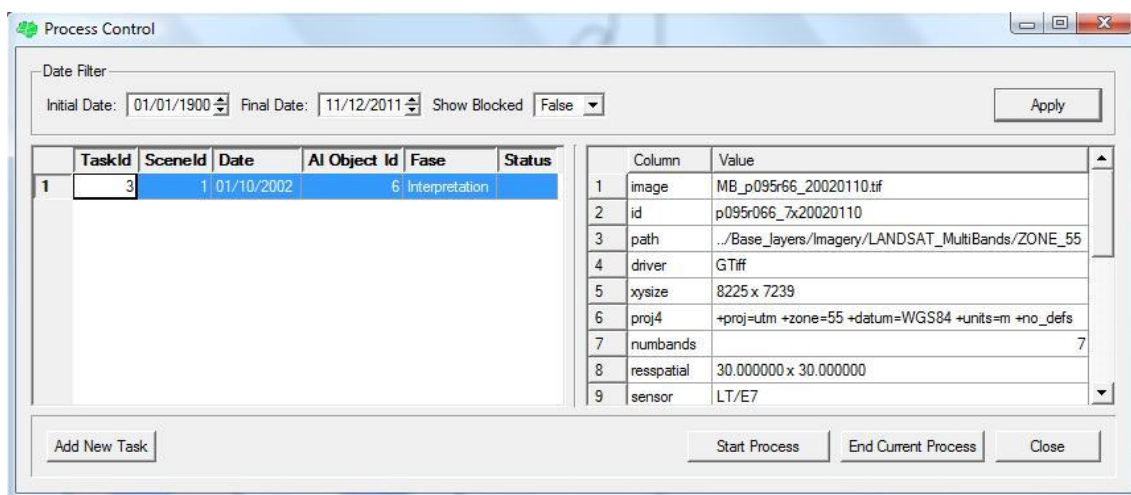
PROJECTION:
    LatLong/WGS84/DecimalDegrees

BOX: LL(x) = 140.00, LL(y) = -12.00, UR(x) = 158.00, UR(y) = 0.00

POLYGONS NUMBER: 1

6.5.17   Create a task

This is the only setting that can be done by users without administrator privileges. It is required to

start editing the draft layer.

Considering that there is only one Interest Area covering the whole country, the users are required to create only one task in order to edit any unlocked cell within the session of one project. In other words one user needs one task for each one of the two projects: MASK_1990 and CHANGE_2000.