4. *Post classification analysis*

The last step in ALUCT is the land cover change analysis itself. Two form of land cover change analysis is conducted for each study site: area- based changes analysis and trajectories analysis, which are conducted under 3 zones/windows: (1) *plantation area*, (2) *plasma area* (if any) and (3) *all area outside plantation and plasma*. The result provided an indication of the overall trend of land cover change in the area and its surrounding. As further information was needed on the location and trajectories of changes, a *Trajectories analysis* formed the next step.

Trajectories of changes are the summary of changes sequence over all time period observed at pixel level. In the context of understanding carbon budget from oil palm plantation, types of trajectories is designed to be able to capture changes in C-stock caused by land cover changes. Trajectories types are classified into 10 classes:

1. Undisturbed forest to logged-over forest to oil palm
2. Logged-over forest-high density to oil palm
3. Logged-over forest-low density to oil palm
4. Undisturbed swamp forest to oil palm
5. Logged-over swamp forest to oil palm
6. Non forest to oil palm
7. Non oil palm-related trajectories
8. Stable forest
9. Stable swamp forest
10. Stable oil palm

Often, for a quick and qualitative references, a publicly available maps such as those provided by Google.Earth (Figure 5) is very useful. As many of the scenes are available in graphic format of high resolution, interpreters also use these as additional data to assist the interpretation, especially if GPS points of groundtruthed data are scarce.

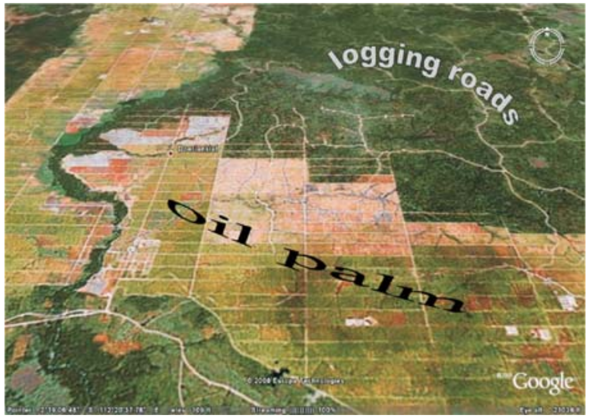


Figure 5. Google.Earth, public domain perspective on how oil palm plantations are spatially and time-wise linked to logging concessions in Kalimantan (Indonesia).

Useful Links and Recommended textbook for Remote Sensing and GIS

http://www.google.com/earth/index.html

http://rst.gsfc.nasa.gov/Front/overview.html (online remote sensing tutorials)

Thomas M. Lillesand, Ralph W. Kiefer, Jonathan W. Chipman. 2004. Remote Sensing and Image Interpretation. 5th Edition. John Wiley and Sons, Inc. U.S.A.

References

Sonya Dewi, Ni'matul Khasanah, Subekti Rahayu, Andree Ekadinata and Meine van Noordwijk. 2009. Carbon Footprint of Indonesian Palm Oil Production: a Pilot Study. http://worldagroforestry.org/sea/publications?do=view_pub_detail&pub_no=LE0153-09

Ekadinata, Andree, Atiek Widayati, and Grégoire Vincent. "Rubber Agroforest Identification Using Object-Based Classification in Bungo District, Jambi Indonesia." Asian Conference on remote Sensing (2004): 551-556.

This flyer is produced by
the TUL-SEA Project
funded by the Federal Ministry for Economic
Cooperation and Development, Germany

World Agroforestry Centre
Federal Ministry for Economic Cooperation and Development

Contacts:
TUL-SEA Project
WORLD AGROFORESTRY CENTRE
ICRAF Southeast Asia Regional Office
Jl CIFOR, Situ Gede, Sindang Barang, Bogor 16115
PO Box 161 Bogor 16001, Indonesia
Tel: +62 251 8625415
Fax: +62 251 8625416
E-mail: icraf-indonesia@cgiar.org
http://www.worldagroforestrycentre.org/sea

Credits:
Authors: Sonya Dewi and Andree Ekadinata
Design and Layout: Diah Wulandari

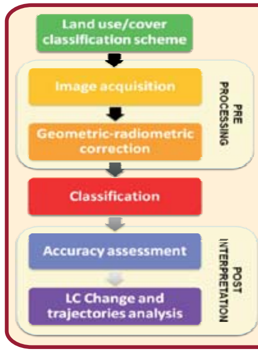
ALUCT: Analysis of Land Use and Cover Trajectory

Trees in Multi-Use Landscape in Southeast Asia (TUL-SEA)
A negotiation support toolbox for Integrated Natural Resource Management

Reconciling the top-down view from satellites with the bottom-up perspective of farmers

Landscape representation, in this case of the format of the land use and cover map, is important base information for sustainable landscape planning. The map can be derived from multi-spectral reflectance of earth surface recorded from the satellite- or airborne- sensors, supported by other ground information of spatial patterns and processes. Different interpreters may come up with different maps out of the same satellite imageries as choices of legend categories of land use/cover maps are infinite.

Land use/cover mapping and analysis of land use/cover trajectories (ALUCT) are important parts of several of the TUL-SEA Tools, including the RaCSA, RHA and RABA (rapid appraisal of carbon stocks, hydrology and agrobiodiversity, respectively) methods. It also forms the basis of scenario studies (FALLOW), land tenure claim appraisal (RATA) and analysis of the drivers of land use change (DriLUC).



ALUCT workflow has four stages:

1. Clarification of the questions, leading to the level of detail needed in the legend of land cover types and the resolution of images needed to do so
2. *Image acquisition* and *pre-processing*: Selecting the resolution, spectral properties and source of the images, selecting an image date relevant to the study and of sufficient quality (low cloud cover)
3. *Image classification* based on ground-truth sample points and/or pre-established spatial patterns,
4. *Post interpretation analysis* focused on the research questions of interest, usually linking 'land use' and system life cycles to the land cover types that can be recognized.

Figure 1. ALUCT Work Flow

(1) *Designing legend categories*

In deciding on legend category, one has to consider: (i) the limitation and potential of particular imageries (ii) the ground realities of agents and drivers of land use systems and land use changes, (iii) description of each category of land use/cover, (iv) the application of the produced maps. Often Remote sensing specialist tends to focus on what is doable technically without much consideration of what should be recognized. Classification efforts result in empirical representation only, unguided by any theoretical basis. Legend categories should be designed such that they can reveal differences among categories in providing environmental services, as results of varying drivers, and as perceived by land managers, especially farmers/local people, as integral part of their livelihoods, i.e., local use value.

(2) *Image acquisition and pre-processing*

Time coverage, *spatial resolution*, and *amount of cloud cover* are three main criteria used in selecting the best satellite images for any study. Middle resolution satellite image such as Landsat (30m resolution) and SPOT (20m resolution) are usually used for basic studies, with high resolution imagery, such as IKONOS and RapidEye (<1 m) for specific areas. Coarser resolution, but frequent data acquisition such as SPOT Vegetation, NOAA-AVHRR and MODIS are commonly used for regional and global monitoring of change. In the tropics with high incidence of cloud cover, sometimes a combination of optical and radar imageries is necessary.

(3) *Image classification*

Several option of image classification ranges from visual interpretation, which relies on manual delineation and ground familiarity of the operator, to unsupervised classification, which relies on statistical analysis to differentiate spectral reflectance based on digital numbers only. Between the two extreme approaches, there are gradients and hybrid approaches, such as supervised classification and mixed of object-based and unsupervised classification. There is no one best approach within huge variation of the extent of mapping, resolution of imageries and objectives of the mapping. However, three main principles, regardless of the approaches, should be retained: (i) given the same imageries and legend categories, the resulted maps should not be too different; (ii) using ground information is a must in assessing the accuracy of the maps, (iii) for a map to be useful the accuracy has to be high enough; as a rule of thumb, 80% accuracy should be achieved.

(4) *Post-interpretation analysis*

One a series of maps are produced from multi-year image acquisitions, several analyses can be conducted on them in conjunction with other data layers, such as land use plan, road network, etc.

1. Temporal changes of areas of each land use/cover class, e.g., primary forest cover declines from x ha in 1990 to y in 2000
2. Trajectory of changes of each particular areas in the landscape and areas of each trajectory, e.g., x ha of primary forest in 1990 converted into rubber in 2005 and settlement in 2010
3. Areas of each land use/cover classes within a particular zone, e.g., x ha of oil palm in the protected forest zone in 1990
4. Trajectories of changes within particular zone, e.,g., x ha of secondary forest converted to oil palm in the protected forest zone and y ha in the production forest zone between 1990 to 2000.

Example of ALUCT in a study of oil palm plantations in Indonesia

To analyze the plantation history and associated 'carbon debt' of plantation establishment, the Analysis of Land Use and Cover Trajectory (ALUCT) method was used for two pilot areas in Indonesia on the basis of time series land cover maps produced from satellite images. In the context of understanding carbon debt, the data is required to cover a sufficient time period of before and after plantation establishment. To get a complete picture of the area, it is also necessary to quantify the changes in the plantation's surrounding area. Therefore, three main outputs from the analysis are:

a. Time series land cover maps from covering time period before and after oil palm establishment
b. Land cover change quantification of the estate area and its surrounding
c. Land cover trajectories for the period of analysis.

1. *Designing legend categories*

Main land use/cover types in the study area is identified during groundtruthing for two purposes: designing the legend categories and collecting geo-referenced information of various land cover type in the field, recorded using global positioning system (GPS) receivers. This data serve two purposes, as guidance in image interpretation process and as a reference to calculate accuracy of the land cover map produced.

Legend categories are designed in hierarchy and structured within three levels, from general to finer classes (Figure2). Forest is class is separated further into dry and swamp forest of different density, i.e., undisturbed, logged-over high density and logged-over low density. This separation is important as we know that by lumping varying density of forest, the uncertainty of magnitude of C-stock is huge, which brings a consequences to the conclusion of the study, if not managed properly. The hierarchy itself is designed such as classification process is most efficient.

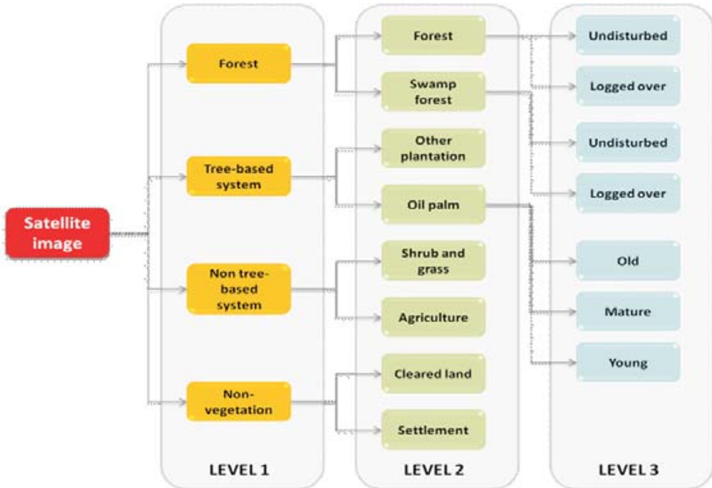


Figure 2. Hierarchical classification structure

2. *Image acquisition and pre-processing*

Geometric distortion in satellite images is rectified using ground control point (GCP) collected from reference datasets. In this case, orthorectified Landsat ETM from United States Geological Survey (USGS) in each study sites is used as reference data. Minimum of 20 GCP were used in geometric correction, ensuring geometric precision of 0.5 pixel (<15m) for all images.

3. *Image classification*

The objective is to produce time series land cover maps through satellite image interpretation. *Object-based hierarchical classification* approach is used in this stage. In this approach, image classification steps begin with a series of image *segmentation* process. The purpose is to produce *image objects*, a group of pixel with a certain level of homogeneity in term of spectral and spatial. Image objects had to be able to represent actual feature on satellite image, therefore several phase of segmentation was conducted to get the required levels of detail. The result of these phases is called *multi-resolution image segments* which serve as a basis for hierarchical classification system. Illustration of segmentation process is showed in Figure 3.

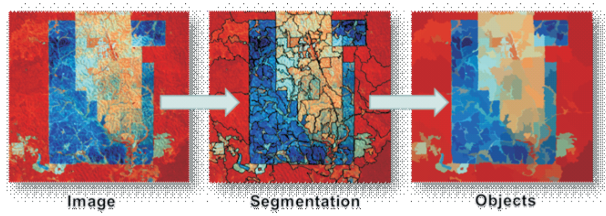


Figure 3. Segmentation process

Following the segmentation process, image classification is conducted using a hierarchical structure developed in step 1. The hierarchy is divided into three levels, where in each level land cover types is interpreted using spectral and spatial rule. Details and complexity of land cover types is increase in each level, therefore each of them has different set of rules applied.

Level 1 consist of general classes such as: *Forest*, *Tree based systems*, *Non tree based systems* and *Non-vegetation*. These classes can be easily distinguished using visual inspections and a simple vegetation index. Vegetation index is a ratio of spectral value between vegetation-sensitive channel (near infra red spectrum) and non vegetation-sensitivechannel (visible spectrum) in satellite image.

The result of *Level 1* is further classified in *Level 2*, using field reference data. A Nearest Neighborhood algorithm is used to distinguished total of 9 land cover types: *forest, swamp forest, oil palm, shrub, grass, agriculture, cleared land*, and *settlement*. Some of the classes in *Level 2* are further classified in more detail in *Level 3*. In this level, spectral value is not the only parameters used, spatial characteristic such as distance to settlement, proximity to visible logging roads, forest concession status, and plantation maps can be used as a rule in classification. Forest is classified into *undisturbed forest*, *logged-over high density*, and *logged-over low density* can be based, beyond the spectral properties, on proximity to observed logging road, forest concession map, and estimated vegetation density derived from vegetation index value. Using the same approach, *Swamp forest* is classified into *undisturbed swamp forest* and *logged-over swamp forest*. *Oil palm* area is classified into *young oil palm*, *mature oil palm* and *old oil palm*. These classes can be considered as a proxy to plantation age, in which the level of canopy cover is differentiated. Mature oil palm approximately relates to the beginning of productive stages, but before the full canopy is reached. The old oil palm relates with the stage where full canopy is reached.

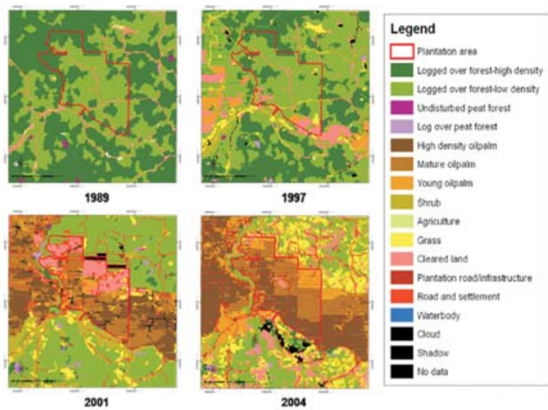


Figure 4. Time series land cover map

Accuracy assessment is conducted by comparing the resulted maps of most recent imagery with the groundthruthed data. The accuracy is assessed for each individual land cover class, and for the entire maps. The assessment is useful should be used to indicate how confident we are about the conclusion drawn from the maps.

TUL-SEA: A negotiation support toolbox for Integrated Natural Resource Management