

Landscape Dynamics Over Time and Space From Ecological Perspective

Sonya Dewi and Andree Ekadinata

Southeast Asia



World Agroforestry Centre
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Abstract

Land use and land cover changes driven by multiple factors have tremendous impact on environmental services as well as livelihoods and economic development of people living in the landscapes and external to the landscapes. In particular for biodiversity, landscape configuration is at the very least as important as landscape composition by increasing fragmentation and reducing connectivity of habitat. Protected areas are necessary but not sufficient in maintaining biodiversity at the landscape level for several reasons: (i) management and enforcement are often weak, (ii) protected areas are often delineated in remote, rough terrain areas which does not represent various ecoregions with various species assemblages and endemism, (iii) the extent of protected areas sometimes are not large enough to allow minimum viable population such that in the long run species extinction might continue to happen, (iv) protected areas without buffer zones and corridors can easily be isolated areas rather than integral part of a landscape. Multifunctional landscapes that accommodate conservation and development need to be considered as an integrated, rather than segregation, systems; this will allow us to achieve the objective of maintaining biodiversity at the landscape level. Land use plan that aims to increase multifunctionality of landscapes should be informed by the current status of landscape composition and configuration, process of land use/cover changes in the past and future, areas that are vulnerable to changes in the future and options for intervention. The land use planning process should be conducted within a negotiation process among multiple stakeholders. This work provides some results to be used as a basis for negotiation, which are produced from the combination of tools from remote sensing, GIS and spatial analysis guided by ecological principles. The results provide data for further research as well as suggest follow-up research questions.

These analysis of five landscapes (Bungo in Indonesia, Viengkham in Laos, Manompana in Madagascar, Takamanda-Mone in Cameroon and East Usambara in Tanzania) using the same methodology and tool allows comparisons across sites. Deforestation rates and land use/cover changes across landscapes along with land use/cover changes are used to define the stage of forest transition; Takamanda-Mone, Viengkham, Manompana, East Usambara and Bungo is the ordered list from earliest to advanced stages. Spatial pattern of deforestation, depending on landscape topography, level of accessibilities and state of forest transition, either are concentrated in relatively flat areas in the landscape, follow encroachment pattern of primary forest block, along the transportation network, or expansion of existing settlement. Combining these spatial patterns of deforestation with changes in landscape configuration, especially at sub-landscape level (quantified by selected indices), we can identify vulnerable areas in the future such that options to reduce risks can be discussed and negotiated within land use planning processes.

Keywords

Landscape composition, configuration, matrix, connectivity, fragmentation, drivers of land use changes, multifunctional landscapes

Acknowledgements

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Introduction

Loss of habitat and fragmentation of habitat due to agricultural expansion are the primary causes of biodiversity loss across the planet (Sala et al., 2000, Tilman et al., 1994, Tilman et al., 2001, and Gardner et al., 2009). Fragmentation even leads to further biodiversity loss through time-delayed extinctions, or extinction debts, and co-extinctions (Krauss et al., 2010). Under extinction debt, loss of biodiversity is better explained by the history of land use/cover characteristics rather than the current ones (Kuusari et al., 2010). The very first large-scale evidence of extinction debts of vascular plants in fragmented European semi-natural grassland landscapes and co-extinction of specialized herbivory (Krauss et al., 2010) highlights the importance to take act now in halting fragmentation and inducing connectivity to avoid greater loss of biodiversity in the distant future, beyond the immediate loss (Lindenmayer et al. 2008; Krauss, et al., 2010). Meta-analysis on impacts of fragmentation on biodiversity is scarce and one has to include spatial variability and spatial dimension, therefore integrating traditional statistical analysis with spatial analysis in drawing conclusions (Ewers et al., 2010). Due to lack of long term and large-scale biodiversity data of tropical landscapes (Collen et al., 2008), such comparable evidences of extinction debt and meta-analysis of fragmentation impacts on tree diversity cannot be conducted for tropical landscapes.

The potential roles of agroforestry with regards to biodiversity conservations are understood better recently, as refugia habitat of biodiversity, as matrix to connect nature reserves, to reduce pressure to natural ecosystem, to reducing risk of alien invasive species and by farmer planting to enrichment valuable species in multifunctional landscapes (Bhagwat et al., 2008, McNeely and Schroth, 2006, Swallow and Boffa, 2006, van Noordwijk, 2006). Review of literatures comparing richness and similarities between species of birds, insects, reptiles, mammals and plants in 69 agroforestry systems across 14 countries found that species richness in agroforestry system ranges from 39-61% of forest while similarities range from 25-69% (91% of the cases show 39-61% similarities) (Bhagwat et al., 2008). Agroforestry system is also shown to maintain below ground biodiversity (Giller et al, 2005). Yet, most species shared between agorforest and forest is habitat generalists (Uezu, 2008, for birds in agroforest woodlots of Brazil; O'Connor, 2005, for birds in coffee agroforest of Indonesia; Rasnovi, 2005, for trees in rubber agrofrest of Indonesia). Distance to forest, configuration of landscape, age of agroforestry plots, intensity of management, canopy density of the agroforest determine the richness and similarities of biodiversity of an agroforest plot with natural forests. Agroforest could not and should not replace natural forest; its roles is optimum when is situated in the middle ground zone within the multifunctional landscape where trade-offs between conservation and development are necessary. The understanding of ecological processes underlines the importance of connectivity in designing conservation at the landscape level (Koh et al., 2009).

Biodiversity studies in a multifunctional landscape need to consider the dynamics of land cover and land uses over space in order to understand the changes in states, the threat and opportunities for interventions to maintain biodiversity. Composition and configuration of a landscape mosaicked by various land use and land cover, along with biophysical and

ecological consideration, should be addressed in assessing/evaluating biodiversity in a (fragmented) landscape, both at global and local landscape level.

In most tropical landscapes, however, landscapes are also very dynamic temporally. The pattern and location of changes are rarely random. Drivers of land cover patterns and changes determine the extent, pattern and location of changes. Drivers can also change rapidly due to changes in infrastructure, policies, economies (local to global) and increasing extreme climatic events. Some changes are part of a long cycle within particular land-use systems and some are 'permanent'. For instance, shrub cover might be part of a shifting cultivation cycle while changes from forest to plantation are more permanent.

A landscape is a manifestation of direct, local livelihood driving factors, and indirect land use drivers. Land use and cover changes affect biodiversity indirectly through habitat changes (habitat loss and changes in micro- and global-climate) by changing landscape composition and connectivity by altering landscape configuration. In addition, livelihood activities might also affect biodiversity directly through extraction and management (hunting, harvesting and selective weeding).

Understanding the interaction between landscape dynamics over time and space is of immense importance since it will enable us to identify the location of (past and future) hotspots of threats to biodiversity in the landscape, drivers associated to those, and opportunities in addressing those including scenarios or options for intervention. Whilst many of the issues are location specific, the tropics share common governance and livelihoods issues and therefore cross-learning from different places will hopefully speed up awareness raising and the ability to respond to the urgent need of addressing biodiversity and livelihoods in integrative manner.

The complexities of interaction between livelihoods and ecological processes are not easily understood, while rapid changes on the ground continue to take place. A relatively quick approach to study the dynamics and interactions is therefore needed to address the issue. Data collection is expensive and time consuming. Remotely sensed data offer an extensive spatial and temporal coverage that are invaluable as proxies of some ecological factors and means of extrapolation. Maps are a universal way to capture spatial variabilities and can be effective tools in communicating results to decision-makers as well as negotiating interventions to achieve common agenda among multiple stakeholders.

Further, spatial analysis can derive indices to quantify patterns of composition and configuration of patches in an image. Unfortunately, the theoretical understanding to make explicit links between patterns and ecological processes in interpreting the indices are seriously lacking. In addition, livelihoods are an inherent part of the system that are often missing or simplified in the analyses. Land use/cover changes are predominately resulted from livelihood and economic driven processes. These changes are detectable from remote sensing and some drivers can be made spatially explicit via geographical information systems. Whilst the elements of livelihood activities and strategies that affect biodiversity directly can only be studied through on-the-ground surveys, a quick discussion (participatory mapping) can help to formulate hypotheses about the intensity of uses. By using proxies such as distance to settlement, road etc. some "map-able" activities that directly affect biodiversity in correlation to land cover/use types can be inferred. Therefore even though the overall

ecological processes affected by livelihoods and other economic drivers cannot be covered in high detail, an understanding at the coarse level, sufficient for landscape scale, can be derived.

Such a study will also be species-specific in terms of 'functional' landscape indices otherwise they will be quantifications of structural physical patterns only. In this study, we are focusing on tree species diversity. Traversability is inferred through dispersal agent, mode and range.

This report will address landscape dynamics over time and space with explicit links to the interface between livelihood and biodiversity in 5 study areas of the project: Bungo (Indonesia), Viengkham (Laos), Manompana (Madagascar), Takamanda-Mone (Cameroon) and East Usambara (Tanzania). General descriptions of sites are provided in the project documentation. The report is structured as follows:

- Landscape dynamics over time: quantification, pattern, location, drivers, global landscape composition and configuration (5 sites and comparison)
- Landscape dynamics over space: connectivity, hotspots of threat (local landscape composition and configuration) (5 sites and comparison)
- Landscape dynamics over time and space: changes in connectivity, hotspots of threats (changes in local landscape composition and configuration) (5 sites and comparison)
- Synthesis of comparison among the 5 sites

This interim report is written based on progress we achieve so far. There are still gaps in data and analysis to be filled. In the end of the report, we list some steps to be completed later during the project. Due to varying degrees of familiarity of the spatial analysis team to the reality on the ground in the 5 sites (only Bungo site was rigorously visited and studied by the spatial analysis team), the interpretation and discussion are not uniform in terms of details and accuracy.

Materials and Methods

Within this report, the time reference is categorized into three time periods in order to simplify discussion per site and sites (Table 1). Land cover maps are derived from the satellite imagery interpretation using object-based image analysis under hierarchical classification. We used Definiens software for the remote sensing analysis.

Dynamics in land cover/use over time and space are captured both using area-based (non-spatially explicit) analysis and location-based (spatially explicit) analysis. Visualization and simple statistical analysis are used to describe the change patterns. Drivers over time and space are inferred from the understanding of the dominant processes of land use and land cover changes in the landscape and also from spatial analysis using several spatially-explicit proxies, like roads, rivers, settlements, concession boundaries, spatial plans and also patterns of past deforestation and changes.

Spatial dynamics with regards to biodiversity were quantified through local and global indices using FRAGSTAT software (McGarigal and Marks, 1995). Changes in the indices over time were used to infer the changes in spatial dynamics over time. Superimposition and visual interpretation were used to identify hotspots of threat and drivers associated to that.

Table 1. Periods of analysis based on satellite image availabilities.

No	Site	# Time series	Time series		
			Period I (earlier than 1990's)	Period II (1990's- 2000's)	Period III (2000's - 2007)
1	Indonesia	7	1973, 1988	1993, 1999	2002, 2005, 2007
2	Laos	2			2002, 2007
3	Madagascar	3	1990		2004, 2005
4	Cameroon	6	1986, 1990		2001, 2002, 2004, 2005
5	Tanzania	4	1992	2000	2006, 2007

Materials

Multiple types of sensor and resolution of remote sensing data were used in this study. Most of the historical datasets were captured by Landsat sensors. The sensor resolutions range from 79m (Multipectral scanner/MSS) to 30m (Thematic Mapper/Enhanced Thematic Mapper-TM/ETM). Most recent imageries were captured by SPOT sensor. The resolution is 10 m for multispectral channel and 2.5 m for panchromatic channel. Table 2 showed the complete list of dataset used in this study.

Landscape dynamics over time

Landscape dynamics over time were assessed by conducting independent classification and land cover change analysis for each site. The main objective of this particular phase was to produce time series land cover maps covering the three time periods and gather information regarding the dynamics of the landscape. Using Landsat and SPOT imageries as primary datasets, the classification was conducted using object based-hierarchical classification approach using Definiens software, while land cover change analysis was conducted using

post-classification comparison approach with ArcGIS. Accuracy assessment should be the last steps taken to ensure the quality of information produced by image classification. However, at this stage due to the non-availability of groundtruthed data in most sites, the accuracy has not been calculated yet.

At this stage, we use level two of our classification hierarchy, which comprises the following land cover types:

- Forest: natural forest at various levels of quality;
- Tree-based cover: monoculture and agroforest (mixed, multistrata trees);
- Non-tree based cover: vegetation cover but not dominated by trees, e.g., cropland, imperata, shrubs (young natural re-growth);
- Non-vegetation cover: cleared land; and
- Settlement: cleared land with physical man-made buildings on top.

In this report, for land cover changes analysis, all dataset were re-sampled into 30x30m pixel size, despite of the variation in spatial resolution of Landsat and SPOT imageries. Change analysis are then conducted post-classification and resampling, i.e., by overlaying pairwise of land use/cover maps of different time periods and cross-tabulating the two for location-based change analysis or simply by quantifying the area of each land use/cover class in each time period and comparing those across different time period for area-based change analysis.

These analyses capture the landscape composition and changes in landscape composition over time. The analysis of landscape configuration derives heavily from FRAGSTAT, both in theories and in technical aspects. Interested readers are recommended to consult FRAGSTAT background materials (McGarigal and Marks, 1995). For landscape configuration analysis, due to the extensive computing requirement, we resampled the maps to a 1 ha pixel size.

Table 2. List of materials used for this interim report (additional images will be used in the near future, especially for Laos and Madagascar)

No	Site name	Country	Time series	Sensor	Resolution
1	Bungo	Indonesia	1973	MSS	79m
			1988	TM	30m
			1993	TM	30m
			1999	TM	30m
			2002	ETM	30m
			2005	ETM-SLC off	30m
			2006	SPOT 5	10m/2.5m
2	Viengkham	Laos	2005	ETM-SLC off	30m
			2007	SPOT 5	10m/2.5m
3	Manompana	Madagascar	1990	ETM	30m
			2005	ETM-SLC off	30m
			2007	SPOT 5	10m/2.5m
4	Takamanda Mone	Cameroon	1986	TM	30m
			1990	TM	30m
			2001	ETM	30m
			2002	ETM	30m
			2004	SPOT 5	10m/2.5m
			2005	ETM-SLC off	30m
5	East Usambara	Tanzania	1992	TM	30m
			2000	TM	30m
			2006	ETM-SLC off	30m
			2007	SPOT 5	10m/2.5m

We use FRAGSTAT software to calculate some landscape and class indices for pattern quantification. We selected a few indices only among extensive number of indices made available by FRAGSTAT based on the uniqueness of information expressed by the indices since many indices highly correlate to each other and on the relevancies to ecological processes. In this interim report we will only present a few of the indices. We will cover both structural and functional indices and run the analysis both at the global and local (sub-landscape level). Global level indices are calculated for the entire landscapes while the local level indices are calculated based on a specified window sizes.

Modified Simpson's Diversity and Evenness indices are used to capture landscape composition while Total core area, Aggregation Index and Connectivity Index measures landscape configuration, with Connectivity Index reflects the ecological functions of connecting one habitat to another from species' perspectives.

- Modified Simpson's Diversity Index measures the proportional abundance of each patch type. When the landscape contains only 1 patch (i.e., no diversity), the index is equal to 0. It increases as the number of different patch types increases and the proportional distribution of area among patch types becomes more equitable.

- Modified Simpson’s Evenness Index measures the proportional abundance of each patch divided by the total number of patch types. It is equal to 0 when h (i.e., no diversity) and equals 1 when distribution of area among patch types is perfectly even (i.e., proportional abundances are the same).
- Total Core area is the sum of the core areas of each patch, which is calculated, based on specified depth-of-edge distance(s) from the patch perimeters. Total Core area considers the reduction in the area by the encroachment from the edge at a specified depth; as patch shapes are more complicated and patch perimeters are longer, the differences between total area and total core area are larger.
- Aggregation Index measures the likeliness of patches of corresponding classes to be adjacent to each other.
- Connectivity Index measures the functional joining between all patches of the corresponding patch type based on defined similarity.

Further description of the indices can be found in the FRAGSTAT manual and user guides. These indices are calculated at the global (across the entire dataset) landscape; one landscape has one value of these indices attached to it under the same set of parameters. Changes in landscape over time and differences in patterns across landscapes of different places can be studied by comparing these values. Some of these indices are normalized such that they are not sensitive to sizes of landscapes to allow direct comparison of landscapes with varying extents..

We use the same parameters across landscapes of 5 study sites, as follows:

Edge depth:

Land cover type	Forest	Tree-based	Non-tree-based	Non-vegetation
Forest	0	200	100	100
Tree-based	0	0	200	100
Non-tree-based	0	0	0	100
Non-vegetation	0	0	0	0

Similarity:

Land cover type	Forest	Tree-based	Non-tree-based	Non-vegetation
Forest	1	0.8	0.2	0
Tree-based	0.8	1	0.3	0
Non-tree-based	0	0.3	1	0.1
Non-vegetation	0.3	0	0.1	1

Edge weight

Land cover type	Forest	Tree-based	Non-tree-based	Non-vegetation
Forest	0	0.3	0.8	1
Tree-based	0.3	0	0.5	0.8
Non-tree-based	0.8	0.5	0	0.3
Non-vegetation	1	0.8	0.3	0

Edge depth parameter assumes that the encroachment to forest by tree-based is 200 meters while non-tree and non-vegetation are half of that of tree-based. Similarity parameter assumes that tree-based is 80% similar to forest, while non-tree is only 20%. The edge weight assumes dissimilarity of tree-based and forest is 30% while non-tree is 80%. These parameters are at this moment solely based on expert judgment and will be evaluated against field data later.

Landscape dynamics over space

The landscape indices above are derived with the assumption that only the overall patterns at the landscape level matter, while variations within a landscape can be neglected. However, for a large enough landscape and for small body sized species or species that only forage or disperse narrowly, local variations in sub-landscape level are at least as important and therefore quantifying patterns locally over a landscape space is crucial. The direct application might be the hotspot and threat location identification for land use planning.

We use a circular moving window of radius 1000 m to define a sub-landscape of such size and calculate several indices that reflect composition and configuration within the sub-landscapes. These computations require extensive processing power especially for large landscape, high resolution maps and a large number of classes/land cover types. Re-sampling from the original resolution to a coarser resolution is needed for these computations due to hardware limitations. The parameters we use for calculating local composition and configuration indices are the same as those for global ones. The outputs are presented as a series of maps; each pixel represents the value of the indices of the sub-landscape, calculated within a circle of 1 km radius around it.

Landscape dynamics over time and space

In this report the comparison across time and space and among landscapes will only be presented through the series of maps. The output at this stage will be useful for the practical uses of focus group discussion and visioning and as the basis of further exploration using different sets of parameters. Further, these results will be analyzed and summarized under the what-if scenario and projections of land use/cover changes.

Results and discussions

Landscape dynamics over time

This section describes the current land cover, temporal change, location change and drivers of each landscape, and then discusses them across landscapes. Description of global landscape composition and configuration of landscapes over time will also be presented.

Indonesia (Bungo)

Topography and current land cover

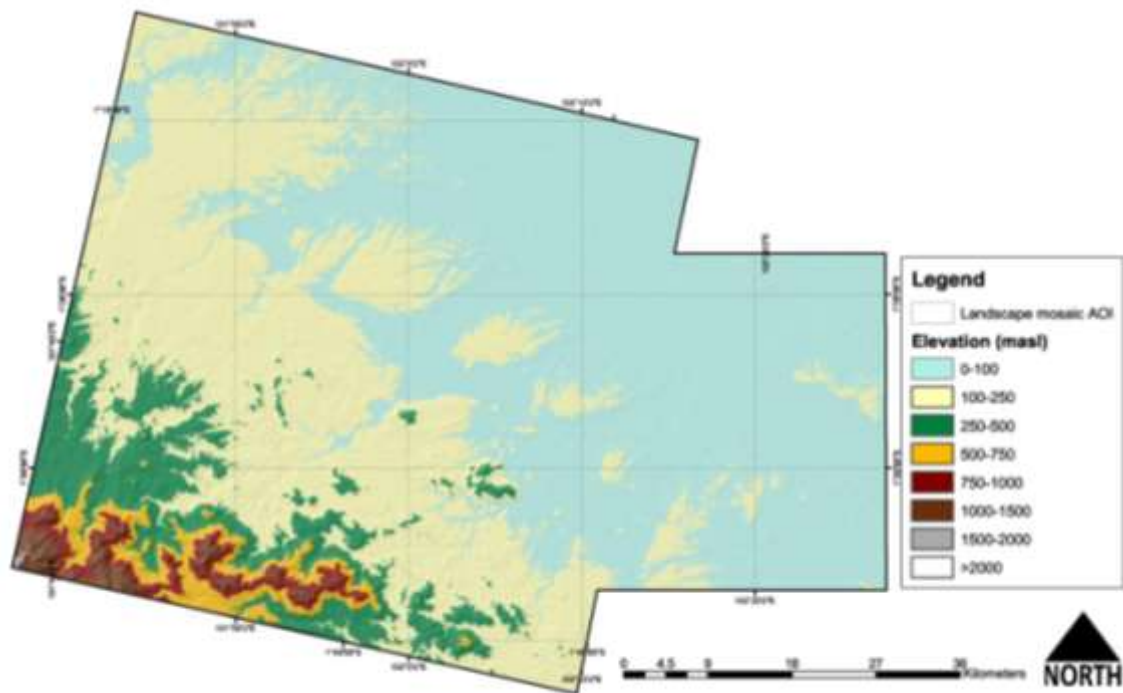


Figure 1. Elevation of Bungo site, ranges from 100 to 1700 meter above sea level

The landscape of Bungo is composed of lowland in the northeast and submontane ecosystem in the southwest with rough topography. Most of the submontane area is delineated as Protected Areas and currently this is the only large primary forest block left in the landscape.

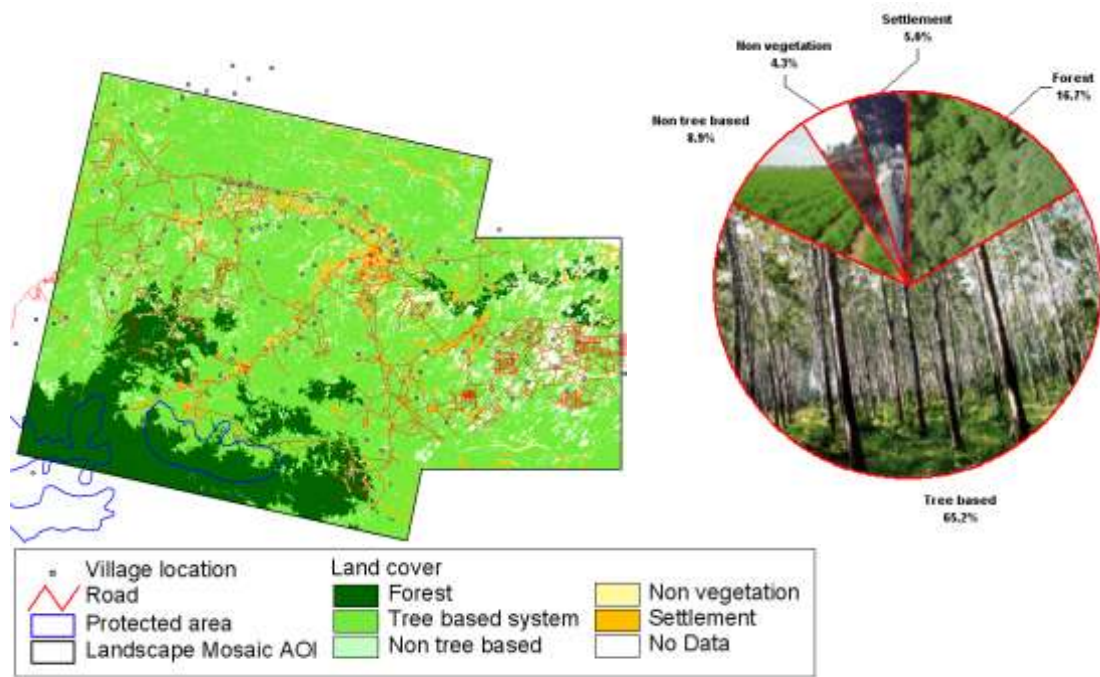


Figure 2 (a). Land cover map of Bungo site in 2007 (interpreted from SPOT 2007) (b). Landscape composition in 2007

In 2007, two thirds of Bungo landscape was dominated by tree-based land cover type; only 16% of the area is covered by natural forest. Most of the natural forests cover is exist as primary forest blocks of substantial sizes with complex shapes and only remains in higher altitude, surrounded by some small disconnected patches of primary, but degraded forest. Other even smaller forest patches still exist in the lower Batang Hari River as riparian forest.

Temporal Pattern

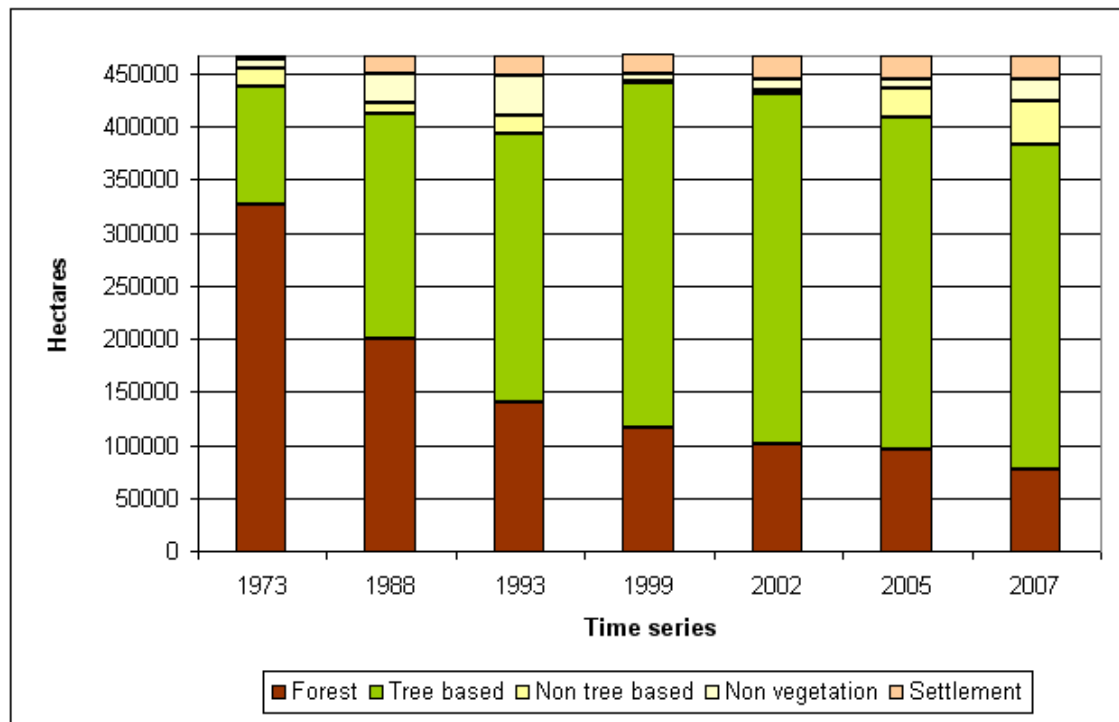


Figure 3. Time series of land cover composition of Bungo site.

Natural forest cover declined in period I, especially between 1973 to 1988, but tree-based land cover took over and became the dominant land cover since then (Figure 3). This tree-based land cover continued to increase until 1999 (period II) when it stabilized. During period III, changes were within tree-based land cover class; a large proportion of agroforest (rubber multistrata) was converted to more intensively managed tree-based systems, such as rubber monoculture, oil palm and, very recently, to *Acacia Mangium*. In this case the image interpretation needs a finer classification scheme to differentiate further the types of the tree-based systems, especially when our focus is on biodiversity. Until this interim report is written we have not yet finalized the image interpretation using the finest classification scheme. The finer classification process is scheduled to take place after the fieldwork is conducted in order to get more groundtruthed data.



(a)



(b)



(c)

Figure 4. Pattern of changes in 3 study period (a). Period I (1973-1993) (b). Period II (1993-2002) and (c). Period III (2002-2007). Darker colors indicate larger annual changes in proportion.

The pattern of changes during the three periods follows closely the forest transition theory. The earlier stage was dominated by loss of forest and biomass, in which most forests were converted to tree-based systems in period II (Figure 4). In Bungo, this period was also marked by increases in population and settlement area. There were new areas developed under the transmigration programs, both from surrounding areas and also from Java. The third period was marked with conversion of established tree-based systems to non-tree based systems and vegetation, which suggests either the transition to more intensified cropland and settlement or transition to more intensified tree-based systems, mostly monoculture rather than mixed tree, especially oil palm and rubber.

Location of changes

During the earliest period, deforestation occurred from the northern to the southern part of the district, and while this continues, the second period experiences further changes from the eastern side toward the western direction (Figure 5 and 6). The common characteristics have been that forest loss starts from lowland areas by timber harvesting that provides higher economic benefit, followed by clearing and conversion to either timber plantation, estate plantations, rubber agroforest, cropland or settlement. The most recent deforestation occurred in the edges of major primary forest block mostly found in higher altitudes only.

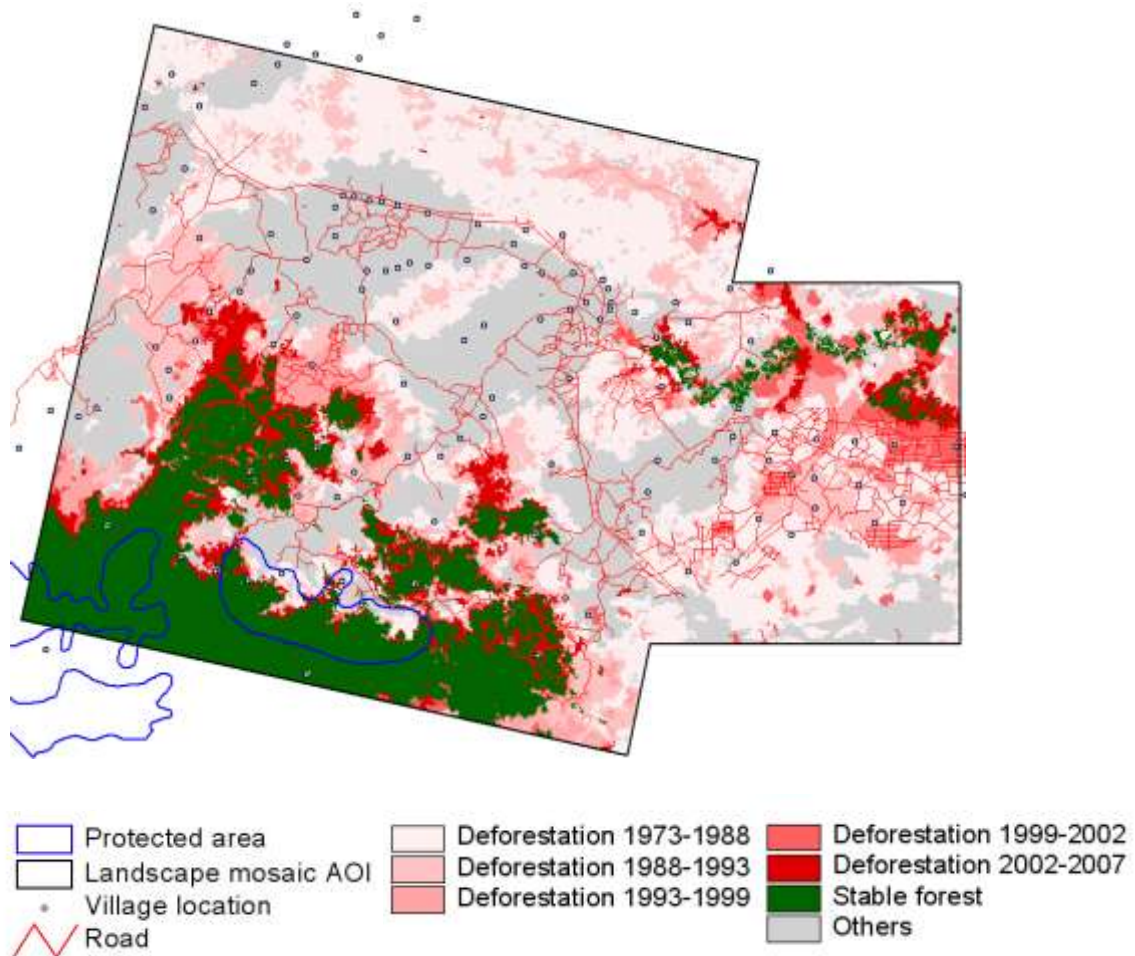


Figure 6. Location of deforestation in each time step in Bungo site.

Drivers

For Bungo site, where the Spatial Analysis team has been visiting repeatedly in the past and the where a long-term study has been conducted, the understanding of drivers of changes has been strong; several important agents of changes over time have been identified (Ekadinata and Vincent, 2008).

During the first period, where commercial timber was abundant, the land use/cover changes were dominated by logging activities under logging concessions. Under the regulations of the Forestry Department, only selective loggings are allowed, however heavily degraded forest were found in a considerable extents, followed by natural re-growth, cropland, imperata, mixed rubber plantation and conversion to timber plantations, and more recently by conversions to oil palm plantations in the second and third periods.

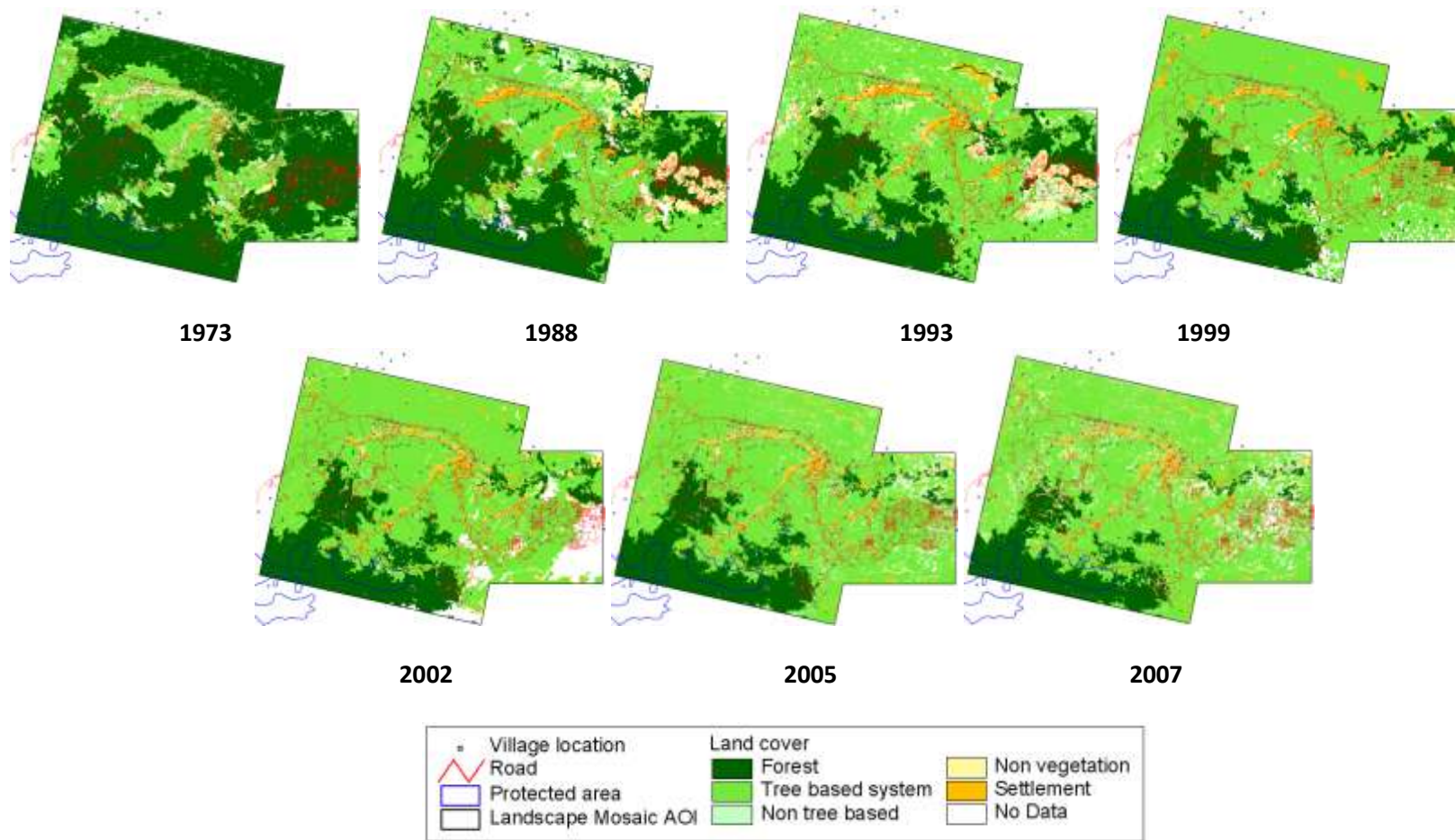


Figure 5. Time series of land cover map of Bungo site.

As for the smallholder managed lands, during the first period dominant land uses were rice field, croplands under shifting cultivation systems, rubber agroforests and some rubber monoculture (intensive rubber). During the first period, there was not much interaction between farmers and the large-scale drivers in terms of land cover/use. In the second period, farmers started to convert their rubber agroforest to more intensively managed rubber gardens. Also some farmers started to plant oil palm a result of the interaction with larger scale agents.

The third period up to now is heavily dominated by conversion to oil palm and, to a lesser degree, timber plantations mostly for fiber, both under large-scale concessions and small-scale concessions under out-grower schemes. This latest trend is driven by global demand for oil palm and for rubber, and regional demand for raw materials for pulp and paper due to depletion of natural forest and improved law enforcement. Following the ‘anarchy’ period due to the euphoria of the enactment of decentralization law, which has not been resolved up to now, resulting in lack of clarity and uncertainty of land tenure, land grabbing by farmers is quite prevalent. Overall forest and landscape governance of Bungo could be found in Martini et al (2010).

The transmigration program, facilitated by the government, has been quite active. This involves people migrating from the surrounding area, known as local transmigration, and those from Java. Associated with this program is the establishment of cropland and tree-based systems from forest and shrubs.

Most recently, activities and permits for coal mining have been increasing sharply. This becomes a new driver of land use and land cover changes in the area. Despite of this, in Lubuk Beringin, one of the village within the Bungo landscape, has been awarded the Hutan Desa (Village Forest) permit, which is the first permit given throughout the country (Akiefnawati et al, 2010).

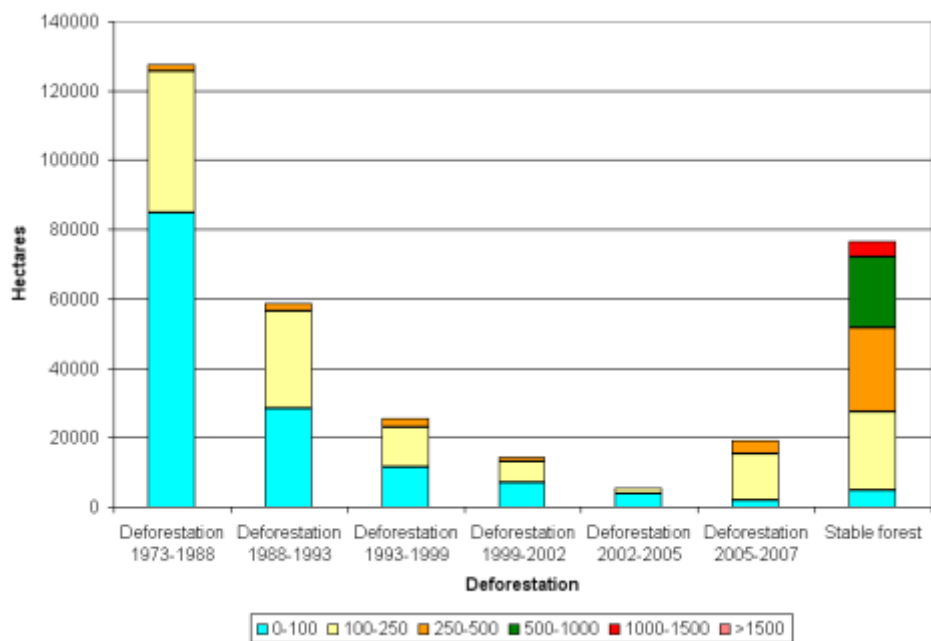


Figure 7. Forest loss (in hectares) in each time series by elevation class.

Access (River or road network)

In the past, people depended on rivers for their transportation network, but lately the road network has been well established; most settlements in Bungo are connected to some larger townships by road. Bungo’s location of deforestation correlates strongly with the existence of roads, like everywhere else in the tropics.

Protected area

Kerinci Seblat National Park covers the higher altitude areas in Bungo and is part of Bukit Barisan mountain range. Up to now the forest area of the national park in Bungo has been well conserved as part of the major block of primary forest remaining in the landscape. However, past trends show active encroachment from the forest edges and the buffer area of national park area are threatened by forest degradation, if not deforestation.

Laos (Viengkham)

Topography and current land cover and description

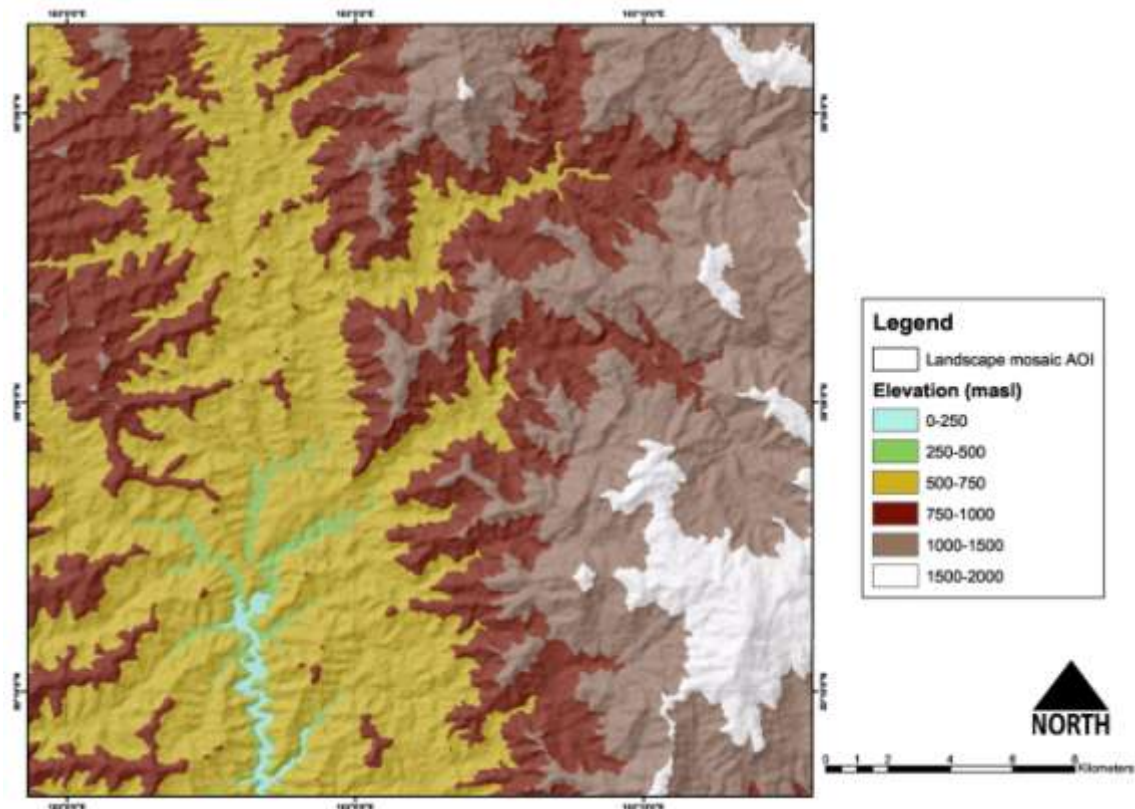


Figure 8. Elevation of Viengkham site, ranges from 400 to 2200 meter above sea level

The landscape of Viengkham is dominated by montane ecosystem with rough topography, especially in the eastern half of the area and some area in the northwestern part (Figure 8). Among the five sites of the project, Laos is highest and roughest in terms of topography.

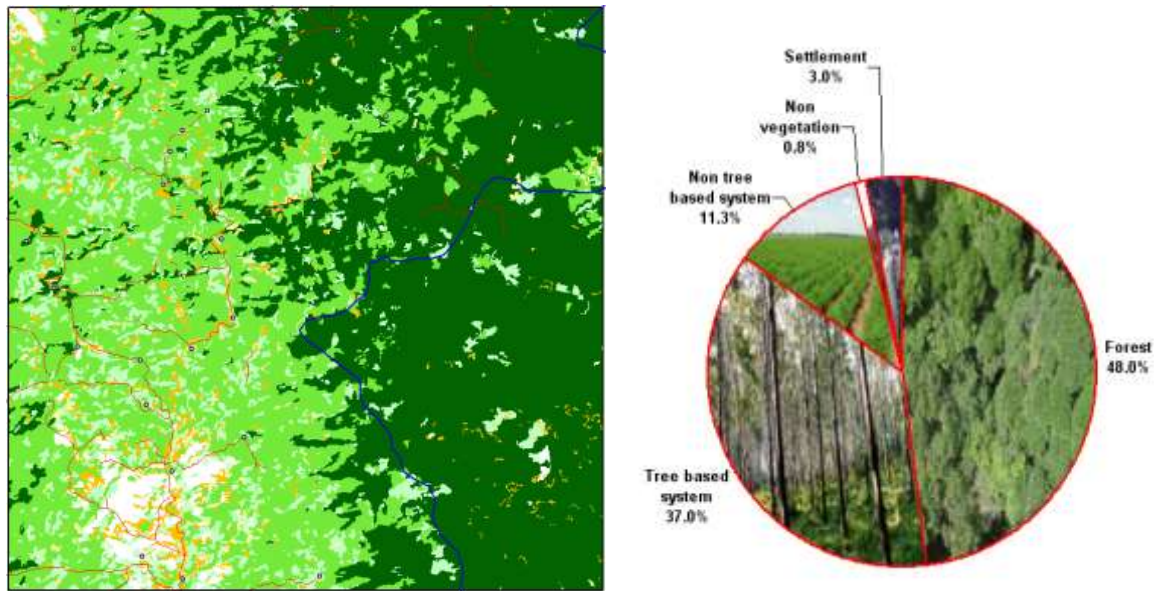


Figure 9 (a). Land cover map of Viengkham site in 2007 (interpreted from SPOT 2007) (b). Landscape composition in 2007

Almost half of the landscape area is covered by natural forest and 37% of tree-based systems (Figure 9), which is most likely natural re-growth (fallow) that is partial to shifting cultivation systems. It seems that in the recent past this area was part of the opium production area but to what extent opium was grown before eradication programs were implemented (the last one was launched in 2004) in this area is yet to be learned. The road networks are limited and the pattern of forested-non-forested areas follow river networks very closely.

Temporal Pattern

From the very limited two time series of land cover maps (2002 to 2007) we have produced so far, during the past 5 years, we can see that the extent of forest cover changed a little while tree-based land cover has increased dramatically replacing non-tree based cover (Figure 10 and 11). These changes perhaps are due to fallow period that allows natural regrowth to shrubs and woody trees. Seasonality might affect the spectral reflectance and the limited number of maps also constraints us to say more about the patterns. In the future this barrier will be addressed by looking for several other imageries that are relatively cloud free.

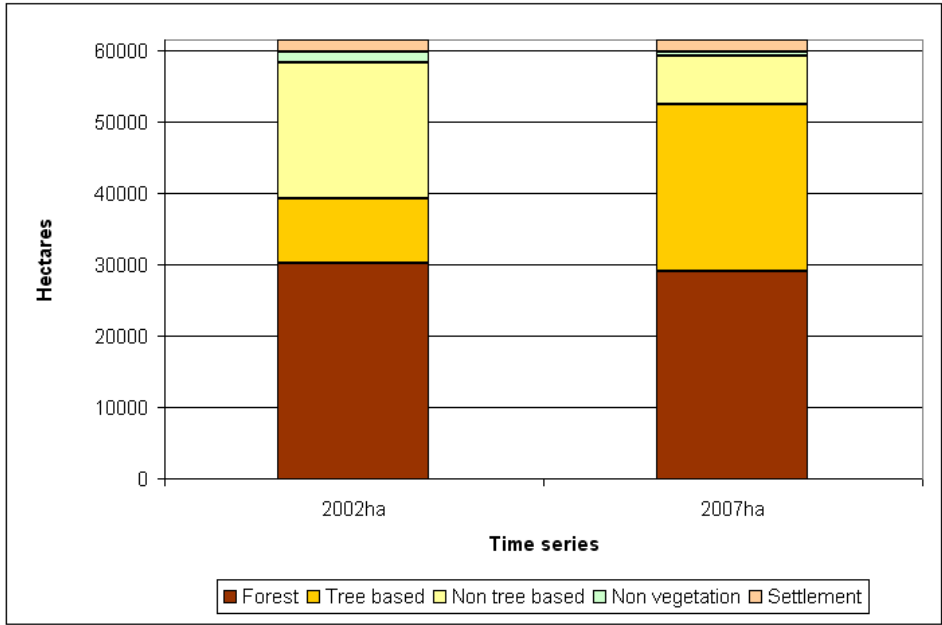


Figure 10. Time series of land cover composition of Viengkham site.

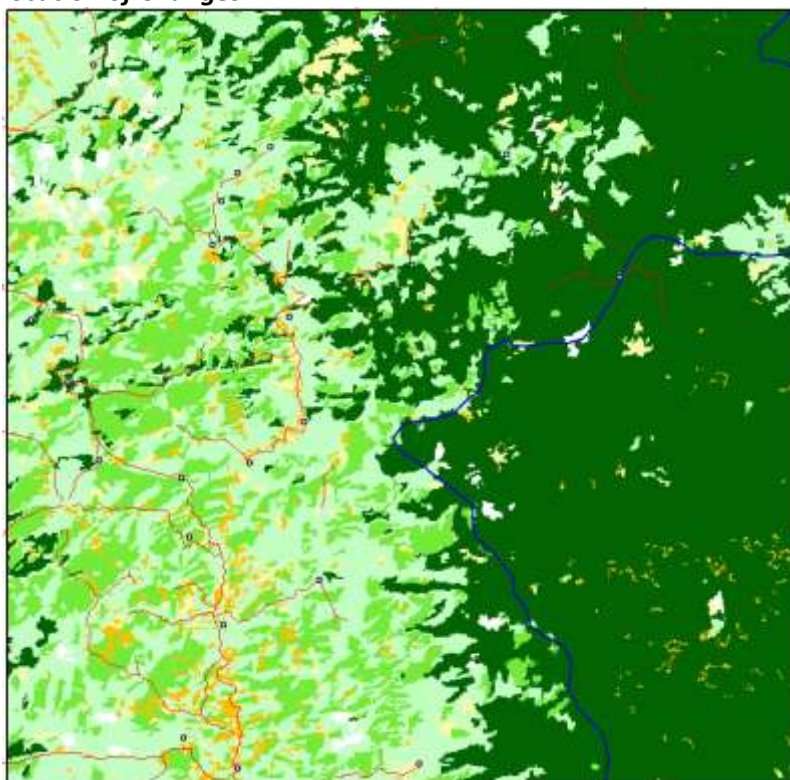


Figure 11. Pattern of changes in Viengkham in Period III (2002 to 2007). Darker colors indicate large annual changes in proportion.

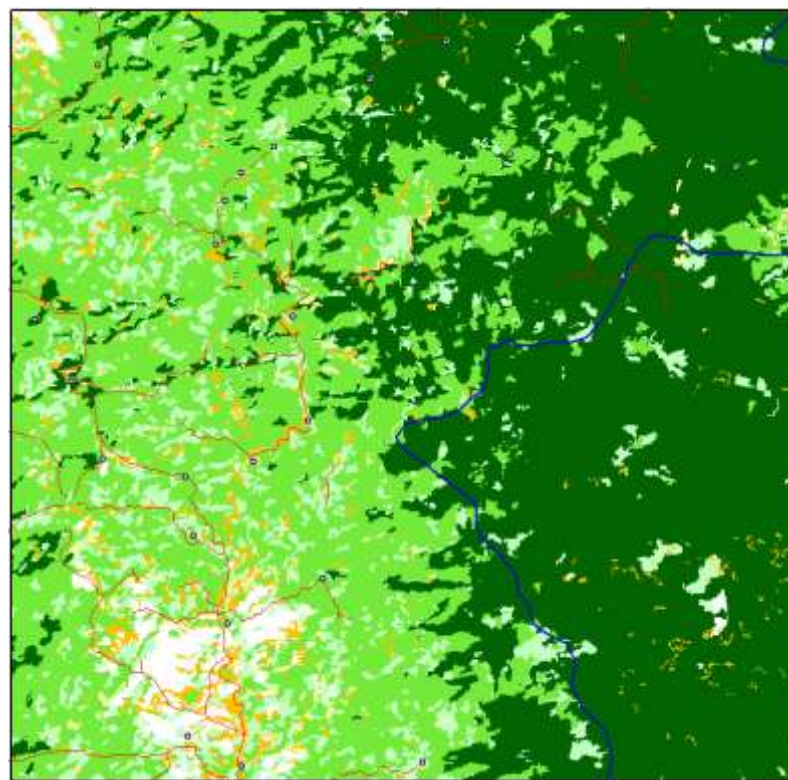
Location of changes

Almost in every part of the landscape where the altitude is relatively low (or outside the Protected Areas), the changes to tree-based land cover have been happening during the past 5 years (Figure 12). Some deforestation happened within the primary forest block area, rather than from the edges. These locations of deforestation are the enlargement or expansion of small patches of deforestation that occurred in the past in the core rather than the more common encroachment pattern from the edges.

Location of Changes



2002



2007



Figure 12. Time series of land cover map of Viengkham site.

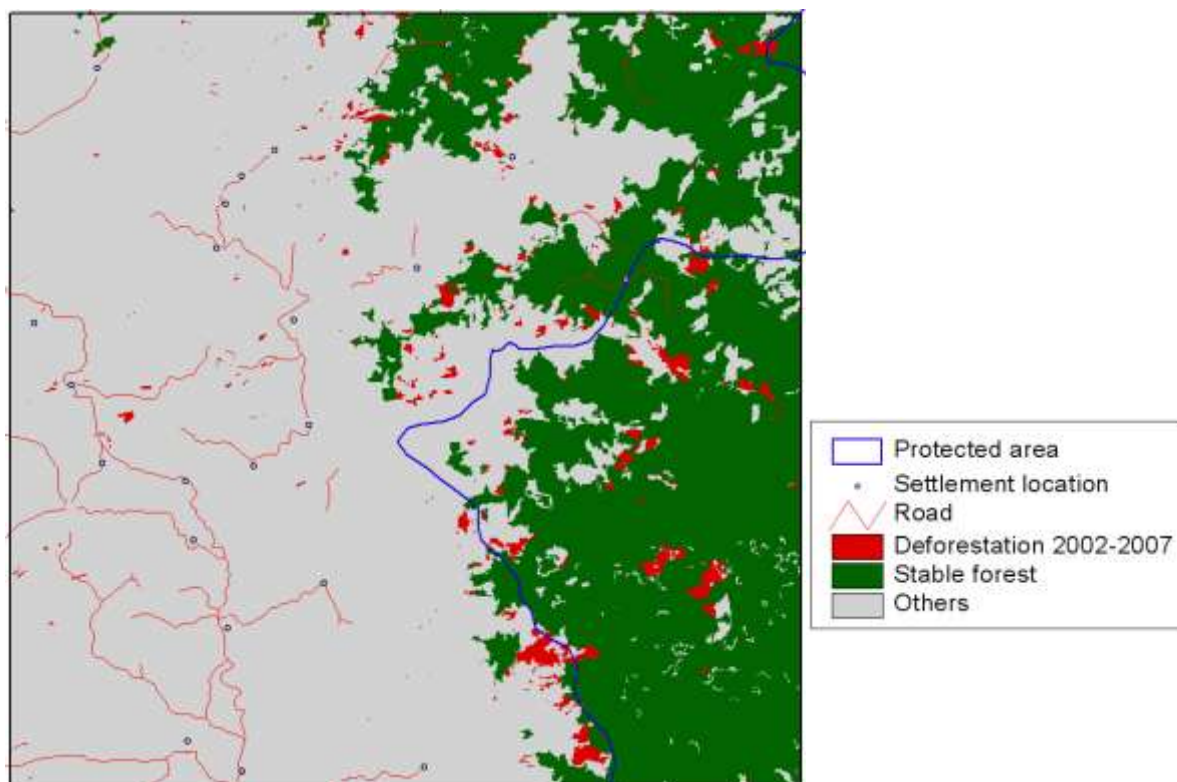


Figure 13. Location of deforestation in Viengkham site.

Drivers

Agents

Deforestation has been relevant in the protected area and dense forests have become scarce in agricultural landscapes with relatively high accessibilities and remains in less accessible areas. The typical landscapes consist of patches of different gradients of vegetation from degraded forest to grassland and are a consequence of human impact (slash and burn cultivation for upland rice, other farming systems, cash crop plantation, possibly effects of war, etc).

The main income sources are livestock (pigs, cattle, chicken etc.), followed by the collection of NTFPs (bamboos, grasses for broom, mushrooms). Teak cultivation is limited due to land tenure/land availability; technical limitation are also marked, e.g., in the case of eaglewood. Rubber planting is of the interest of local people but there are very few trials, mostly due to the rough terrain and market access. Population density of this landscape is very low, shifting cultivation is the most dominant land use system in the area. In 2004 the government enacted the policy to reduce the area of shifting cultivation by shortening the fallow period to three years only, as extensive shifting cultivation is believed to be the single most important reason of deforestation and degradation.

Topography

Figure 14 shows that most forest loss happened in the lower altitude, however since we only have two time series we cannot compare pattern of forest loss with regard to topography during different periods. In the highest elevation area (>1500 m), forest loss is quite marked compare to the intermediate elevation class (1000 to 1500 m), which perhaps are induced by new road development or other external drivers.

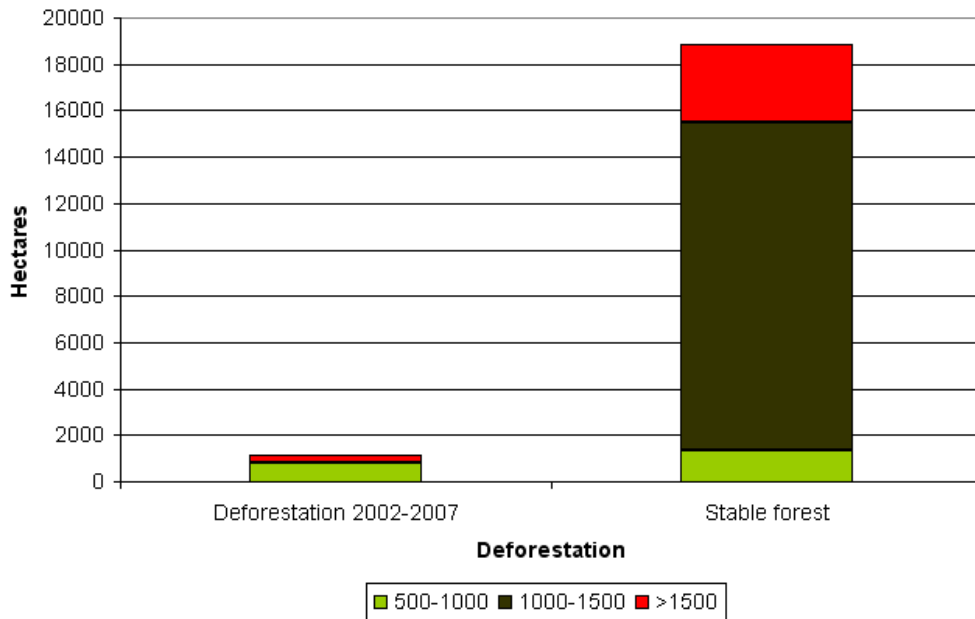


Figure 14. Forest loss (in hectares) by elevation class.

Access

Road access to the forests from Viengkham is limited, but some tracks are passable by motorbike during the dry season, otherwise farmers need to walk or build semi-permanent huts in the forested areas to extract NTFP or grow upland rice. Some major rivers are still functioning as transportation network but in most upland areas road is the main, but limited, transportation network.

Protected area

Phou Loei NBCA covers 150.000 ha (category VI according to WCMC); it was established in 1993 and is located in Phonxay and Viengkham Districts. It is a “managed resource protected area”, where the conservation objective is sustainable use of its natural ecosystems.

Madagascar (Manompana)

Topography and current land cover and description:

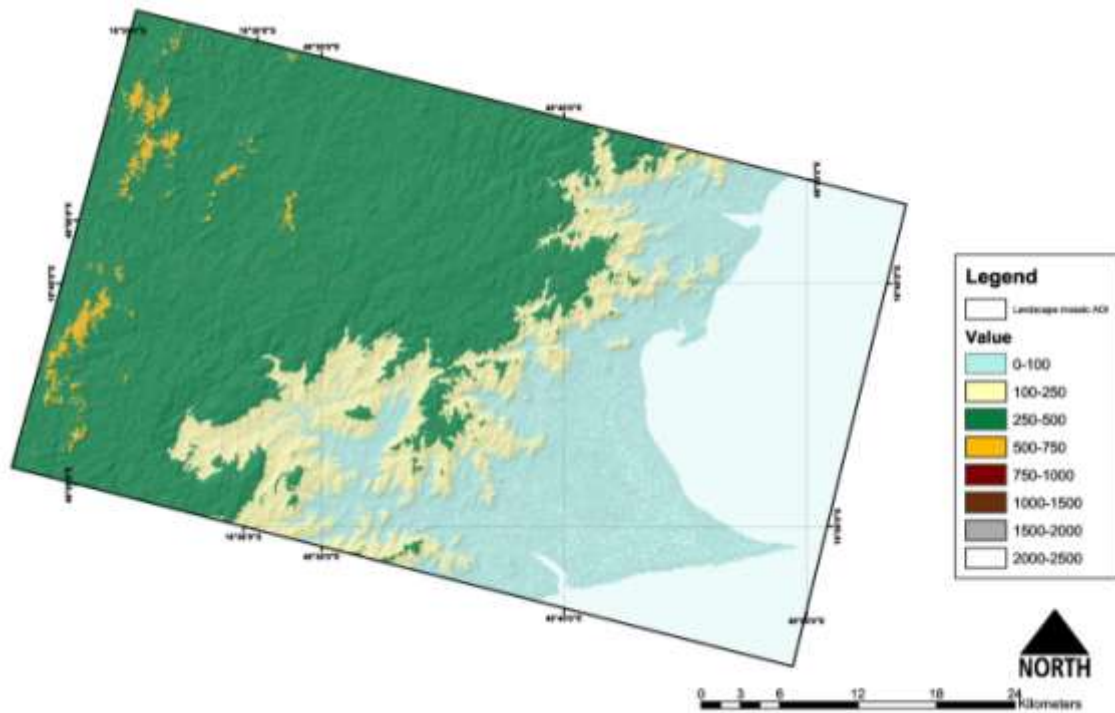


Figure 15. Elevation of Manompana site, ranges from 0 to 624 meter above sea level.

The landscape is dominated by a submontane ecosystem, with low to moderate topographic roughness, and the lowland area along the coastal zone (Figure 15). Within the landscape a little fragment of forest is found in the coastal area while most extents of forest cover are located in the hinterland. In 2005, the extent of forest cover was comparable to that of tree-based land cover and together they constitute two thirds of the landscape area (Figure 16).

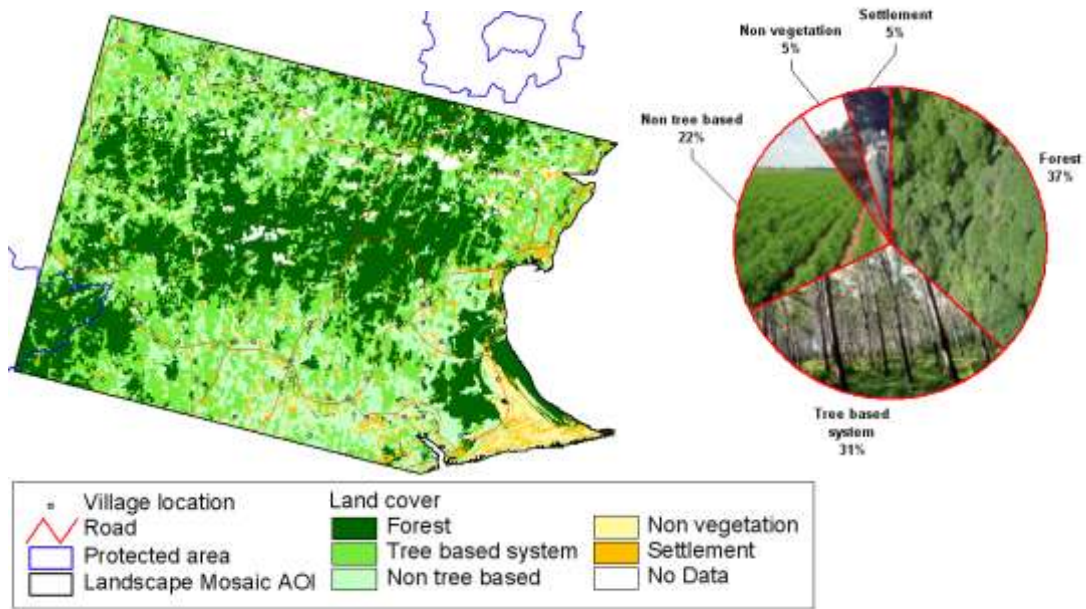


Figure 16 (a). Land cover map of Manompana site in 2005 (interpreted from SPOT 2005) (b). Landscape composition in 2005

Temporal Pattern

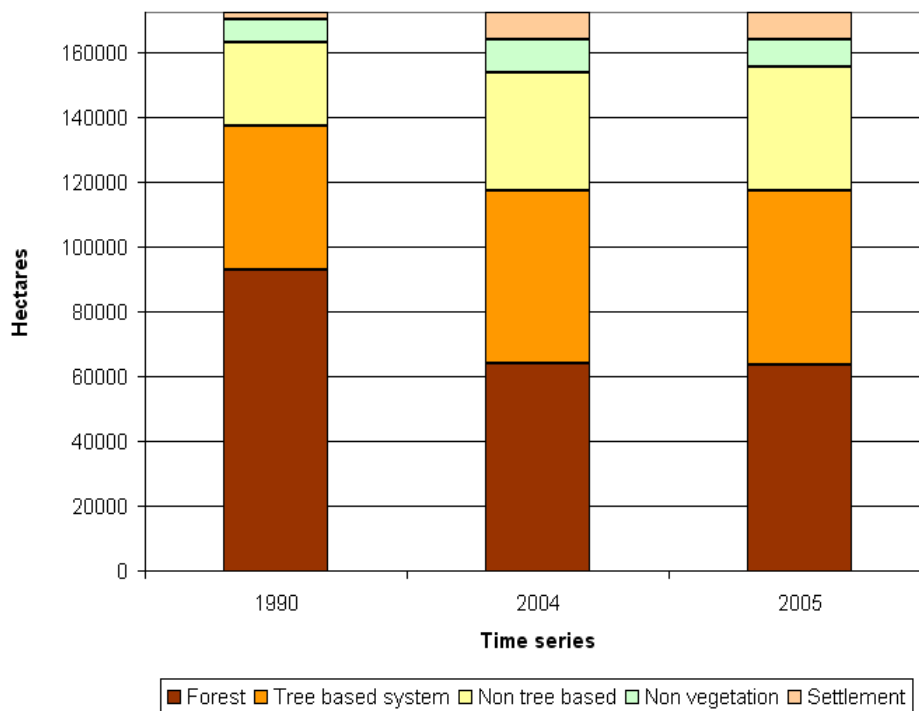


Figure 17. Time series of land cover composition of Manompana site.

A large extent of deforestation took place in period II and there has been little forest loss more recently (note that the observation period is only of one year). Both tree-based land cover and non-tree-based land cover increased as replacements to forest loss. It seems that while the extent of tree-based and non-tree based cover remain quite stable in the landscape (Figure 17), the location is changing (Figure 18) which indicates that shifting cultivation is actively taking place.



(a)



(b)

Figure 18. Pattern of changes in Manompana in Period II (1990 to 2004) (a) and Period III (2004 to 2005) (b). Darker colors indicate larger annual changes in proportion.

Location of changes

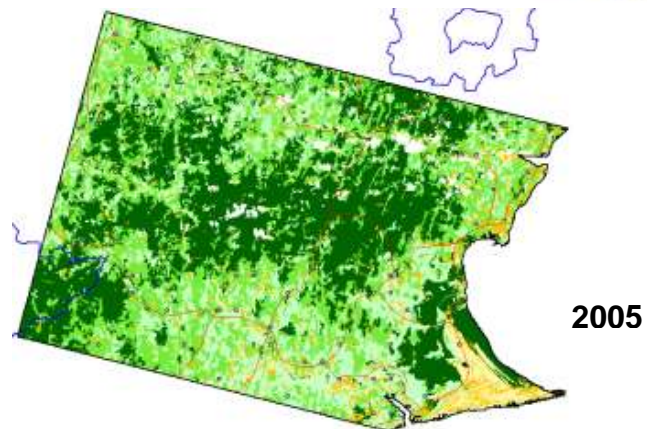
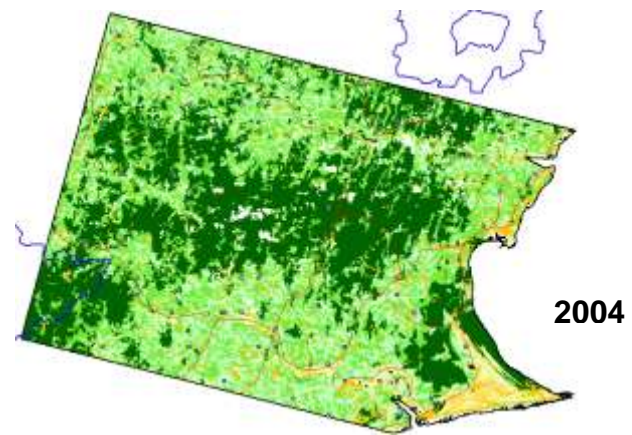
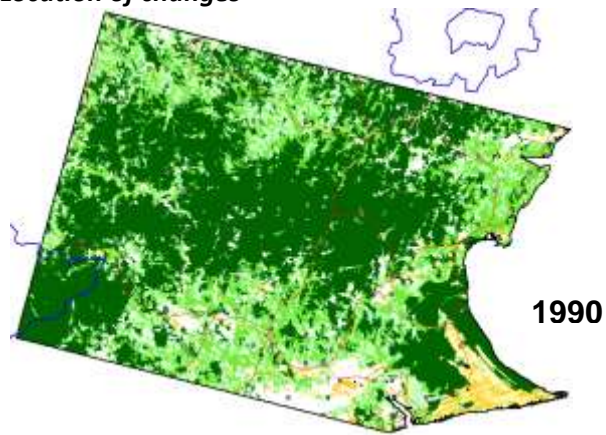


Figure 19. Time series of land cover map of Manompana site.

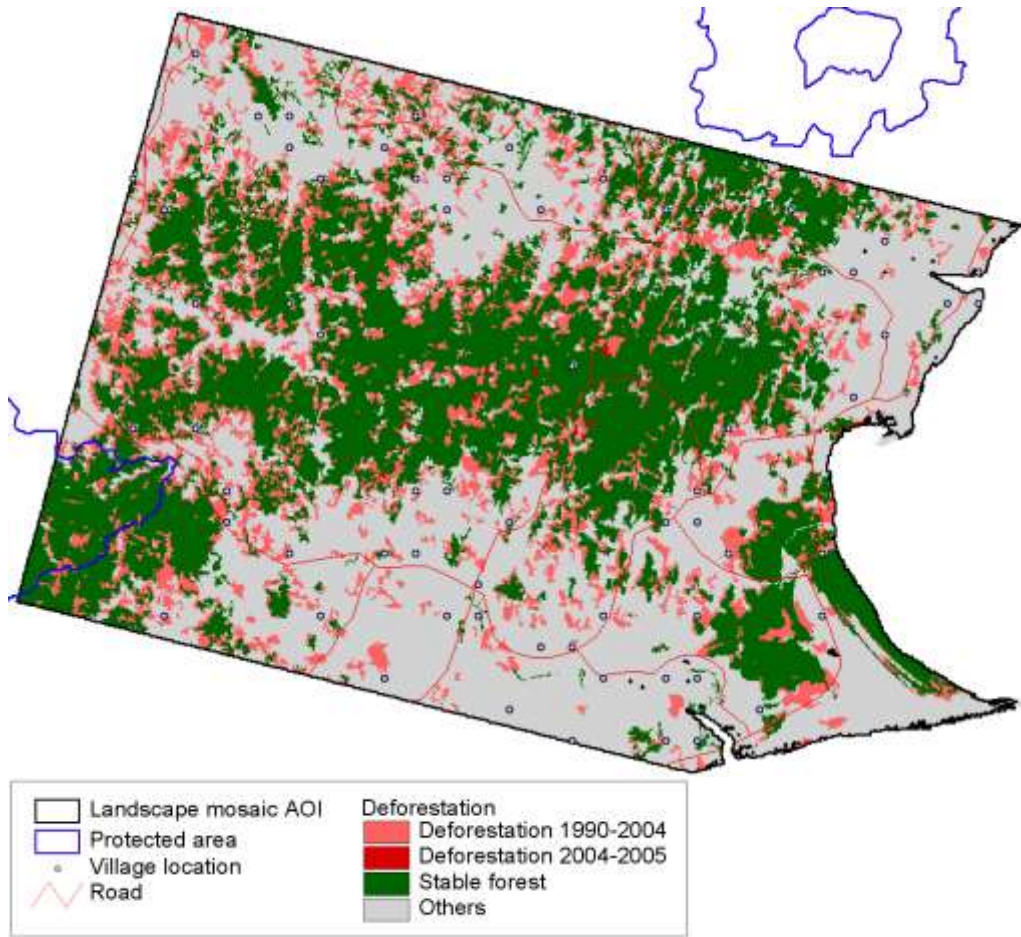


Figure 20. Location of deforestation in Manompana site.

Figure 19 and 20 shows that forest loss mostly happened as encroachment from the edges of primary forest blocks during 1990 to 2004. However in the primary forest block in the centre of the landscape, some forest loss started from the middle of the block and then expanded from there.

Drivers

Agents

Inherent differences between coastal population and population of the hinterland are very important. The traditional hinterland economy is based on the production of upland rice for subsistence while coastal areas take advantage of better access to markets for cash crops (cloves, vanilla, coffee, etc.), fish and other sea products. Slash-and-burn practices for upland rice or cash crops is the dominant land use systems and believed to be the threat to the remaining forest. The national level estimation in 2003 suggested that 60% of the commercialized wood came from

illegal logging. How this figure manifested within this particular landscape in Manompana is yet to be further explored.

Fallow system is a dominant land use systems in Manompana. Most deforestation is believed to be driven by this agricultural expansion. Around the village, home gardens of banana, papaya and other fruit trees are commonly managed in mixed agroforestry system while commodities like coffee, cloves and vanilla are planted as monoculture (Pfund et al., 2010).

Topography

Figure 21 shows that most of the forest loss in each of the elevation class is comparable to the existing forest, which suggest that there is no particular tendency that forest loss is associated with topography.

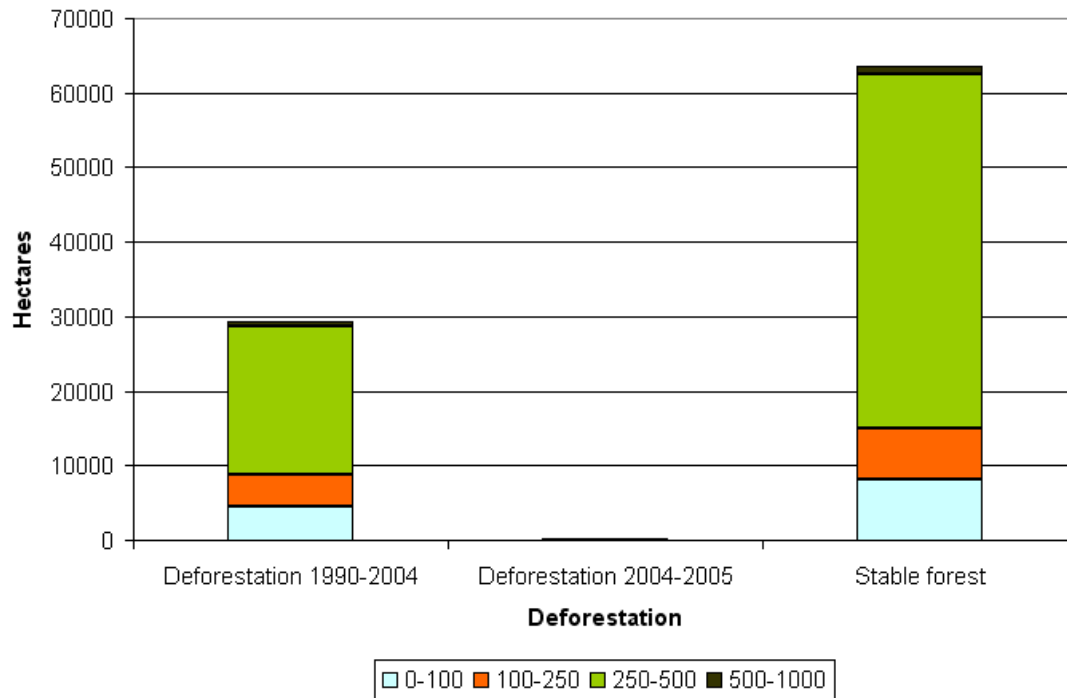


Figure 21. Forest loss (in hectares) in each period by elevation class.

Access

Even though road network is very limited, population seems to be well distributed in the landscape, including in the big forest blocks. Some river network has been functioning as transportation means but generally people use walking paths to travel from place to place.

Cameroon (Takamanda Mone)
Topography and current land cover and description

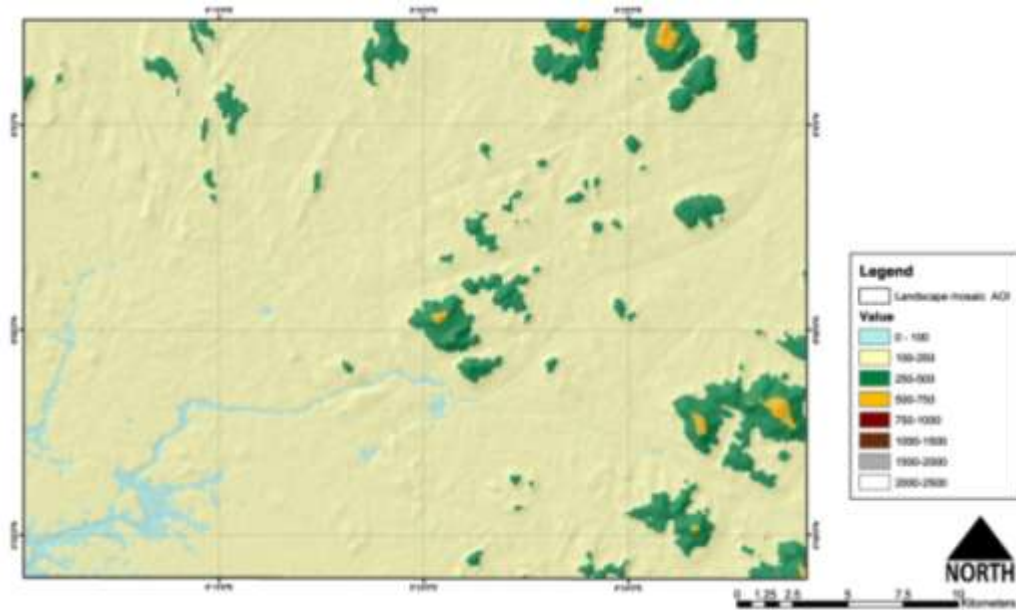


Figure 22. Elevation of Takamanda Mone site, ranges from 0 to 650 meter above sea level

The study site of Takamanda-Mone is quite flat and dominated mostly by lowland (Figure 22). Several islands of submontane and montane areas can be found in the landscape but the extents are small. River networks well cover the landscape.

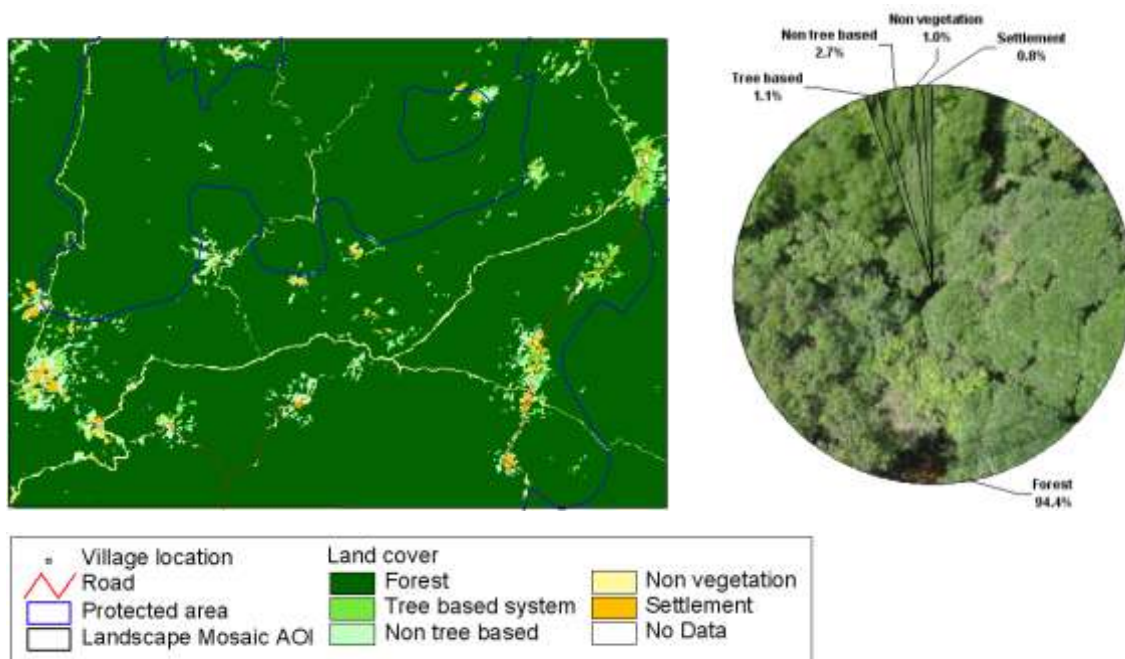


Figure 22 (a). Land cover map of Takamanda Mone site in 2006 (interpreted from Landsat 2006) (b). Landscape composition in 2005

In 2006, Takamanda Mone was highly dominated by forest (94.4%), with some settlements found along the rivers and surrounded by some other land covers (Figure 22). Most of the areas are under protected status.

Temporal Pattern

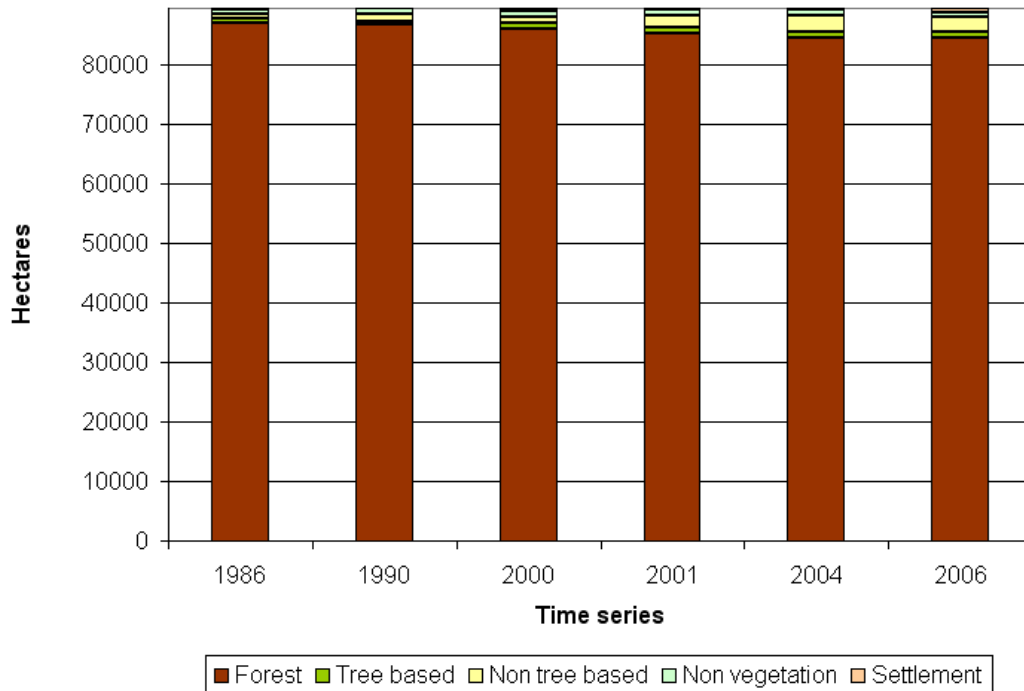


Figure 23. Time series of land cover composition of Takamanda Mone site.

Within the time series, forest loss has been quite small in extent, compared to other sites. The increase of non-tree based cover is quite marked in the most recent years (Figure 23). Another pattern to note that has happened lately is the increase of area of settlement (Figure 24). This perhaps indicates either population increases (due to in-migration) or re-settlement. Interchanges from tree-based to non-tree based cover and vice versa is also high.



(a)



(b)



(c)

Figure 24. Pattern of changes in Takamanda Mone for 3 study periods (a). Period I (1986-1990) (b).Period II (1990-2000) and (c). Period III (2000-2005). Darker colors indicate larger annual changes in proportion.

Location of changes

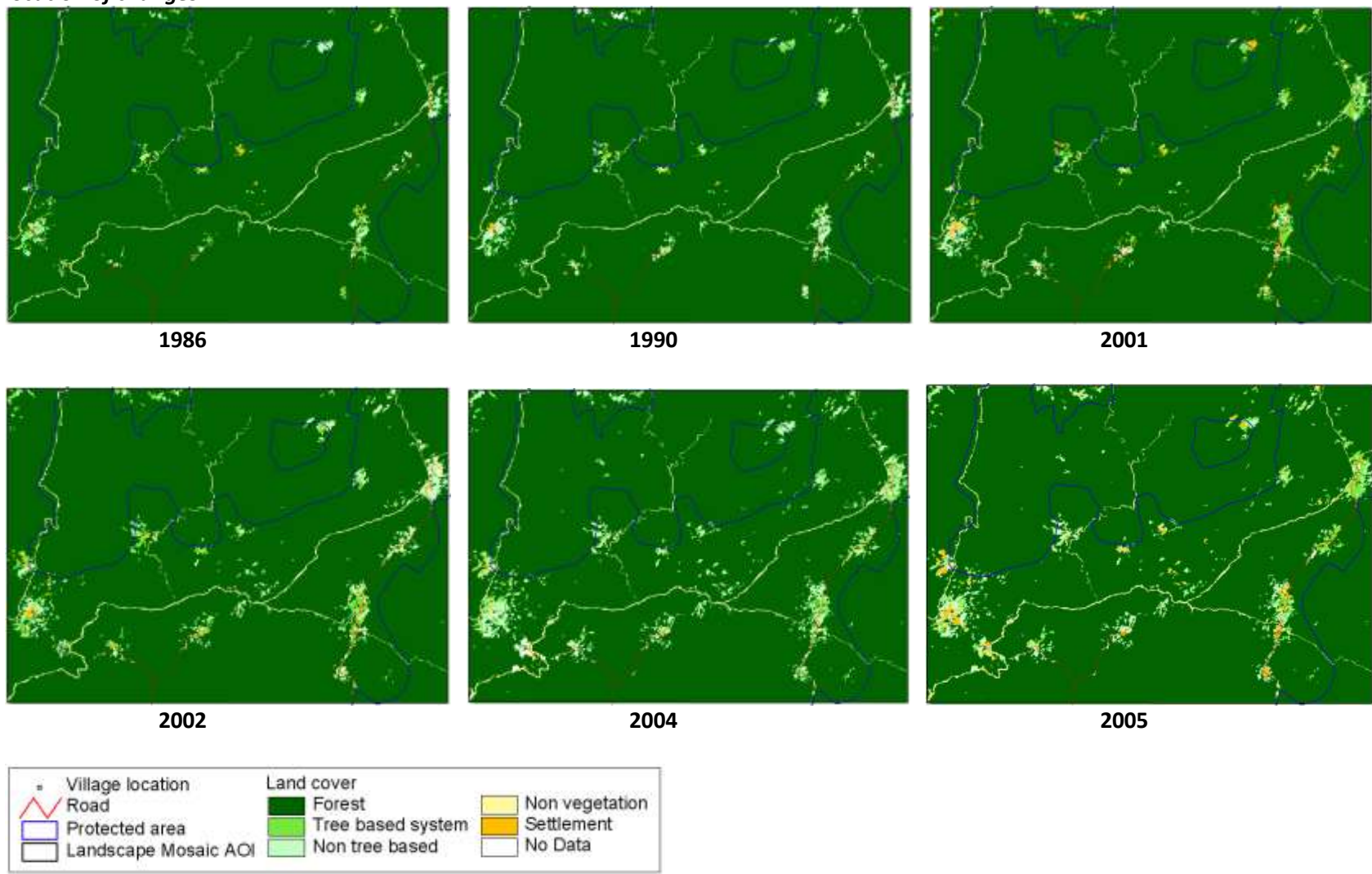


Figure 25. Time series of land cover map of Takamanda Mone site.

Figure 25 shows that most of the deforestation patterns follow the river and road networks. Over time the settlements that started earlier expand further into the forest. This indicates that smallholder farmers are the dominant agent in the landscape.

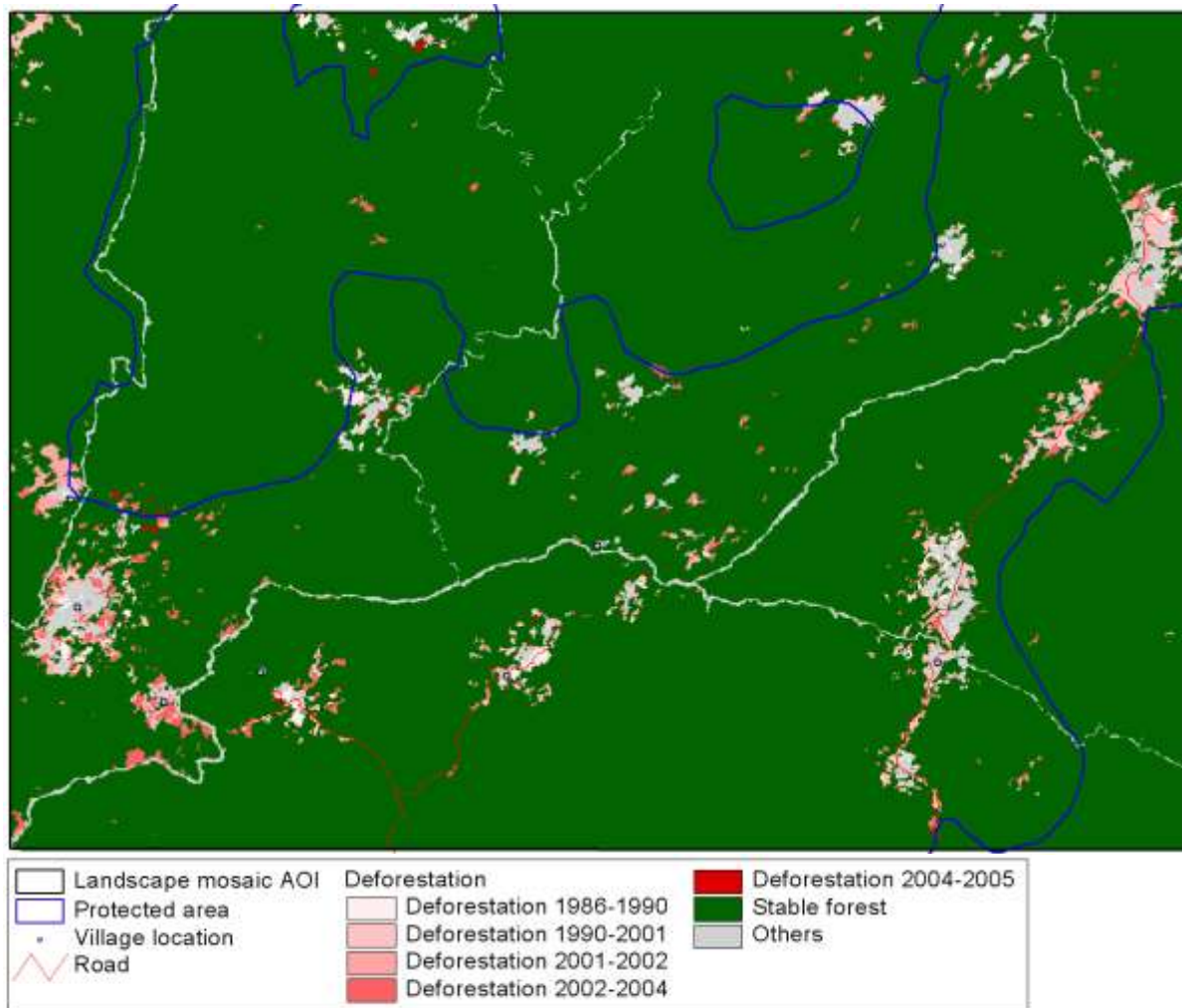


Figure 26. Location of deforestation in Takamanda Mone site.

Drivers
Topography

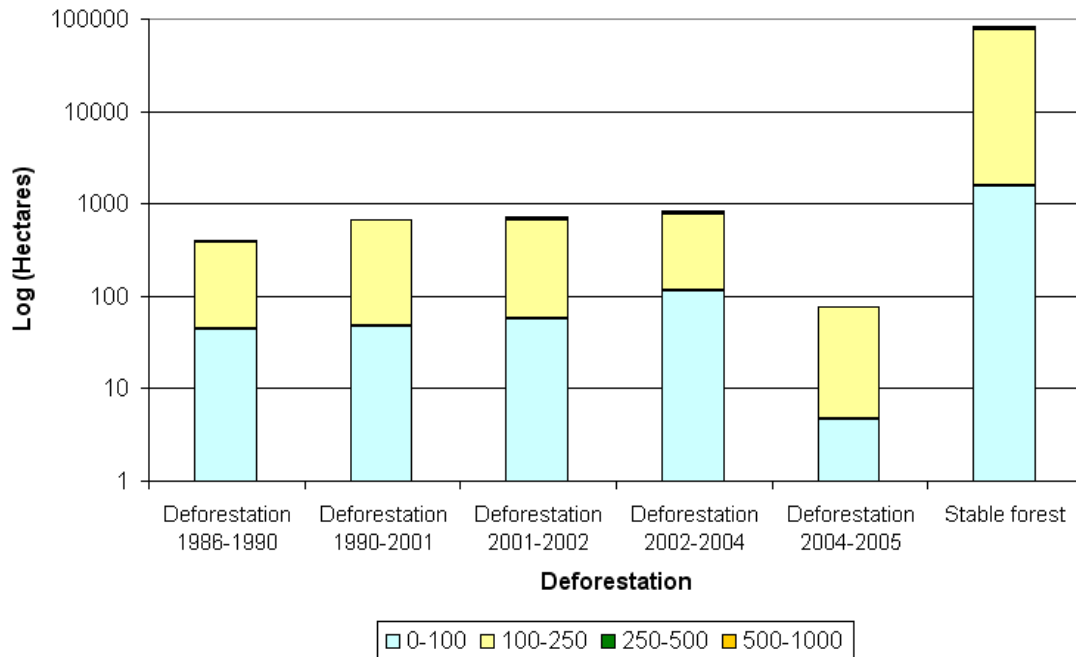


Figure 27. Forest loss over time by elevation class

Whilst the earlier period showed comparable forest loss in the lower and moderate elevation class in relation to the existing forest, the most recent forest loss revealed a new pattern: forest loss in elevations of 100-250 m is higher compared to those in the lower altitude (Figure 27). Population growth, either naturally or by resettlement, in tandem with new road construction can be the explanation of this pattern.

In this landscape, logging is active, but since forests are not differentiated in terms of density, i.e., between dense and degraded or logged-over forest, selected loggings are not detectable. Fallows are not identified as part of a cultivation cycle. Cultivation of cocoa, mixed with banana and plantains, along the road have increased recently due to market access. Small-scale oil palm plantations have been introduced and developed in the secondary forests as well tree plantings such as bush mango (*Irvingia wombolo*), bitter cola (*Garcinia cola*), and *njansang* (*Ricinodendron heudelotii*) which provide substantial income to farmers (Pfund et al, 2010).

Tanzania (East Usambara)

Topography and current land cover and description

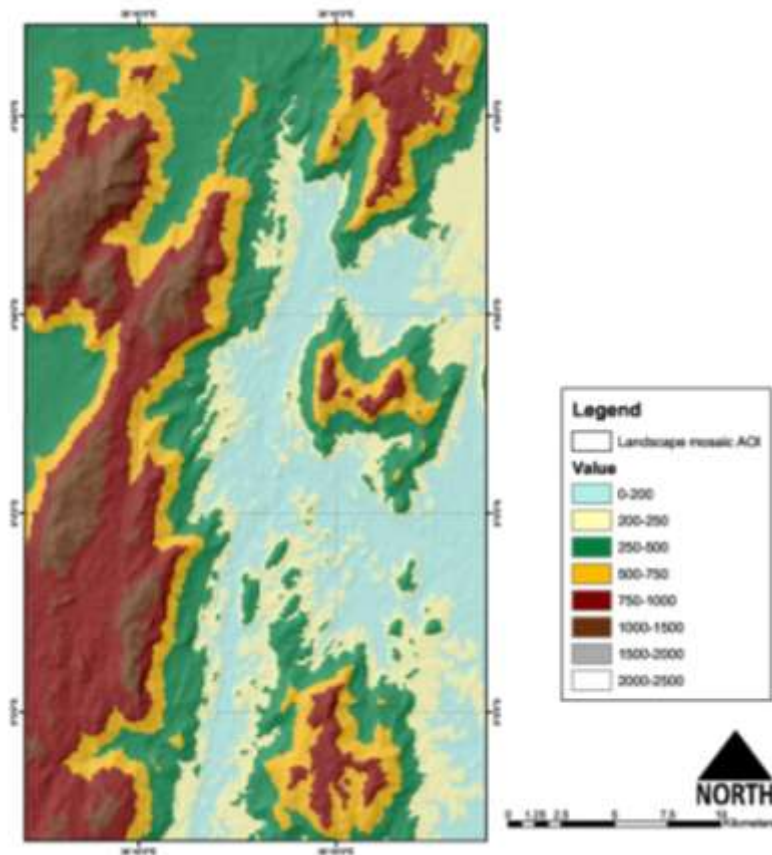


Figure 28. Elevation of East Usambara site, ranges from 100 -1500 meter above sea level

The landscape of East Usambara is the second highest and roughest in terms of topography among the five sites. In terms of topography, the landscape consists of one big island of montane ecosystems and 3 other smaller islands, 2 of them are disconnected from the biggest island (Figure 28).

In 2007, three quarters of the landscape was covered by forest and tree-based systems of comparable proportion. Compared to the other sites, forest cover in East Usambara landscapes is the most scattered and fragmented. The shape of forest patches is also complex with long edges compared to their areas. Forest patches are found mostly in montane and sub-montane, and to some lower extent in the lowland area.

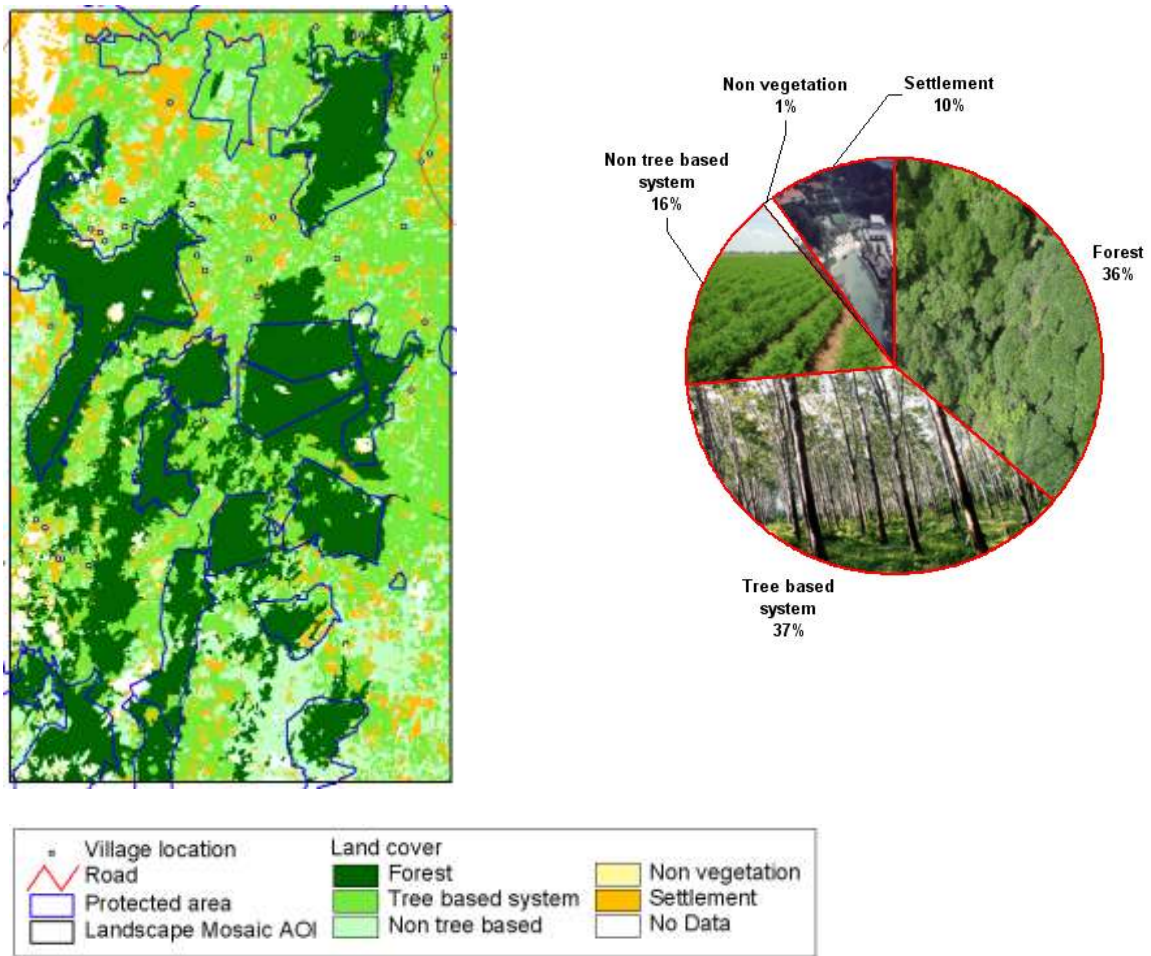


Figure 29 (a). Land cover map of East Usambara site in 2007 (interpreted from SPOT 2007) (b).Landscape composition in 2007

Temporal Pattern

Forest continues to decline over time. Proportion between tree-based and non-tree based cover interchanges over time, whilst settlement areas show steady increases in size. Most recently tree-based cover dominates the landscape.

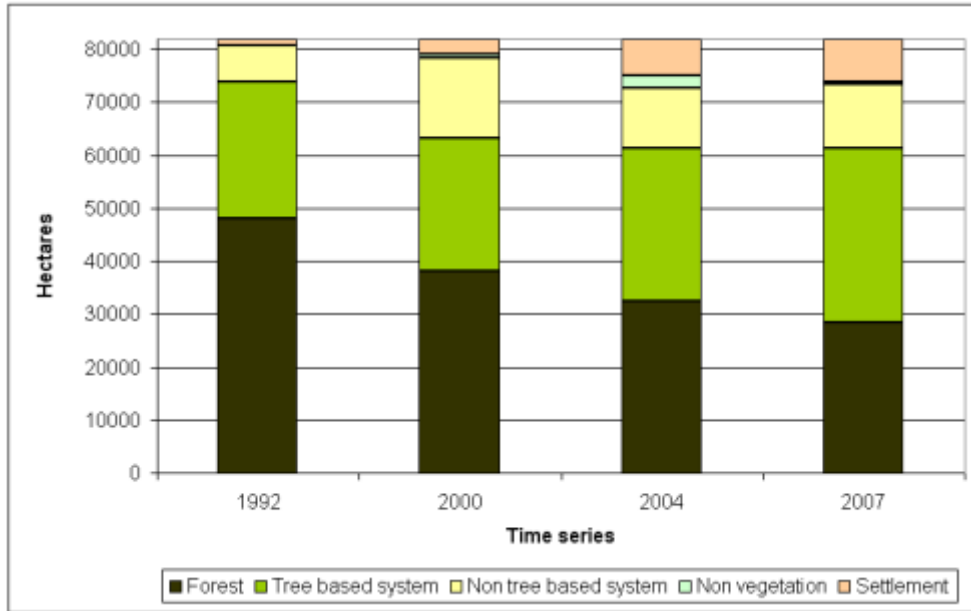
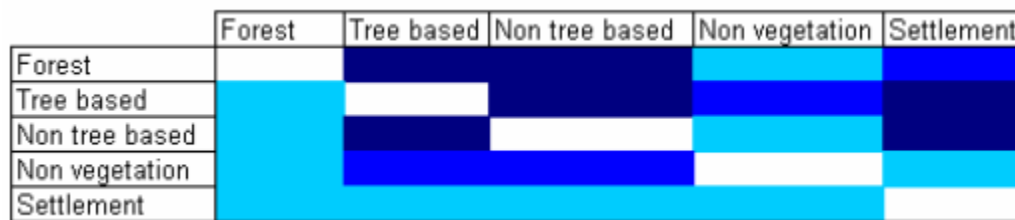


Figure 30. Time series of land cover composition of East Usambara site.



(a)



(b)

Figure 31. Pattern of changes in East Usambara for 2 study periods (a). Period II (1992-2000) (b). Period III (2000-2007). Darker colors indicate larger annual changes in proportion.

Location of changes

Figure 32 shows that forest fragmentation started in 1992 and increases over time; deforestation pattern over time is in the form of encroachment from the long edges of the forest core (Figure 33).

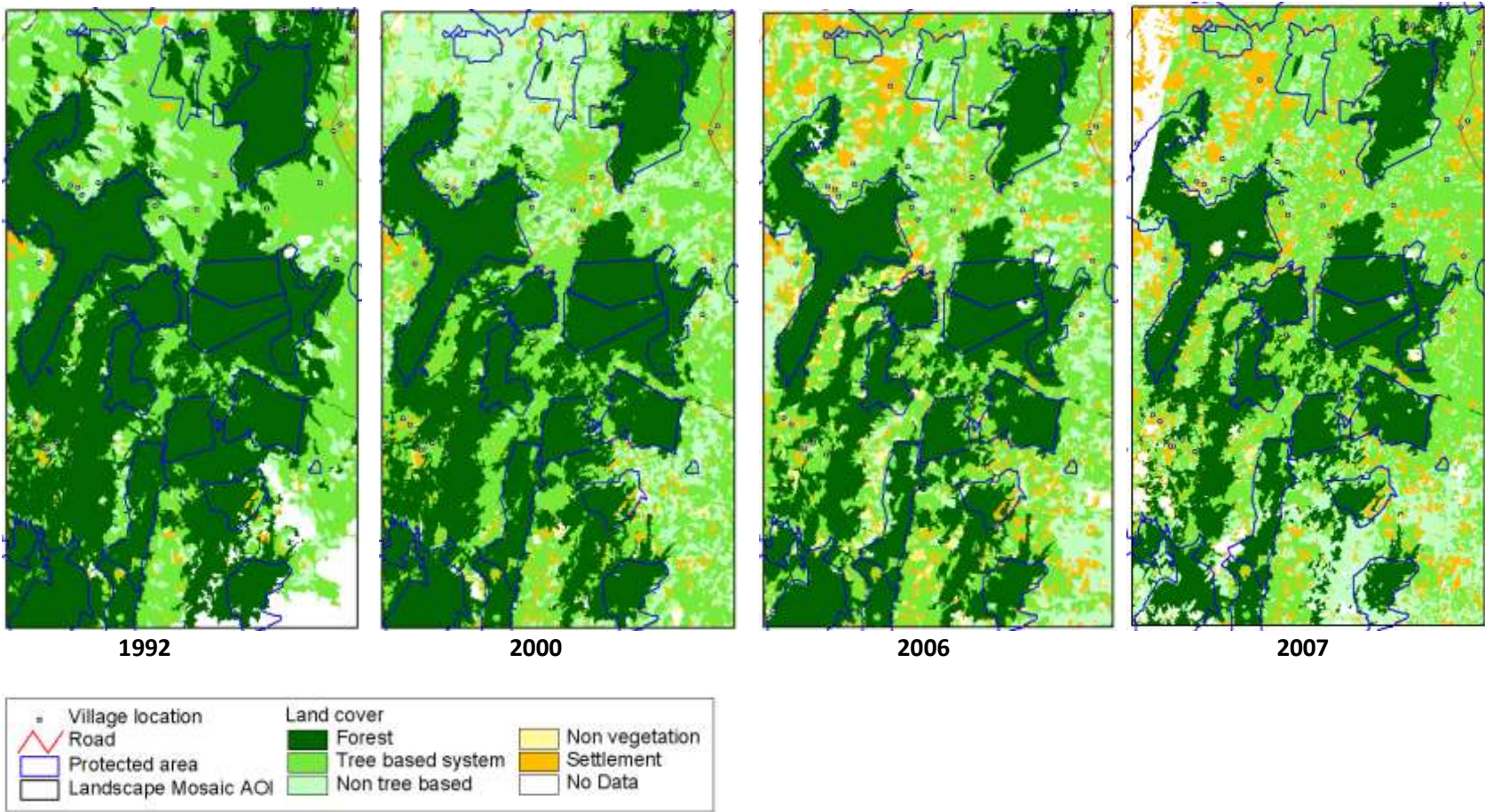


Figure 32. Time series of land cover map of East Usambara site.

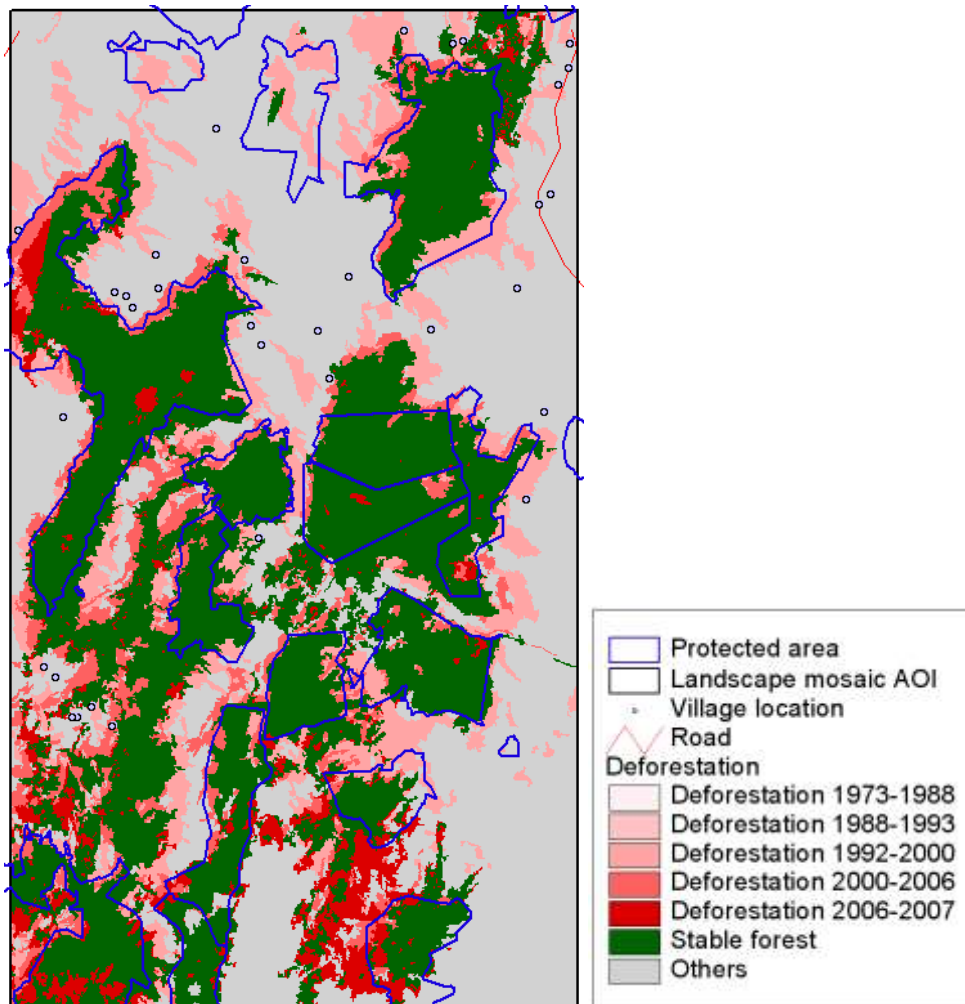


Figure 33. Location of deforestation in East Usambara site.

Drivers

Agents

Some remnant forest can be found on village land and available for conversion to farmland through village land allocation systems. The pattern of farmer managed land is dynamic: in both submontane and lowland forests, cash crops (mainly cardamom) are first cultivated under forest, followed by the gradual clearing of the agroforestry systems for more open cultivations of maize and beans, and finally cassava and sugar cane as land fertility is exhausted. Small-scale farming consists of rotational and continuous cultivation of food and cash crops, whereas commercial estate farming focuses on tea, sisal and cocoa. Tea plantations are perceived to be expanding in the highland areas. In a survey of 1995, forests constituted about 50% of the total land use in the area compared to 43% agricultural land, but the ratio has been estimated to be changing rapidly as more forest is being cleared.

During the past decades, other groups have migrated into the area, attracted by the favourable climatic conditions and job opportunities in the tea plantations. The population is rapidly growing at the annual rate of 2.2% (2001). The majority of the population belongs to the poor segment of smallholder farmers and tea estate workers.

Outside the protected areas forest loss continues rapidly for agricultural conversion due to increasing population pressure. People see the remaining forest as their future agricultural land and resist government efforts to gazette new protected areas to increase connectivity between remnant forest patches. Some advance has been made in the establishment of community managed Village Forest Reserves, since people are now increasingly dependent on the remaining forest in reserves for medicinal plants, fuel wood and building materials, as well as services such as a regular water supply. Fire is a major threat to forests both outside and inside the reserves due to burning of adjacent fields. Since 2004, a new threat to the forests and water reserves has emerged in the form of a considerable increase in small-scale mining. Also the impact of a growing industrial demand for firewood (tea curing) is becoming more significant, and new forest areas are cleared for fuel wood without a strategy for regeneration.

Topography

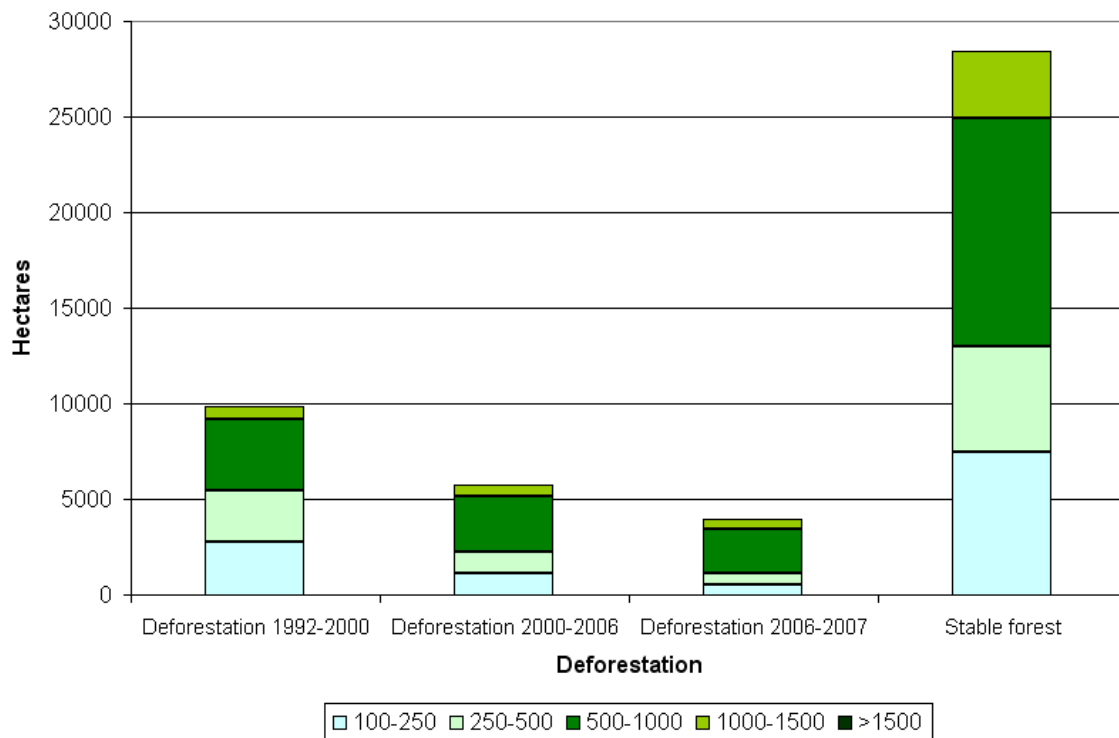


Figure 34. Forest loss over time by elevation class

Figure 34 shows that forest loss was quite well spread in terms of elevation in the earlier period and then growing more towards higher elevation of 500-1000 recently.

Protected area

Protected forest area is about 33,000 ha or 75% of the total forest area (1995). Most of the remaining forests are found in the 18 Catchment Forest Reserves and the Amani Nature Reserve in the southern part of the East Usambaras which is the largest continuous forest area (8,300 ha) along with the Nilo Forest Reserve in the northern part of the East Usambara highlands.

Forest Transition and spatial pattern of deforestation

Forest transition theory was first coined by Mather (1992) to describe process of transitioning of forest at the country level, which starts from continuous declines of natural forest up to a certain point where 'forest' cover increases in different forms either due to demands for forest products, or to the abandonment of agricultural land of low intensification over other income generation, presumably non land-based activities. We use forest transition curve to capture varying stages of forest transition in the five landscapes based on the forest cover (Figure 35), forest dynamics, forest fragmentation, the pattern of changes and the drivers, in order to help us compare and understand the dynamics, and to look for different options for interventions that are suitable for each sites.

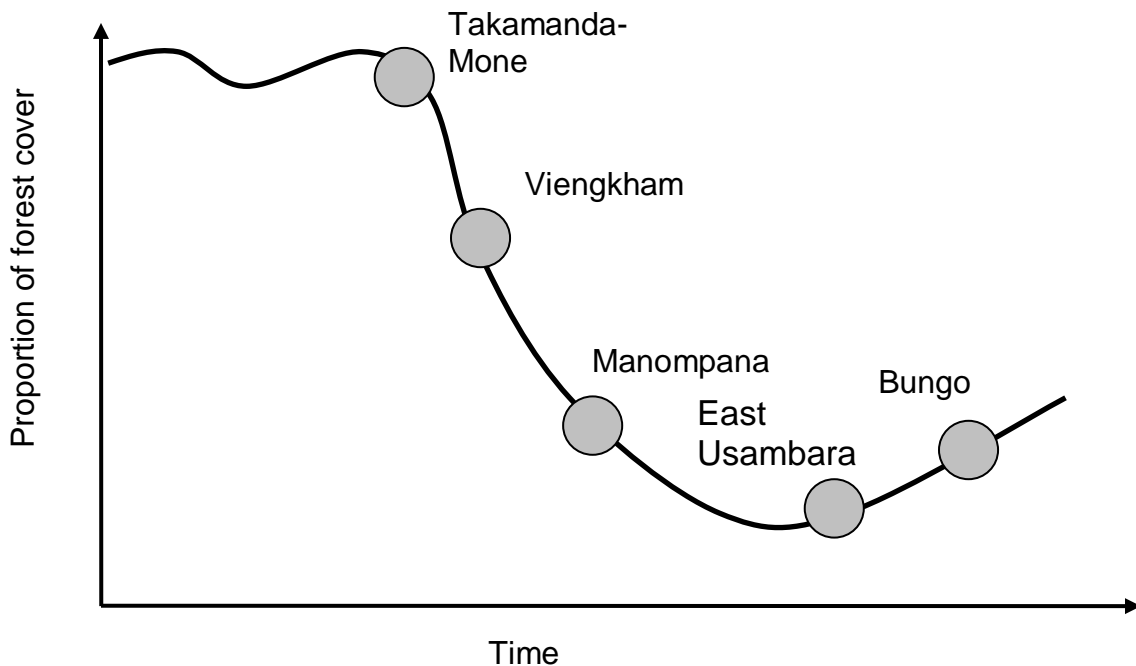


Figure 35. Forest transition stages of the five sites

Takamanda Mone landscape is at the earliest stage in the curve, quantified by its highest proportion of forest cover and lowest rate of forest loss. Population pressure perhaps started to increase lately but compared to other sites, the pressure is much lower. Forest in Viengkham landscape is perhaps protected by its rough topography even though lately there seems to be a

new pattern of increasing deforestation at high altitudes inside the forest core. Manompana landscape has lost significant forest cover in the earlier period, resulting in a fragmented forest. More recently, the rate of deforestation has slowed down. However, the expansion of deforestation in the core area should be noted.

East Usambara currently has twice as much proportion of forest cover in the landscape compared to Bungo, but in absolute forest cover, Bungo is higher. In many aspects the two landscapes are comparable, especially in the existence of large scale operations in addition to smallholder farmers as land managers, and the interaction between the two agents. However, due to differences in topography and the dominating land use systems that replace forest, the two landscapes bifurcate along the forest transition path. In East Usambara, the roughness in terrain is more distributed compared to that in Bungo landscape. Natural forest in flat areas outside protected areas, which has higher probability to be converted, is higher in East Usambara, and therefore if the future land use/cover change follow the same trend as it was in the past, we could anticipate further reduction in forest cover in East Usambara compared to limited availability and accessibility of natural forest in Bungo landscape. Based on this, we position East Usambara and Bungo in similar level of y-axis but different side of x-axis with regards to the lowest possible forest cover level.

Spatial pattern of deforestation across the five landscapes can be summarized based on topography and accessibilities depending on the stage of forest transition:

- In landscapes with varying surface roughness, i.e., relatively flat in one part and rough in others, early deforestation take place in flat areas with high accessibilities and in the later stage in the edge of remnant primary forest blocks which partly is protected by law and topography (Bungo and East Usambara)
- In uniformly flat landscapes with low access, early deforestation predominantly happens along the river and road network and expands from there (Takamanda-Mone) and once forest is more fragmented, deforestation also happens in the form of encroachment of primary forest block as well as expansion of those along the transportation network (Manompana)
- When a landscape is almost uniformly rough in terrain with low accessibility, deforestation follow settlement placement in areas which is relatively flat locally and close to the river (Viengkham)

Each of the five landscapes has some protected areas delineated within it. If treated in segregated manner, the protected areas will be left as isolated small island(s) of submontane primary forest (see the case of Bungo and East Usambara). In this case, at the landscape level conservation of biodiversity will not be achieved for at least two reasons: (i) management and enforcement are often weak, (ii) protected areas are often delineated in remote, rough terrain areas which does not represent various ecoregions with various species assemblages and endemism (only α -diversity is maintained but not β - and γ -diversities), (iii) the extent of protected areas sometimes are not large enough to allow minimum viable population such that in the long run species extinction might continue to happen, (iv) protected areas without buffer zones and corridors can easily be isolated areas rather than integral part of a landscape. Multifunctional landscapes that accommodate conservation and development need to be considered as an integrated, rather than segregation,

systems; this can answer the necessary-but-not-sufficient problem of protected areas. Land use plan that aims to increase multifunctionality of landscapes should be informed by the current status of landscape composition and configuration, process of land use/cover changes in the past and future, areas that are vulnerable to changes in the future and options for intervention. The land use planning process should be conducted within a negotiation process among multiple stakeholders.

Global Landscape composition

Two global landscape composition indices presented here are Modified Simpson's Diversity (MSDI) and Evenness Indices (MSEI). Please note that the Simpson's Indices here are used as measures of diversity of patches, and therefore habitat, rather than biodiversity measures (Figure 36 and 37).

Landscapes like Cameroon-Takamanda Mone which is highly dominated by forest in large contiguous patch show very low diversity and evenness indices. The other four landscapes show comparable diversity indices, but different temporal pathways. Whilst with deforestation and forest conversion, MSDI tends to increase in the Bungo landscape over time, there is period of drop in diversity index between 1999 and 2002 within which tree-based systems dominate the landscape. More recently, with some conversion of tree-based systems into more intensified cropland and others, diversity index increased again (Figure 36). Relative MSDI and MSEI in each site across time is consistent, however across landscape, Viengkham, Manompana and East Usambara landscapes show much higher MSEI than the other two, showing that composition of land use/cover classes are much more even in the three landscapes, while Takamanda landscape is highly dominated by forest and Bungo by tree and forest cover (Figure 37).

MSDI and MSEI in tandem with information on dominant land use/cover type can be used as a quick indication of landscape composition and forest transition stage. Low MSDI and MSEI with forest domination suggest early stage of forest transition (Takamanda-Mone), while high MSDI show broad portfolio of land use/land cover types. In the case of uniform number of land use/cover types under quite general classification scheme, comparison across sites is not very useful but across time within a landscape is quite useful. In the case of Bungo, where the stage of forest transition has reached the turning point from the lowest forest and tree cover fraction, it can be seen that MSDI increases with forest as the dominating land use/cover type until 1993, and MSDI decreases when tree cover took over as the dominating land use/cover type in 1999. MSEI shows similar pattern except that it is normalized by the number of land use/land cover types. Landscapes of Viengkham, Manompana and East Usambara show increasing and very high MSEI over time, indicating that apart from forest, the extents of other land use/cover types are very similar from each other, whilst those of Bungo are not.

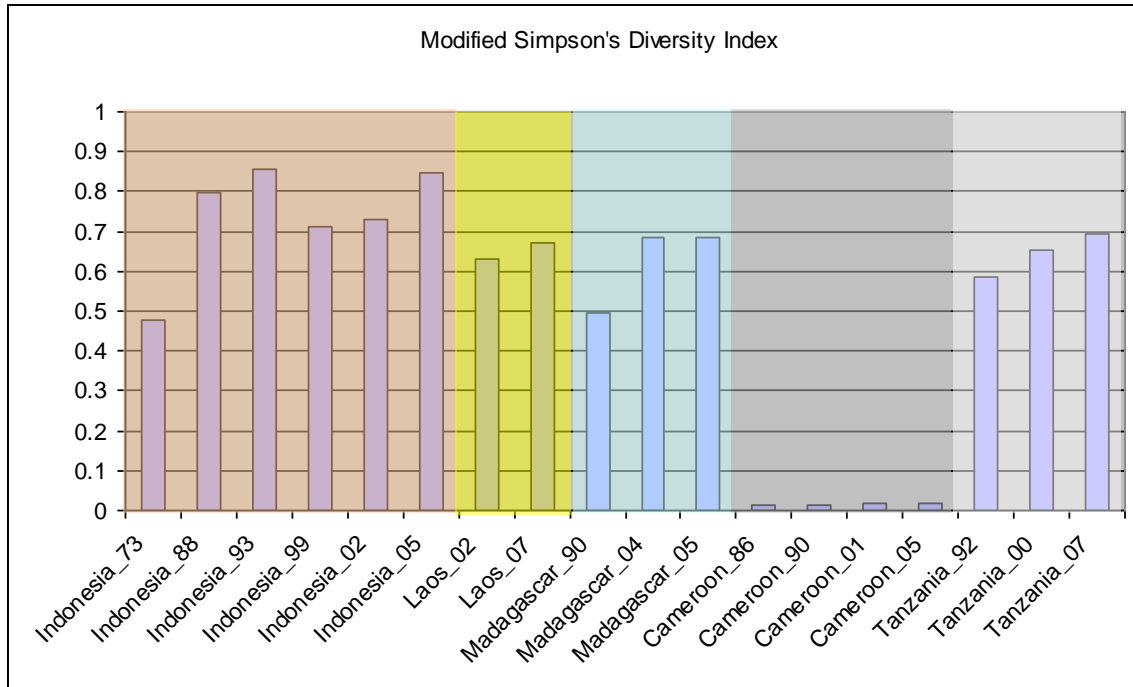


Figure 36. Modified Simpson's Diversity Index

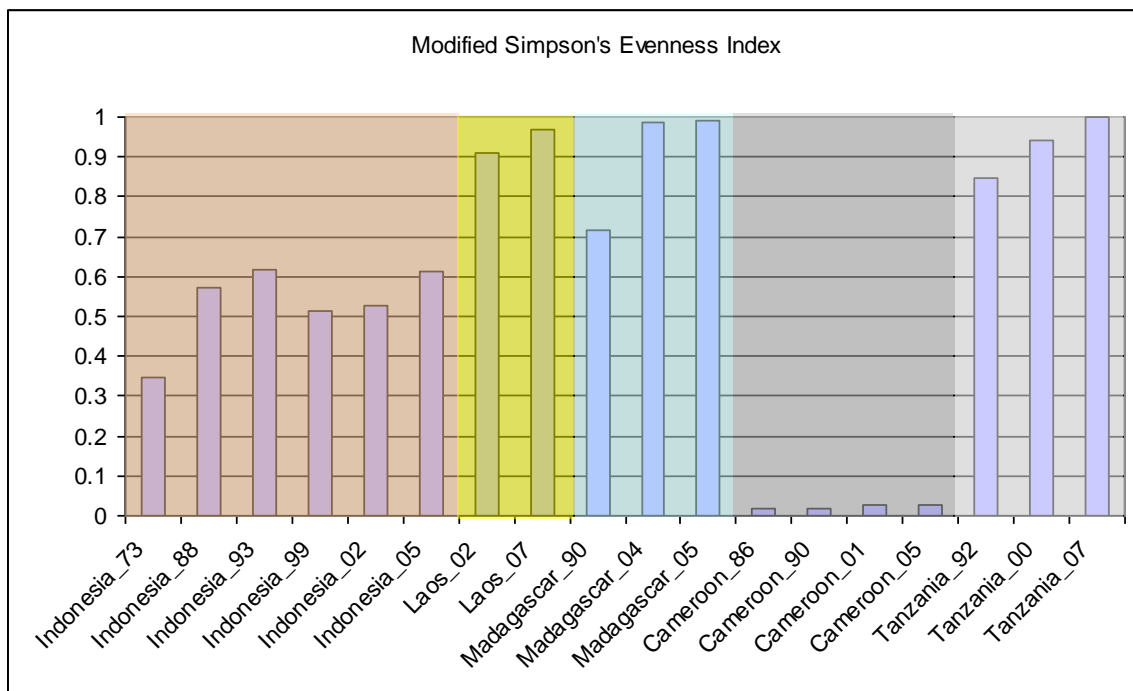


Figure 37. Modified Simpson's Evenness Index

Global Landscape configuration

We selected three global landscape configuration indices to be presented and discussed here in regard to the relevance of our objectives and research questions. *Total area of forest* is relevant in terms of minimum habitat size of organisms, considering encroachment and invasion from the edge; *Aggregation Index* of forest is highly relevant since it shows how likely patches of forest are clumped together such that it reflects fragmentation of habitat, whilst *Connectivity Index* of forest captures the likelihood of other forest patches to be found in a specified radius of a particular forest patch, even if they are not contiguous. This allows the roles of matrix (non-habitat) and the radius should highly be set specific to species based on dispersal ability. The two last indices are normalized such that comparison across landscapes can be done directly. Combination of the three indices should be able to capture some ecological processes that reflect biodiversity at the landscape level.

After a continuous sharp decline of Total core forest area (in hectares) over time in Bungo landscape, at present it is comparable to those of Takamanda-Mone. However in terms of proportion, Bungo total core area is much lower than Takamanda-Mone. While Bungo show the sharpest decline in total core area, Manompana and East Usambara show comparable rate, and Takamanda-Mone shows a much slower rate. Viengkham landscape shows increases in total core area, mostly due to increases of tree cover which reduces pressure of encroachment from the edge of forest block, even though forest cover does not increase in extent.

Aggregation index is highest in Takamanda-Mone, followed by Bungo landscapes, showing the clumpiness of forest in the landscape. Manompana and East Usambara landscapes experience sharp declines in Aggregation Index over time, showing the rapid rate of fragmentation of existing primary forest blocks. Viengkham landscape show relatively low connectivity index despite of high aggregation index showing that when not contiguous, forest patches located sparsely. These landscape level indices and changes over time can be an early indication of the types of species that might be endangered. Species which is general in habitat requirement is less sensitive to the reduction of total core area, while specialist is prone to extinction with sharp and fast decreases in total core area. Species with high ability to migrate is not sensitive to reduce in aggregation given that it does not happen very rapidly, but those without that ability is prone to extinction. Widely dispersed propagules will allow species to survive even when connectivity is available at a relatively large radius but those that do not disperse widely will be prone to extinction with lower connectivity. In East Usambara landscape, for example, specialist species will be threatened, as well as species that does not move across the landscape well, and species that does not disperse well.