Negotiation-support toolkit for learning landscapes

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Dewi S and Ekadinata A. 2013. Analysis of land-use and –cover trajectory (ALUCT). *In:* van Noordwijk M, Lusiana B, Leimona B, Dewi S, Wulandari D (eds). *Negotiation-support toolkit for learning landscapes*. Bogor, Indonesia. World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. P.110-117.

18 | Analysis of land-use and -cover trajectory **(ALUCT)**

Sonya Dewi and Andree Ekadinata

Analysis of land-use and -cover trajectory (ALUCT) provides basic spatial information to support other tools in appraising watershed functions, agrobiodiversity conservation and carbon stocks, and building land-use and land-use-change scenarios.

Introduction

Maps representing the landscape have to represent land cover (what is there), land use (what it's used for) or some combination of the two. Land-cover maps can be derived from the multi-spectral reflectance of the Earth's surface recorded from satellite or airborne sensors, supported by ground information of spatial patterns and processes (Thomas et al 2004). A land-use interpretation will generally require further information sources beyond current cover. Different interpreters may come up with different maps from the same satellite imageries because the potential legend categories of land-use/-cover maps are infinite. Figure 18.1 shows multiple concepts of forest leading to differed deforestation rates.

ALUCT plays an important role in several of the tools described in this book, including RaCSA, RHA, RABA, FALLOW, RaTA and DriLUC.

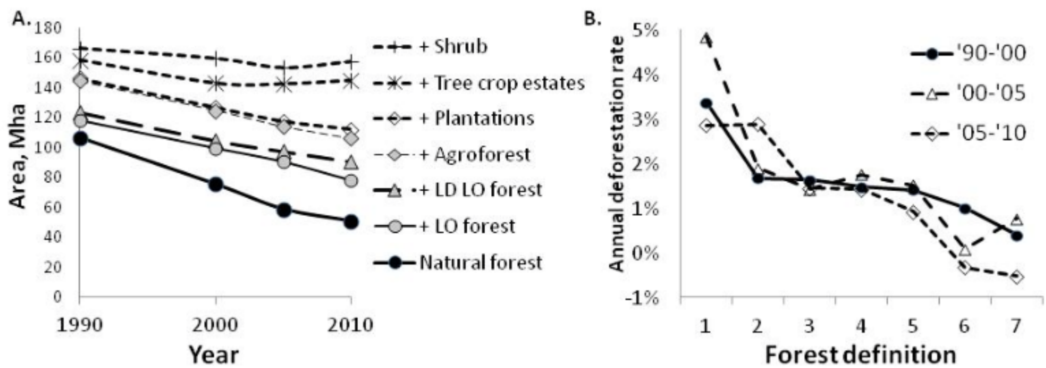

Figure 18.1. Dependence of Indonesia's 'deforestation rate' on the operational definition of forest
Source: van Noordwijk et al 2013

Objectives

The ALUCT procedure was designed to form a systematic approach to spatial analysis, where the intended users of information in interdisciplinary contexts and with science-policy interfaces in mind, interact with the distinctions that can technically be made.

Steps

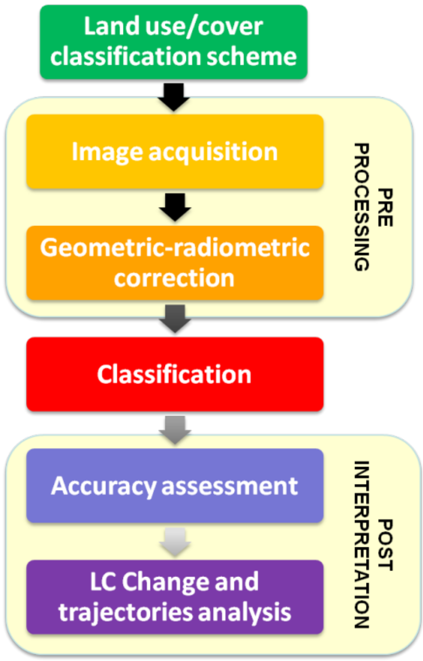

Figure 18.2. The ALUCT workflow

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 field-tested sample points and/or pre-established spatial patterns
4. *Post-interpretation analysis* focussed on the research questions of interest, usually linking 'land use' and system lifecycles to the land-cover types that can be recognized

1. Clarifying the questions: designing legend categories

In deciding on legend categories, the researchers have to consider: 1) the information content and its limitation for specific image sources ; 2) the on-the-ground reality of agents and drivers of land-use systems and land-use changes; 3) the description of each category of land use and land cover; 4) and the application of the produced maps.

Often, remote-sensing specialists tend to focus on what is technically achievable without much consideration of what should be recognized and so classification efforts result in empirical representation only, unguided by any theoretical basis. To avoid this, 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 and local people, as an integral part of their livelihoods, that is, local use value. Figure 18.3 provides an example of legend categories in the context of measuring GHG emissions of oil palm plantations in Indonesia. For this purpose, the researchers specified the oil palm categories: old, mature and young.

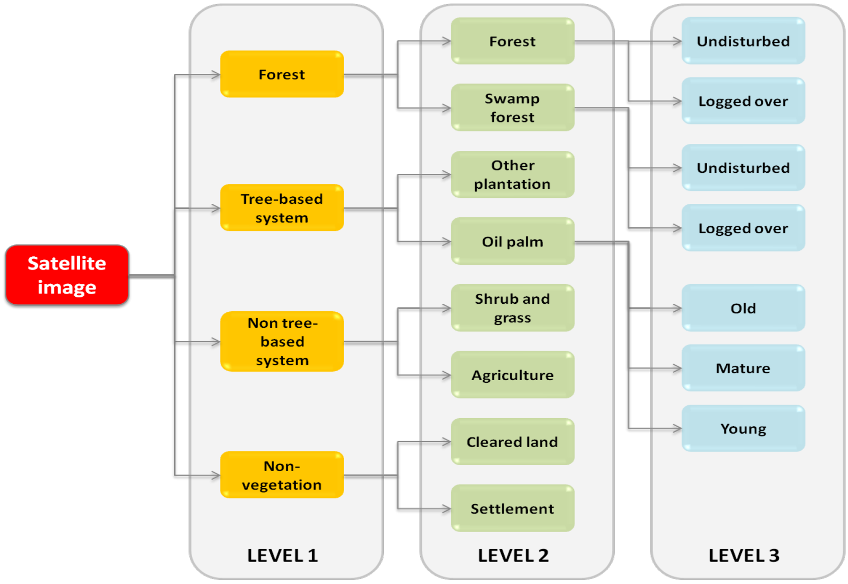

Figure 18.3. Land-use-system legend categories in a hierarchical classification structure

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 images, such as Landsat (30 m resolution) and SPOT (20 m resolution) are usually used for basic studies (Figure 18.4), 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 changes. In the tropics with high incidence of cloud cover, sometimes a combination of optical and radar imageries is necessary.

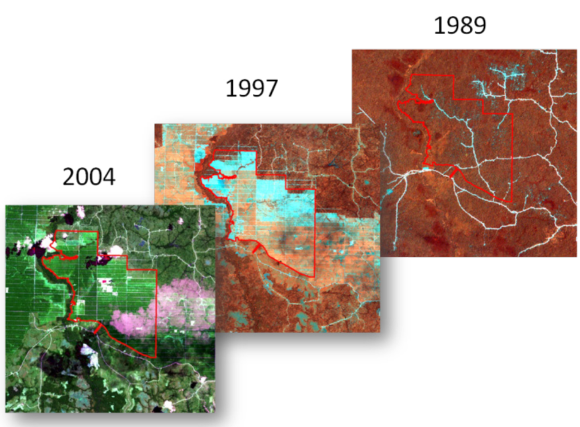

Figure 18.4. Time-series Landsat image

3. Image classification

There are several options for image classification, ranging from visual interpretation, which relies on manual delineation and ground familiarity of the operator, through to unsupervised classification, which uses 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 a mix of object-based and unsupervised classification. There is no one best approach within the huge variation involved with mapping, resolution of imageries and objectives of the mapping. However, three main principles, regardless of the approaches, should be observed: 1) given the same imageries and legend categories, the resulting maps should not be too different; 2) using ground information is a 'must' in assessing the accuracy of the maps; 3) 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

Once a series of maps is produced from multi-year image acquisitions, several analyses can be conducted in conjunction with other data layers, such as land-use plans and road network:

1. temporal changes of areas of each land-use and land-cover class, for example, primary forest cover declines from x hectares in 1990 to y in 2000;
2. trajectories of changes of each particular area in the landscape and areas of each trajectory, for example, x hectares of primary forests in 1990 converted into rubber plantations in 2005 and settlements in 2010;
3. areas of each land-use and land-cover class within a particular zone, for example, x hectares of oil-palm in the protected forest zone in 1990;
4. trajectories of changes within particular zones, for example, x hectares of secondary forests converted to oil-palm plantations in the protected forest zone and y hectares in the production forest zone between 1990 and 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, ALUCT was deployed in two pilot areas in Indonesia using time-series, land-cover maps from satellite images. In the context of understanding carbon debt, data was required to cover a sufficient time period of before and after plantation establishment. To get a complete picture of the area, it was also necessary to quantify the changes in the plantation's surrounding area. Therefore, three main outputs from the analysis were:

1. time-series, land-cover maps covering the period before and after oil-palm establishment;
2. land-cover-change quantification of the estate area and its surroundings; and
3. land-cover trajectories for the period of analysis.

Legend categories were designed in a hierarchy and structured within three levels, from general to finer classes (Figure 18.3). 'Forest' as a class was separated further into 'dry' and 'swamp' forest of different density, that is, 'undisturbed', 'logged-over high density' and 'logged-over low density'. This separation is important as we know that by lumping together varying densities of forests the uncertainty of magnitude of carbon stock is huge, which has consequences for the conclusion of the study if not managed properly. The hierarchy itself was designed such that the classification process was most efficient. Time-series, orthorectified, Landsat images covering the periods 1989, 1997, 2001 and 2004 were used to produce the land-cover maps (Figure 18.4).

The object-based hierarchical classification approach (Ekadinata and Vincent 2011) was used at the stage of image classification. In this approach, image classification began with a series of image segmentations. The result is called multiresolution image segments, which serve as a basis for the hierarchical classification system (Figure 18.5).

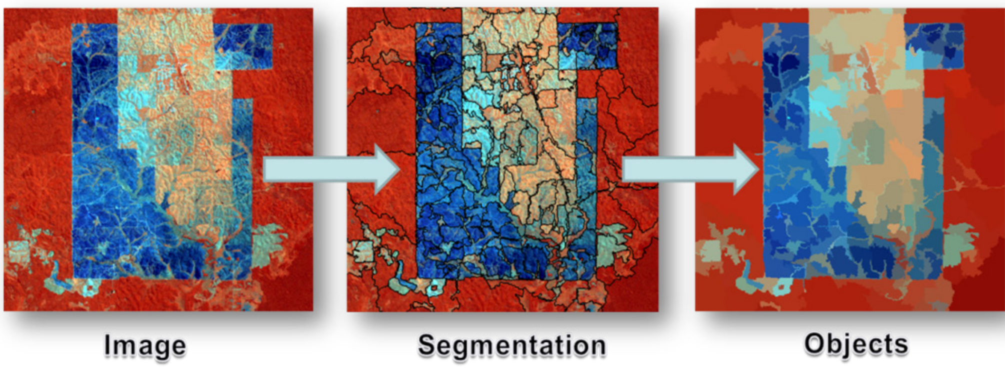

Figure 18.5. Multiresolution image segments

Following the segmentation process, image classification was conducted using the hierarchical structure developed in Step 1. The hierarchy is divided into three levels. At each level, land-cover types were interpreted using spectral and spatial rules. Level 1 consisted of general classes, such as 'forest', 'tree-based systems', 'non-tree-based systems' and 'non-vegetation'. These classes could be easily distinguished using visual inspections and a simple vegetation index. The result of Level 1 was further classified in Level 2, using field reference data. A 'nearest neighborhood' algorithm was used to distinguished a total of nine land-cover types: 'forest', 'swamp forest', 'oil palm', 'shrub', 'grass', 'agriculture', 'cleared land' and 'settlement'. Some of the classes in Level 2 were further classified in more detail in Level 3. At this level, spectral value was not the only parameter used. Spatial characteristics, such as distance to settlement, proximity to visible logging roads, forest concession status, and plantation maps could be used as rules in the classification. At the end of the classification process, an accuracy assessment was conducted by comparing the resulting maps of most recent imagery with the data collected in the field.

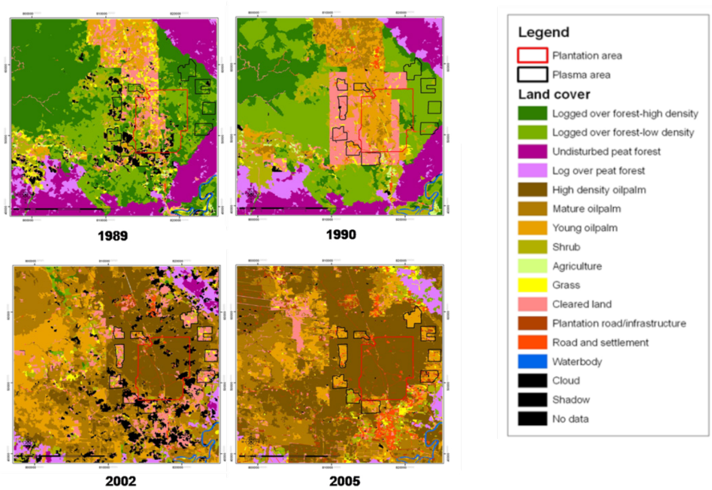

Figure 18.6. Time-series, land-cover map

The last step in ALUCT is the land-cover-change analysis itself. Two forms of analysis were conducted for each study site: area-based-change and trajectories. These were conducted for three zones: 1) plantation areas; 2) plasma[1] areas (if any); and 3) all areas outside plantation and plasma. The result provided an indication of the overall trend of land-cover changes in an area and its surrounding.

Further information was needed on the location and trajectories of changes, so a trajectories analysis formed the next step. Trajectories of changes are the summaries of a change sequence over all time periods, observed at pixel level (Figure 18.7 and 8). In the context of understanding the carbon budget for oil-palm plantations, types of trajectories were designed to be able to capture changes in carbon stock caused by land-cover changes.

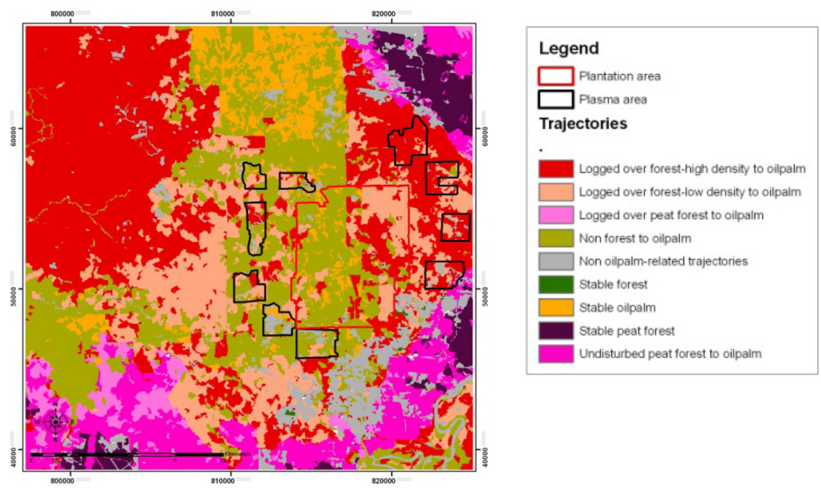

Figure 18.7. Trajectories map

[1] 'Plasma' in this context describes a scheme whereby a large plantation forms a 'nucleus' around which there are smallholding plantations, the 'plasma'.

The trajectories map showed all oil-palm-related sequences of changes, the locations and spatial patterns in the study area. Trajectories analysis clearly showed that more than 40% of conversions inside plantation areas started from logged-over forest. Nearly half were in the high-density, logged-over forest areas.

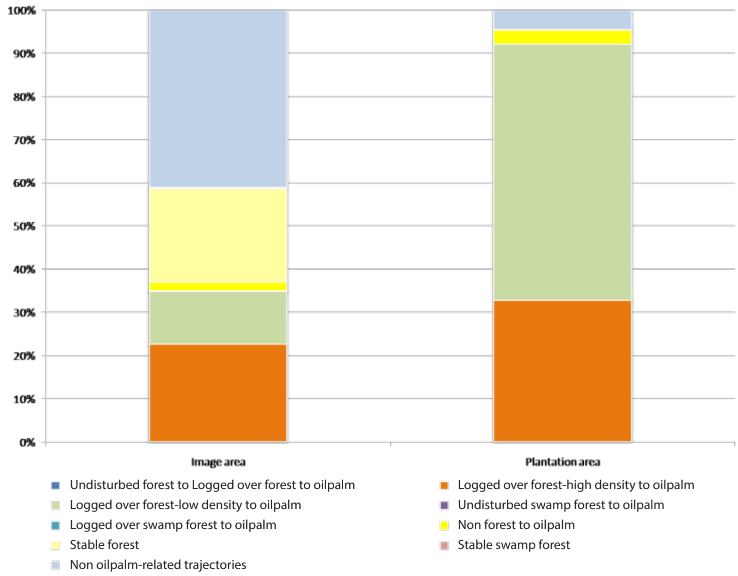

Figure 18.8. Summary of trajectories analysis

Often, for quick and qualitative references, publicly available maps, such as those provided by Google Earth, are very useful (Figure 18.9). As many of the scenes are available in graphic format of high resolution, interpreters also use these as additional data to assist interpretation, especially if GPS points of data in the field are scarce.

Figure 18.9. Google Earth: a public-domain perspective on how oil-palm plantations are spatially and chronologically linked to logging concessions in Kalimantan, Indonesia

Key references

Dewi S, Khasanah N, Rahayu S, Ekadinata A, van Noordwijk M. 2009. *Carbon footprint of Indonesian palm oil production: a pilot study*. Bogor, Indonesia:World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. http://worldagroforestry.org/sea/publications?do=view_pub_detail&pub_no=LE0153-09.

Hairiah K, Dewi S, Agus F, Velarde SJ, Ekadinata A, Rahayu S, van Noordwijk M. 2011. *Measuring carbon stocks across land use systems: a manual*. Bogor, Indonesia:World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

Useful websites

http://www.google.com/earth/index.html
http://rst.gsfc.nasa.gov/Front/overview.html (online remote-sensing tutorials)

The landscape scale is a meeting point for bottom–up local initiatives to secure and improve livelihoods from agriculture, agroforestry and forest management, and top–down concerns and incentives related to planetary boundaries to human resource use.

Sustainable development goals require a substantial change of direction from the past when economic growth was usually accompanied by environmental degradation, with the increase of atmospheric greenhouse gasses as a symptom, but also as an issue that needs to be managed as such.

In landscapes around the world, active learning takes place with experiments that involve changes in technology, farming systems, value chains, livelihoods' strategies and institutions. An overarching hypothesis that is being tested is:

> Investment in institutionalising rewards for the environmental services that are provided by multifunctional landscapes with trees is a cost-effective and fair way to reduce vulnerability of rural livelihoods to climate change and to avoid larger costs of specific 'adaptation' while enhancing carbon stocks in the landscape.

Such changes can't come overnight. A complex process of negotiations among stakeholders is usually needed. The divergence of knowledge and claims to knowledge is a major hurdle in the negotiation process.

The collection of tools—methods, approaches and computer models—presented here was shaped by over a decade of involvement in supporting such negotiations in landscapes where a lot is at stake. The tools are meant to support further learning and effectively sharing experience towards smarter landscape management.

World Agroforestry Centre
ASB Partnership for the Tropical Forest Margins
AARD
Federal Ministry for Economic Cooperation and Development
Norad
IFAD
Enabling poor rural people to overcome poverty
CGIAR
Research Program on Forests, Trees, and Agroforestry