Landscape Dynamics Over Time and Space From Ecological Perspective

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About the authors

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Sonya Dewi is a landscape ecologist with formal backgrounds in soil science, computer science and theoretical ecology. She works extensively on broad tropical landscape issues from assessment of livelihoods, environmental services, identification of opportunities and constraints on sustainable livelihoods through multifunctional landscapes to studies of spatial land-use planning principles and practices. She also researches possible mechanisms for rewards for environmental services schemes, including in climate change mitigation through REDD+.

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Abstract

Land-use and land-cover changes driven by multiple factors have a tremendous impact on services provided by the environmental as well as the livelihoods and economic development of people living in, and far from, particular landscapes. For biodiversity in particular, landscape configuration is as important as landscape composition especially where there is increasing fragmentation and reduced connectivity of habitat.

Protected areas alone 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 in remote, rough terrain that does not represent various eco-regions with various species assemblages and endemism; (iii) the extent of protected areas is sometimes not large enough to allow minimum viable populations so that in the long run species extinction might happen nevertheless; (iv) protected areas without buffer zones and corridors can easily be isolated rather than integral parts of a landscape.

Multifunctional landscapes that accommodate conservation and development need to be considered as integrated, rather than segregated, systems; this will allow us to achieve the objective of maintaining biodiversity at the landscape level. Land-use plans that aim to increase multifunctionality of landscapes should be informed by the current status of landscape composition and configuration, the process of land-use and land-cover changes in the past and planned for the 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.

Our research provides some results to be used as a basis for negotiation, which are produced from a combination of tools for 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 analyses of five landscapes (Bungo in Indonesia, Viengkham in Laos, Manompana in Madagascar, Takamanda-Mone in Cameroon and East Usambara in Tanzania) use the same methodology and tools, allowing comparisons across sites. Deforestation rates and land-use and land-cover changes across landscapes 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 patterns of deforestation, depending on landscape topography, level of accessibility and the state of forest transition, either are concentrated in relatively flat areas in the landscape, follow encroachment patterns on the primary forest block, run along the transportation network or expand from existing settlements. 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 so 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

Contents

Introduction

Loss of habitat and fragmentation of habitat owing to agricultural expansion are the primary causes of loss of biodiversity across the planet (Sala et al. 2000, Tilman et al. 1994, Tilman et al. 2001, 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). With extinction debt, loss of biodiversity is better explained by the history of land-use and land-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 specialised herbivory (Krauss et al. 2010) highlights the importance of acting now in halting fragmentation and inducing connectivity to avoid greater loss of biodiversity in the future (Lindenmayer et al. 2008, Krauss et al. 2010).

Meta-analysis of the impacts of fragmentation on biodiversity is scarce. Spatial variability and spatial dimension need to be included, too, thereby integrating traditional statistical analysis with spatial analysis (Ewers et al. 2010). Owing to a lack of long-term and large-scale biodiversity data for tropical landscapes (Collen et al. 2008), research into extinction debt and meta-analyses of fragmentation impacts on tree diversity cannot be conducted for these landscapes.

The potential roles of agroforestry in biodiversity conservation have only begun to be better understood, primarily as refugia habitat of biodiversity, as a matrix to connect nature reserves, to reduce pressure on natural ecosystems and the risk of alien invasive species and by enriching valuable species through planting schemes in multifunctional landscapes (Bhagwat et al. 2008, McNeely and Schroth 2006, Swallow and Boffa 2006, van Noordwijk 2006). A review of the literature, 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 systems ranges while similarities range through 25–69% (91% of the cases show 39–61% similarities) compared to primary forests (Bhagwat et al. 2008). Agroforestry systems also maintain belowground biodiversity (Giller et al. 2005). Yet, most species shared between agroforests and forests are habitat generalists (Uezu 2008 for birds in agroforest woodlots of Brazil; O'Connor 2005 for birds in coffee agroforests of Indonesia; Rasnovi 2005 for trees in rubber agroforests of Indonesia). Distance to forest, configuration of landscape, age of agroforestry plots, intensity of management and canopy density of the agroforest determine the richness and similarities of biodiversity of an agroforest plot with a natural forest. Agroforests could not and should not replace natural forests; an agroforest's role is optimum when it is situated in the middle zone within a multifunctional landscape where trade-offs between conservation and development are necessary. An 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 use over space in order to understand the changes in states and the threats and opportunities for intervention to maintain biodiversity. Composition and configuration of a landscape mosaicked by various land uses and covers, along with biophysical and ecological

considerations, should be addressed in assessing biodiversity in a (fragmented) landscape, both at global and local landscape levels.

In most tropical landscapes, however, landscapes are also very dynamic temporally. The pattern and location of changes are rarely random. The drivers of land-cover changes determine the extent, pattern and location of changes. These drivers can also change rapidly owing 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 factors and indirect land-use drivers. Land-use and land-cover changes affect biodiversity indirectly through habitat changes (habitat loss and changes in global and micro-climates) by changing the landscape's composition and connectivity, altering its 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 with them, 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 an integrated 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. 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. Mapping is a universal way to capture spatial variabilities and can be an effective tool in communicating results to decision makers as well as negotiating interventions to achieve a 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 analyses. Land-use and land-cover changes are predominately the result of economic processes. These changes are detectable with 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 and roads, we can infer some mappable activities that directly affect biodiversity and correlate with land-cover and land-use types. Therefore, even though the overall

ecological processes affected by livelihoods and other economic drivers cannot be covered in great detail, we can still understand matters at a coarser level, which is sufficient for a landscape scale.

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 five study areas of the project: Bungo (Indonesia), Viengkham (Lao PDR), 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 (five sites and comparison)
- Landscape dynamics over space: connectivity, hotspots of threat (local landscape composition and configuration) (five sites and comparison)
- Landscape dynamics over time and space: changes in connectivity, hotspots of threats (changes in local landscape composition and configuration) (five sites and comparison)
- Synthesis of comparisons among the five sites

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

Materials and Methods

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

Dynamic changes in land use and cover over time and space are captured both using area-based (non-spatially explicit) analysis and location-based (spatially explicit) analysis. Visualisation 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 with the threats.

Table 1. Periods of analysis based on satellite image availabilities

No	Site	# 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 79 m (Multipectral scanner/MSS) to 30 m (Thematic Mapper/Enhanced Thematic Mapper-TM/ETM). Most recent images were captured by SPOT sensor. The resolution is 10 m for multispectral channel and 2.5 m for panchromatic channel. Table 2 shows the complete list of datasets used in this study.

Landscape dynamics over time

Landscape dynamics over time were assessed by conducting independent classifications and land-cover-change analysis for each site. The main objective of this 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 an object-based, hierarchical classification approach using Denifiens software, while land-cover-change analysis was conducted using a post-classification comparison approach with ArcGIS. Accuracy assessment was the last step to ensure the quality of information produced by image classification. However, at this stage, owing to the non-availability of groundtruthed data at most sites, the accuracy has not yet been calculated.

We used level two of our classification hierarchy, which is comprised of 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, for example, cropland, grass, shrubs (young natural re-growth)
- Non-vegetation cover: cleared land
- Settlement: cleared land with physical man-made buildings on top.

For the land-cover-change analysis all datasets were re-sampled into 30 x 30 m pixel size, despite the variation in spatial resolution of Landsat and SPOT images. Change analyses were then conducted post-classification and resampling, that is, by overlaying pairs of land-use and land-cover maps from different time periods and cross-tabulating the two for location-based change analysis or simply by quantifying the area of each land-use or land-cover class in each time period and comparing those across different time periods for area-based change analysis. These analyses captured the landscape composition and changes in 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, owing 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 Lao PDR and Madagascar)

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

We used FRAGSTAT software to calculate some landscape and class indices for pattern quantification. We selected a few indices only, among a large number made available by FRAGSTAT, based on the uniqueness of information expressed by the indices, since many indices highly correlate to each other, and on their relevance 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) levels. Global-level indices are calculated for the entire landscape while the local level indices are calculated based on a specified window size.

Modified Simpson's diversity and evenness indices are used to capture landscape composition while total core area, aggregation index and connectivity index measure landscape configuration, with the connectivity index reflecting 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 one patch (that is, 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 (that is, no diversity) and equals 1 when distribution of area among patch types is perfectly even (that is, 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 likelihood of patches of corresponding classes being 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 normalised so that they are not sensitive to sizes of landscapes to allow direct comparison of landscapes of varying extent.

We use the same parameters across landscapes at the five study sites.

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	
on				

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

The edge depth parameter assumes that the encroachment on forest by tree-based vegetation is 200 m while non-tree and non-vegetation are half of that of tree-based. The similarity parameter assumes that tree-based vegetation 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 from the assumption that only the overall patterns at landscape level matter and variations within a landscape can be ignored. However, for a large enough landscape and for small- body species or species that only forage or disperse narrowly, local variations in sub-landscape level are at least as important and therefore it is crucial to quantify patterns locally over a landscape space. The direct application might be 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-landscape. These computations require extensive processing power, especially for large landscape, high resolution maps and a large number of classes or land-cover types. Re-sampling from the original resolution to a coarser resolution is needed for these computations owing 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.

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 for further exploration using different sets of parameters. Further, these results will be analysed and summarised under the what-if scenario and projections of land-use and land-cover changes.

Results and discussion

Landscape dynamics over time

This section describes the current land cover, temporal changes, location changes and drivers in each landscape and then discusses them across landscapes. We also present descriptions of global landscape composition and configuration of landscapes over time.

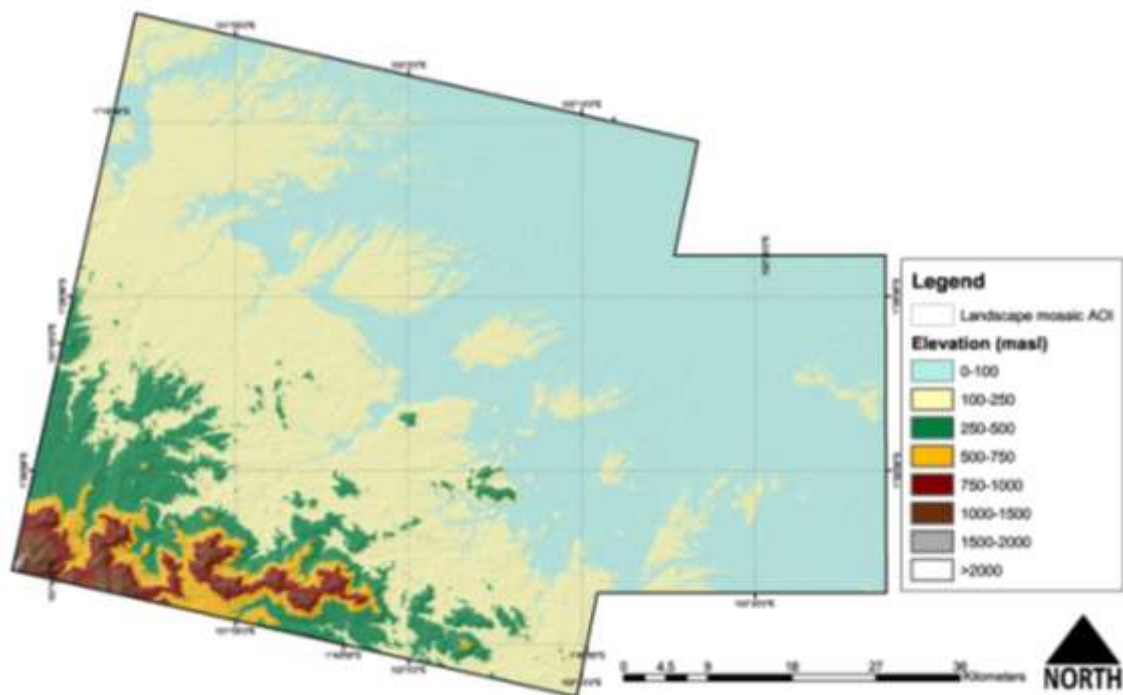**Indonesia (Bungo)**
Topography and current land cover

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

The landscape of Bungo is composed of lowlands in the northeast and submontane ecosystems in the southwest with rough topography. Most of the submontane area is designated as protected areas and currently this is the only large primary forest block left in the landscape.
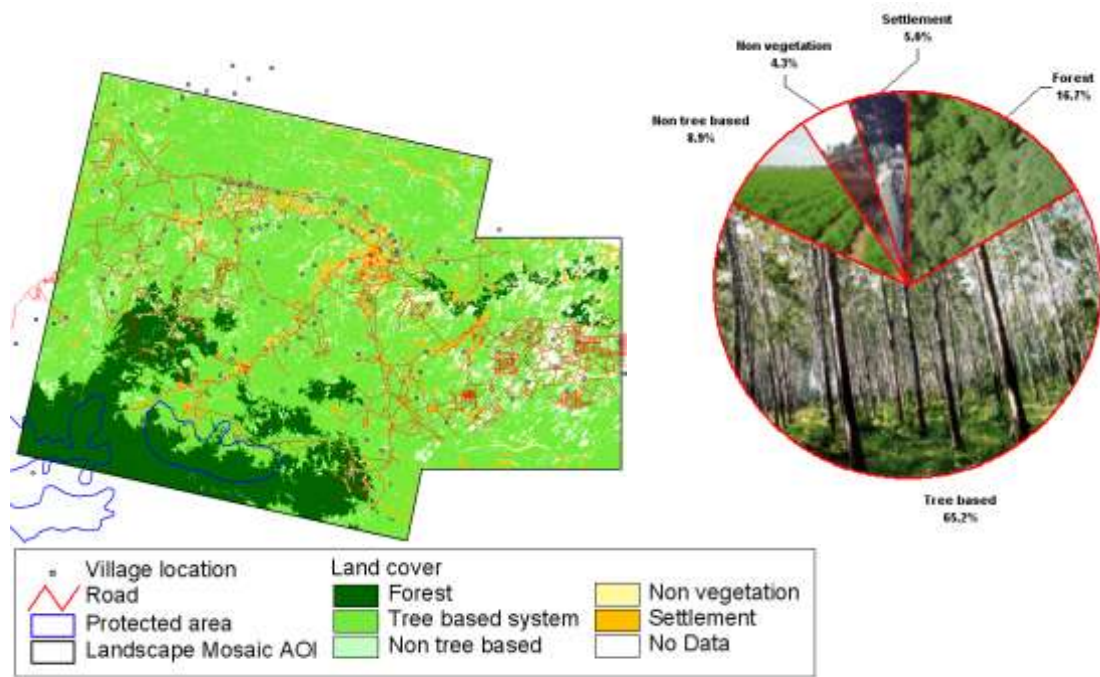
Figure 2. (a) Land-cover map of Bungo site in 2007 (interpreted from SPOT 2007); (b) Landscape composition in 2007

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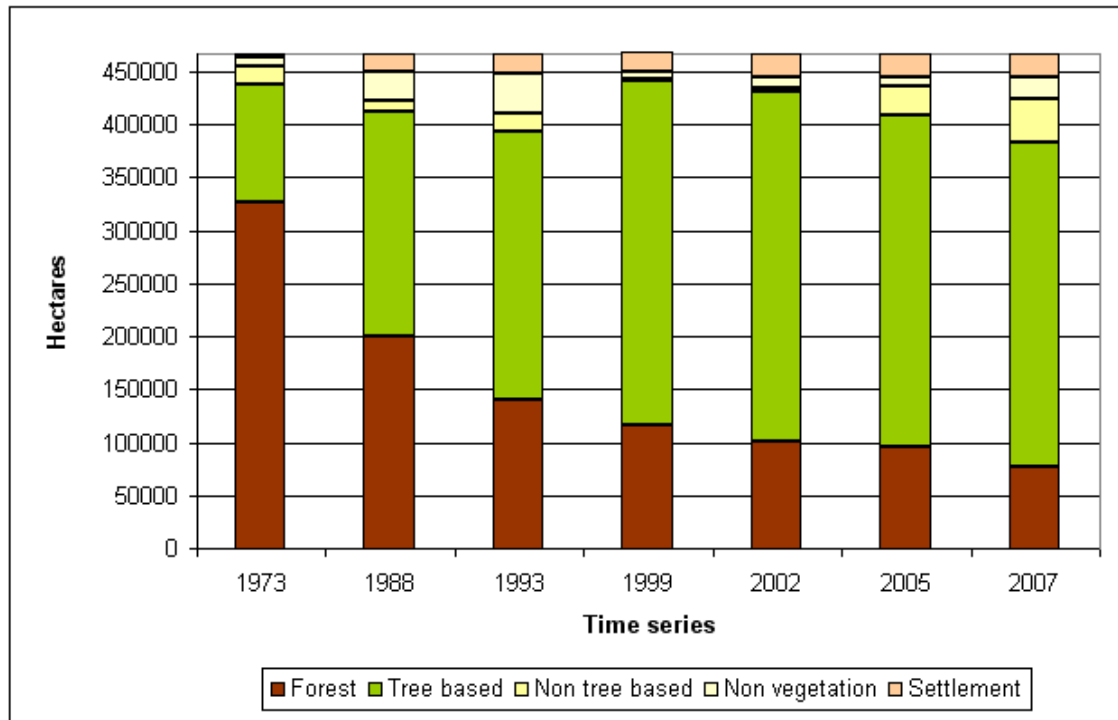
Temporal pattern

Figure 3. Time series, 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 has become the dominant land cover since then (Figure 3). This tree-based land cover continued to increase until 1999 (period II), when it stabilised. During period III, changes were within the 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 the focus is on biodiversity. At the time of writing this interim report, we had not yet finalised 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 obtain more groundtruthed data.

	Forest	Tree based	Non tree based	Non vegetation	Settlement
Forest					
Tree based					
Non tree based					
Non vegetation					
Settlement					

(a)

	Forest	Tree based	Non tree based	Non vegetation	Settlement
Forest					
Tree based					
Non tree based					
Non vegetation					
Settlement					

(b)

	Forest	Tree based	Non tree based	Non vegetation	Settlement
Forest					
Tree based					
Non tree based					
Non vegetation					
Settlement					

(c)

Figure 4. Patterns of changes in three study periods: (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 east toward the west (Figure 5 and 6). The common characteristics have been that forest loss started from lowland areas by timber harvesting that provided higher economic benefits, followed by clearing and conversion to either timber plantations, estate plantations, rubber agroforests, cropland or settlements. The most recent deforestation occurred on the edges of the major primary forest block mostly found in higher altitudes only.
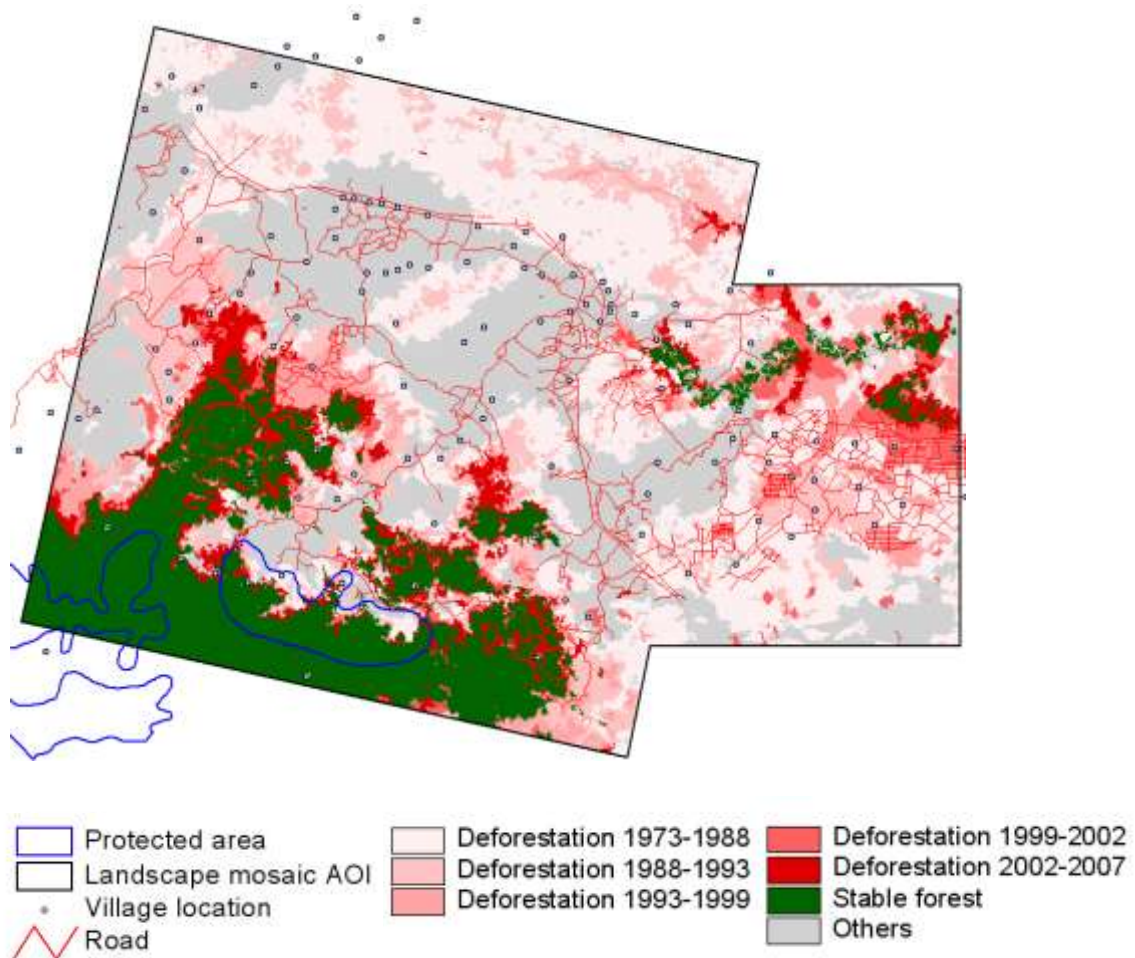
Figure 6. Location of deforestation in each time period at the Bungo site

Drivers

For the Bungo site, which the spatial analysis team had been visiting repeatedly and where a long-term study had been conducted, our understanding of drivers of changes has been strong and several important agents of change over time have been identified (Ekadinata and Vincent 2008).

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

1973 **1988** **1993** **1999**

2002 **2005** **2007**

	Village location	Land cover		
	Road	Forest		Non vegetation
	Protected area	Tree based system		Settlement
	Landscape Mosaic AOI	Non tree based		No Data
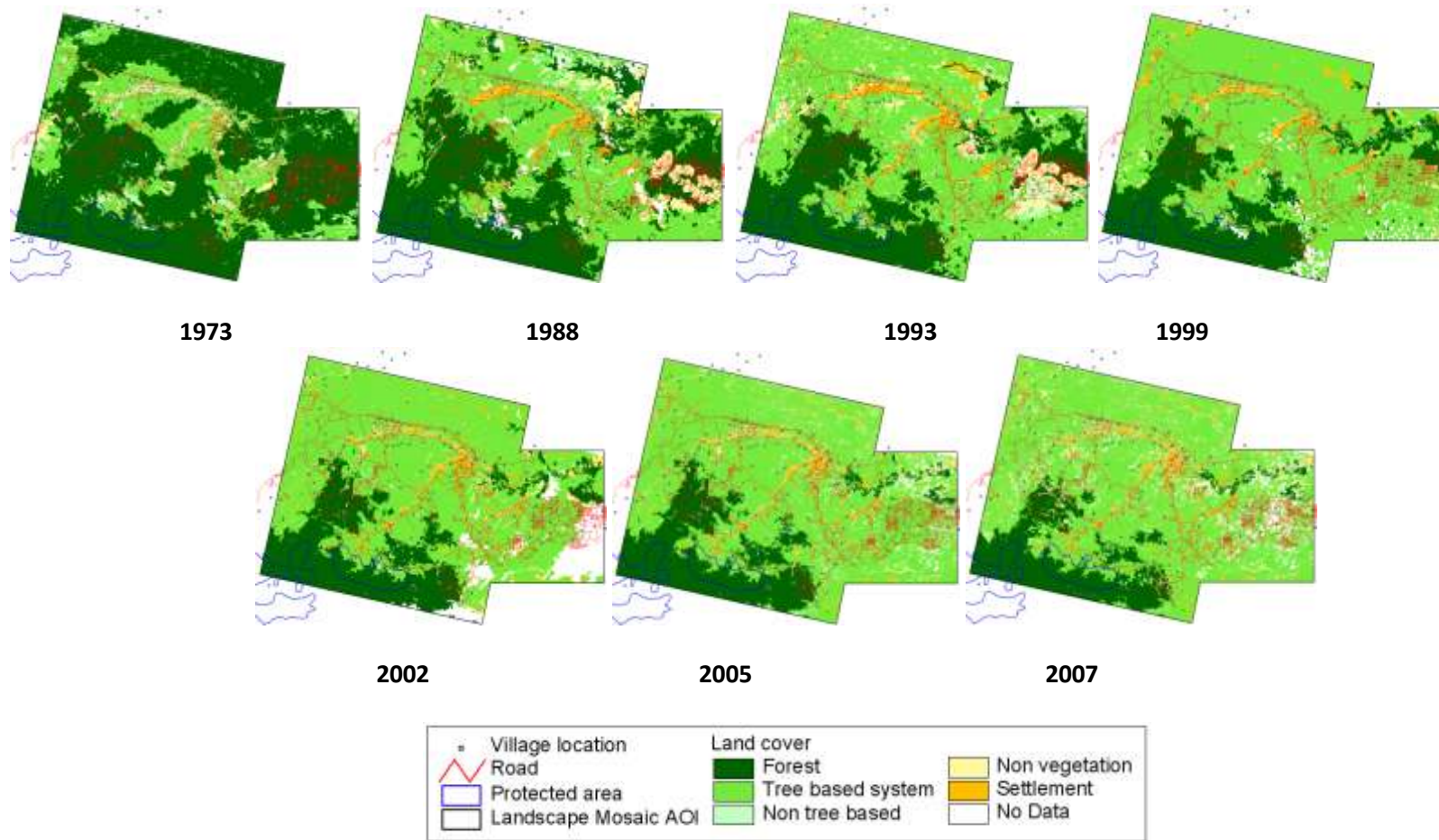
Figure 5. Time series, land-cover maps of Bungo site

On smallholder-managed land, during the first period the dominant land uses were rice fields, 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 and 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 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 fibre, both under large- and small-scale concessions with out-grower schemes. This latest trend is driven by global demand for oil palm and rubber and regional demand for raw materials for pulp and paper owing to depletion of natural forest and improved law enforcement. Following the 'anarchy' period caused by the euphoria of the enactment of the decentralisation law, which resulted in lack of clarity and uncertainty over land tenure (aspects of which have not been resolved up to now), land grabbing by farmers was quite prevalent. A discussion of the overall forest and landscape governance issues of Bungo can be found in Martini et al. (2010).

The transmigration program, facilitated by the government, has also been active. This involved people migrating from the surrounding area, known as local transmigration, and from Java. Associated with this program was 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 has become a new driver of land-use and land-cover changes in the area. Despite this, Lubuk Beringin, one of the villages within the Bungo landscape, has been awarded a Hutan Desa (Village Forest) permit, the first in Indonesia (Akiefnawati et al. 2010).
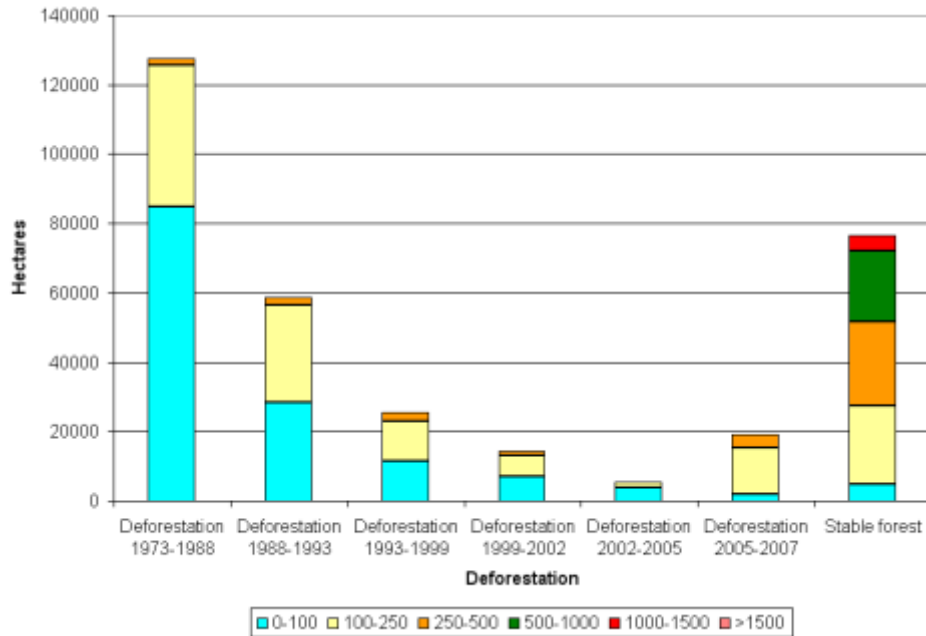
Figure 7. Forest loss (in hectare) in each time series by elevation class

Access (river or road network)

In the past, people depended on rivers for their transportation network but, lately, the road network has become well established; most settlements in Bungo are now connected to larger townships by road. The location of deforestation in Bungo 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 the 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, threatening the buffer area of the national park with forest degradation, if not deforestation.

Lao PDR (Viengkham)
Topography, current land cover and description
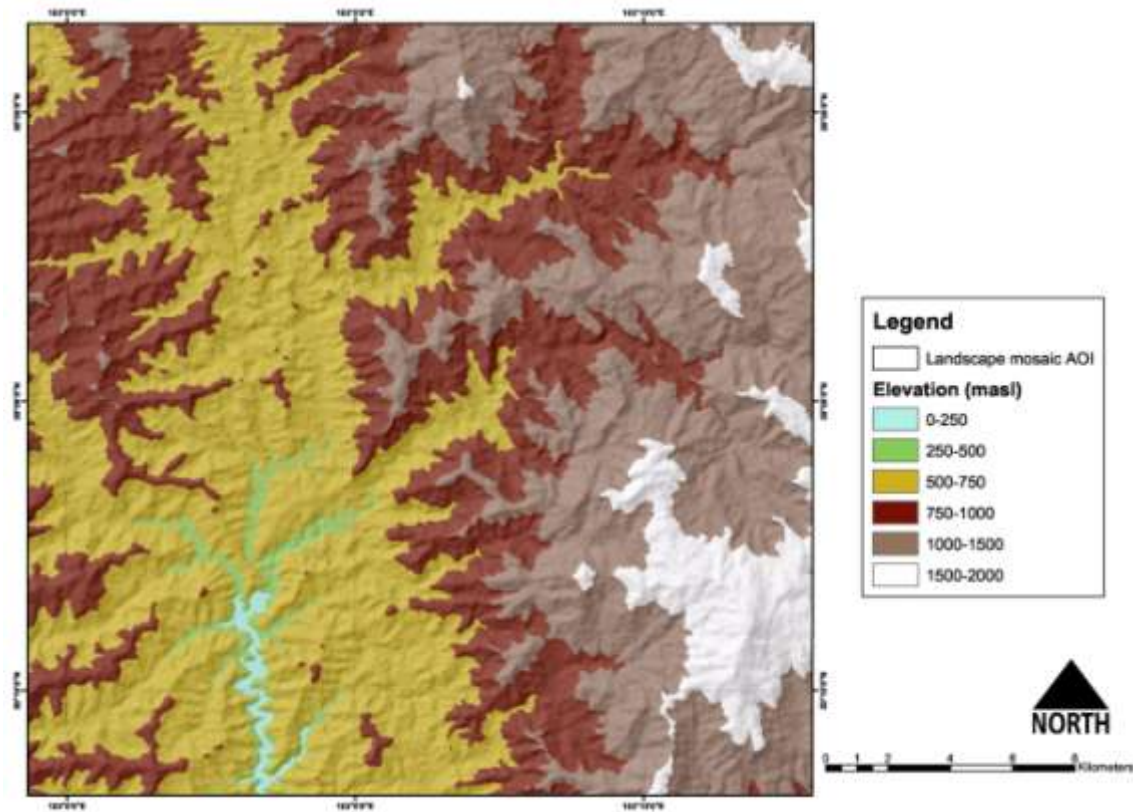
Figure 8. Elevation of Viengkham site ranges from 400 to 2200 metre above sea level

The landscape of Viengkham is dominated by a montane ecosystem with rough topography, especially in the eastern half of the area and some parts of the northwest (Figure 8). Among the five sites of the project, Lao PDR is highest and roughest in terms of topography.
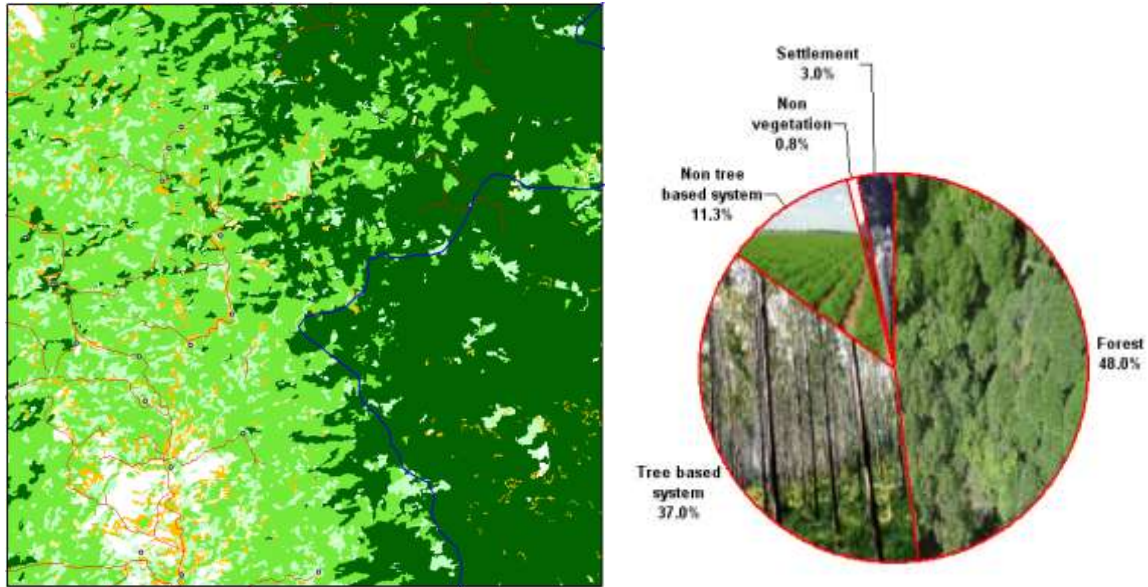
Figure 9. (a) Land-cover map of Viengkham site in 2007 (interpreted from SPOT 2007); (b) Landscape composition in 2007

Almost half of the landscape is covered by natural forest and 37% with tree-based systems (Figure 9), which is most likely natural re-growth (fallow) that is part of 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 two, very limited, time-series, land-cover maps (2002 to 2007) we have produced so far, during the past five 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 (Figures 10 and 11). These changes are perhaps due to the fallow period that allows natural regrowth of shrubs and trees. Seasonality might affect the spectral reflectance and the limited number of maps also constrains us from saying more about the patterns. In the future, this barrier will be addressed by looking for other image sets that are relatively cloud free.
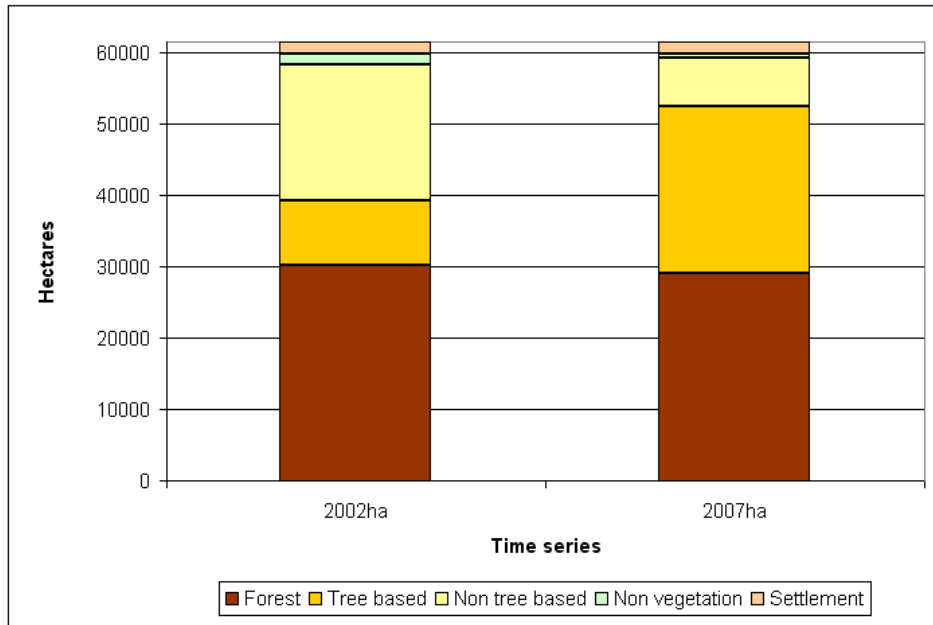
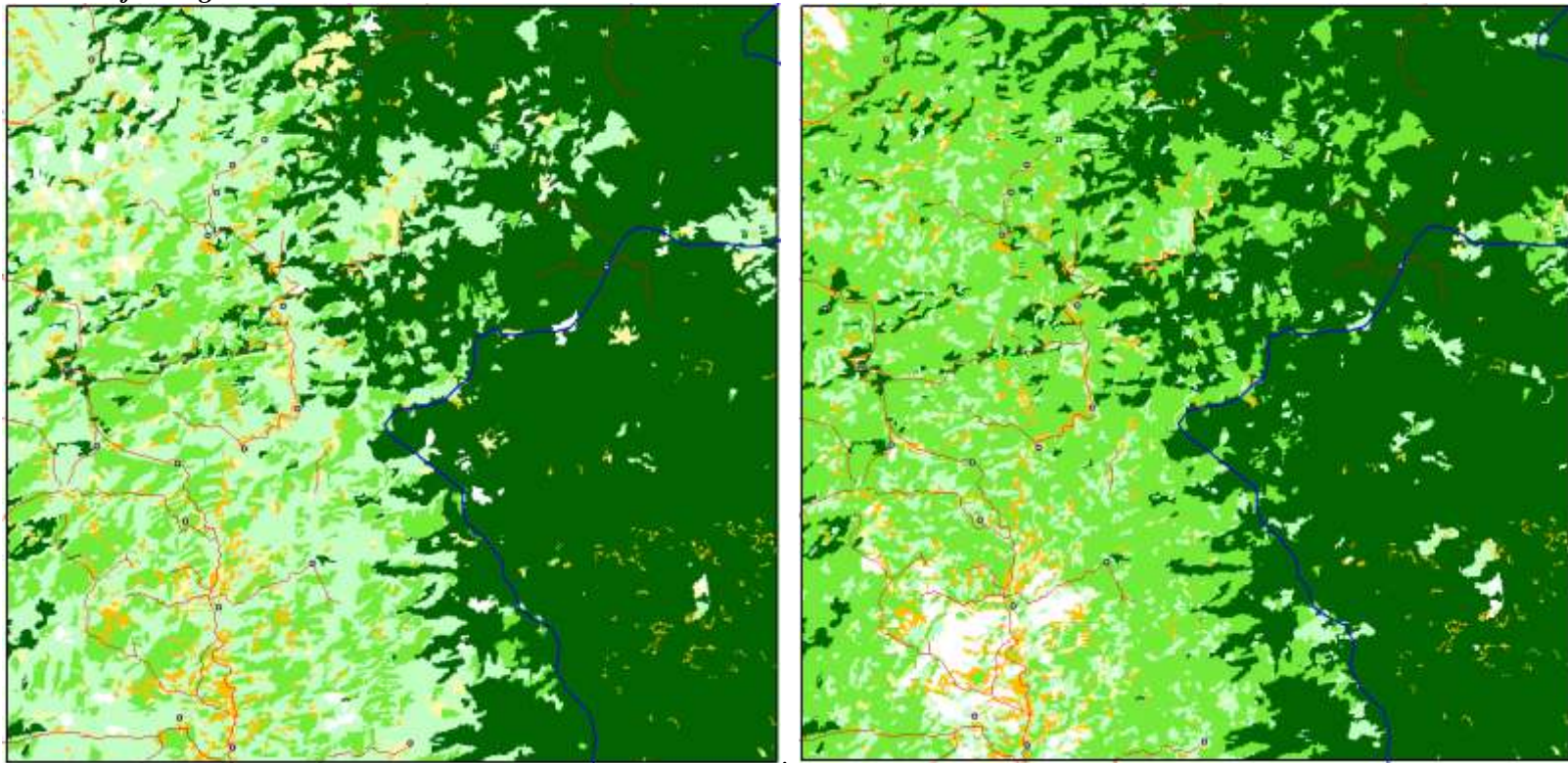**Figure 10.** Time series, land-cover composition of Viengkham site

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 was relatively low (or outside the protected areas), changes to tree-based land cover have occurred during the past five years (Figure 12). Some deforestation happened within the primary forest block, 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

	Village location	Land cover			
·	Village location		Forest		Non vegetation
/\	Road		Tree based system		Settlement
	Protected area		Non tree based		No Data
	Landscape Mosaic AOI				

Figure 12. Time series, land-cover maps of Viengkham site
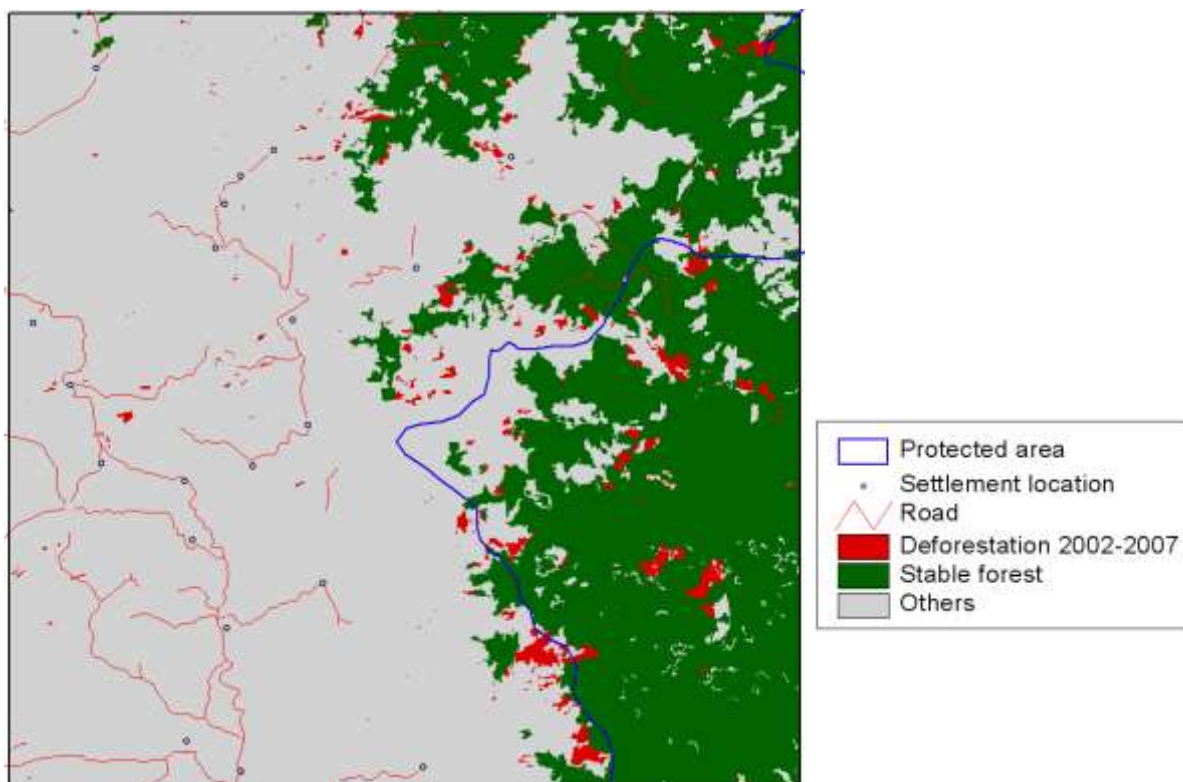
Figure 13. Location of deforestation at the Viengkham site

Drivers

Agents

Deforestation has occurred in the protected area. Dense forests have become scarce in agricultural landscapes with relatively high accessibility and remain only in less accessible areas. The typical landscape consists of patches of different gradients of vegetation from degraded forest to grassland and is 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 non-timber forest products (bamboos, grasses for brooms, mushrooms). Teak cultivation is limited owing to land tenure issues and availability. Technical limitations are also marked, for example, in the case of eaglewood. Rubber planting is of interest to local people but there are very few trials, mostly owing to the rough terrain and difficult market access. Population density of this landscape is very low. Shifting cultivation is the dominant land-use system in the area. In 2004, the government enacted a 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 for deforestation and degradation.

Topography

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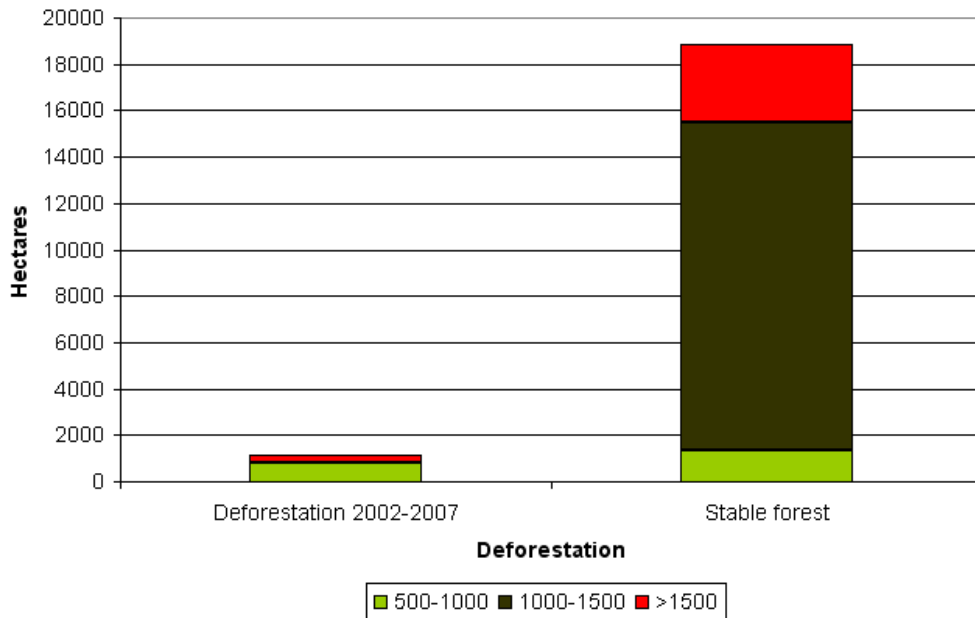

Figure 14. Forest loss (in hectare) by elevation class

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 non-timber forest products or grow upland rice. Some major rivers are still functioning as transportation networks but in most upland areas road is the main, but limited, network.

Protected area

Phou Loei National Biodiversity Conservation Area covers 150 000 ha (category VI according to the United Nations Environment Programme's World Conservation Monitoring Centre). 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)

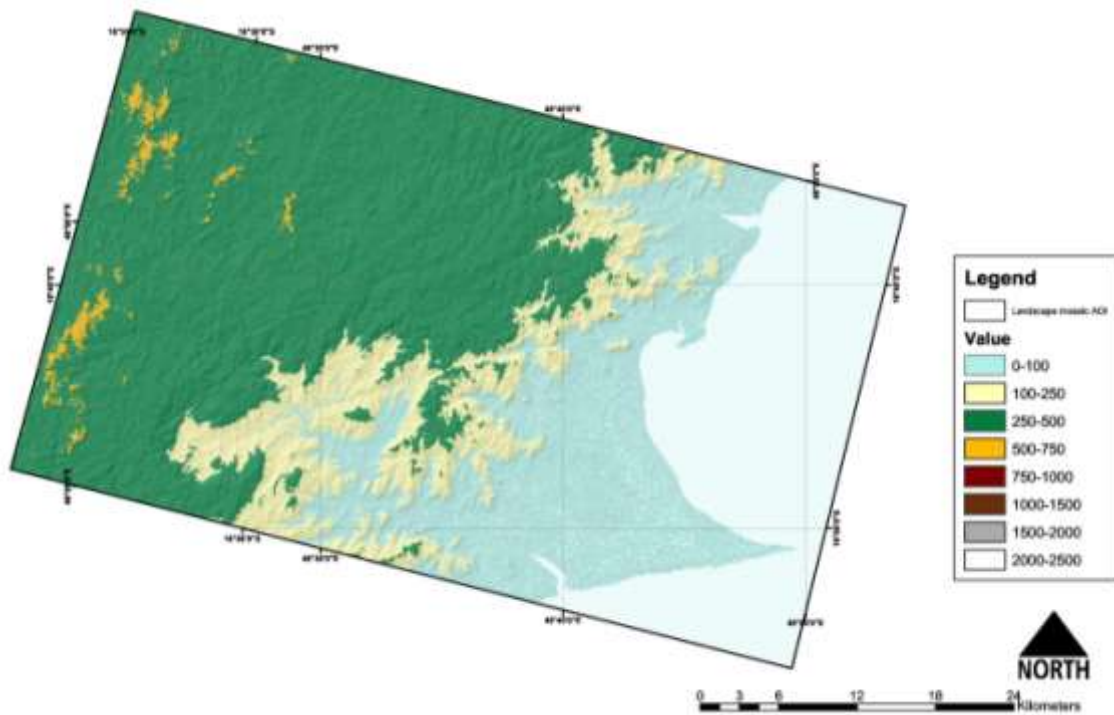*Topography, current land cover and description*

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

The landscape is dominated by a submontane ecosystem, with low to moderate topographic roughness, and a lowland area along the coast (Figure 15). Within the landscape, a fragment of forest is found on the coast while most forest cover is located in the hinterland. In 2005, the extent of forest cover was comparable to that of tree-based land cover and together they constituted two-thirds of the landscape (Figure 16).
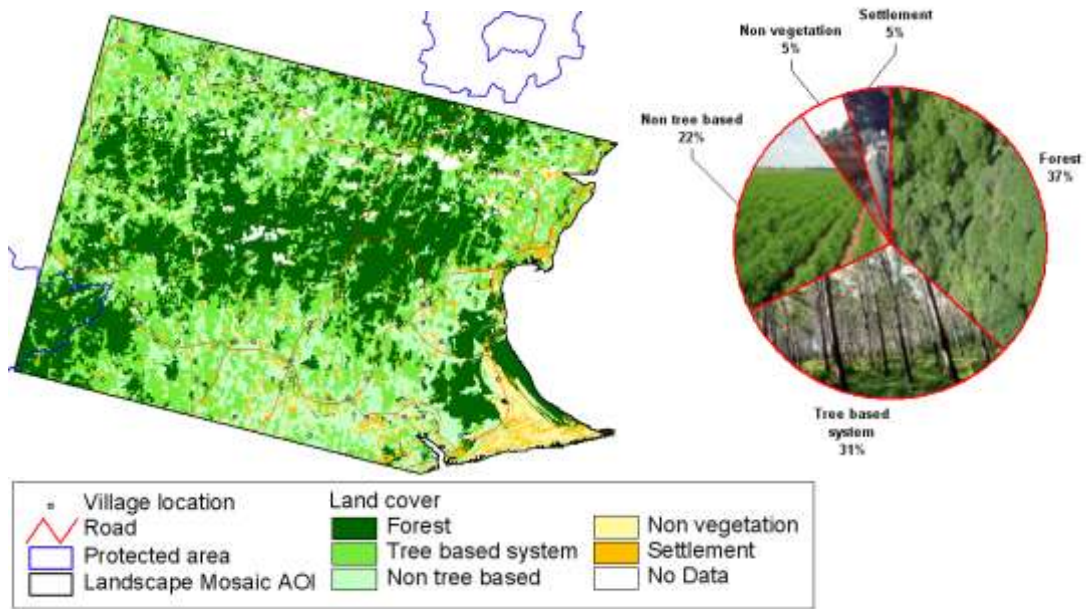
Figure 16. (a) Land-cover map of Manompana site in 2005 (interpreted from SPOT 2005); (b) Landscape composition in 2005

Temporal pattern
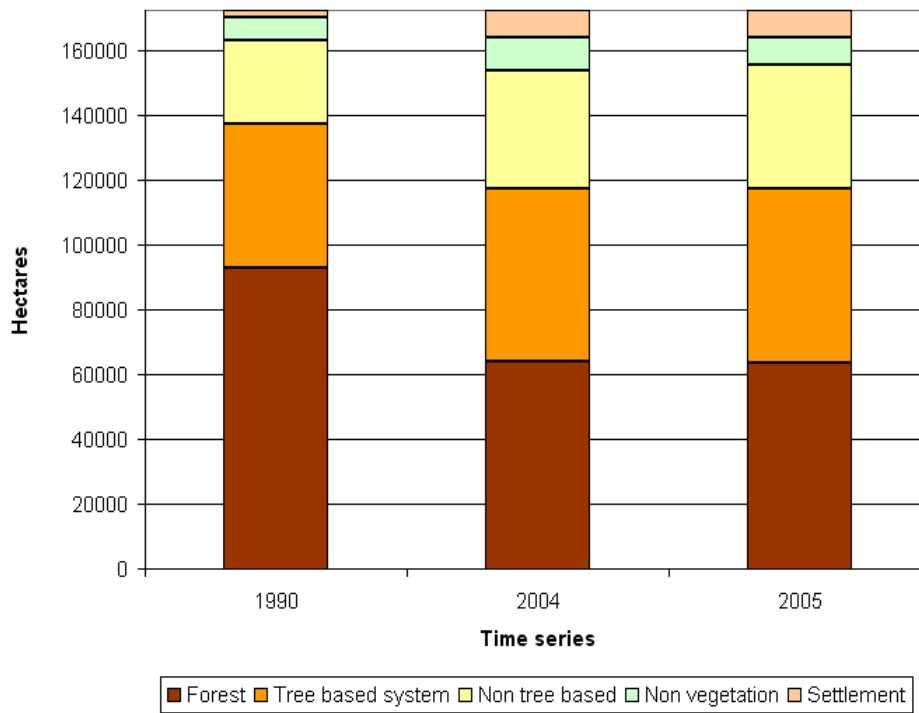
Figure 17. Time series, land-cover composition of Manompana site

A large amount of deforestation took place in period II and there has been little forest loss since (note that the observation period is only one year). Both tree-based and non-tree-based land cover increased as replacements to forest. It seems that while the extent of tree-based and non-tree based cover remains 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. (a) Pattern of changes in Manompana in Period II (1990 to 2004); and (b) Period III (2004 to 2005). Darker colors indicate larger annual changes in proportion

Location of changes

1990

2004

2005

Village location
Road
Protected area
Landscape Mosaic AOI

Land cover
Forest
Tree based system
Non tree based

Non vegetation
Settlement
No Data
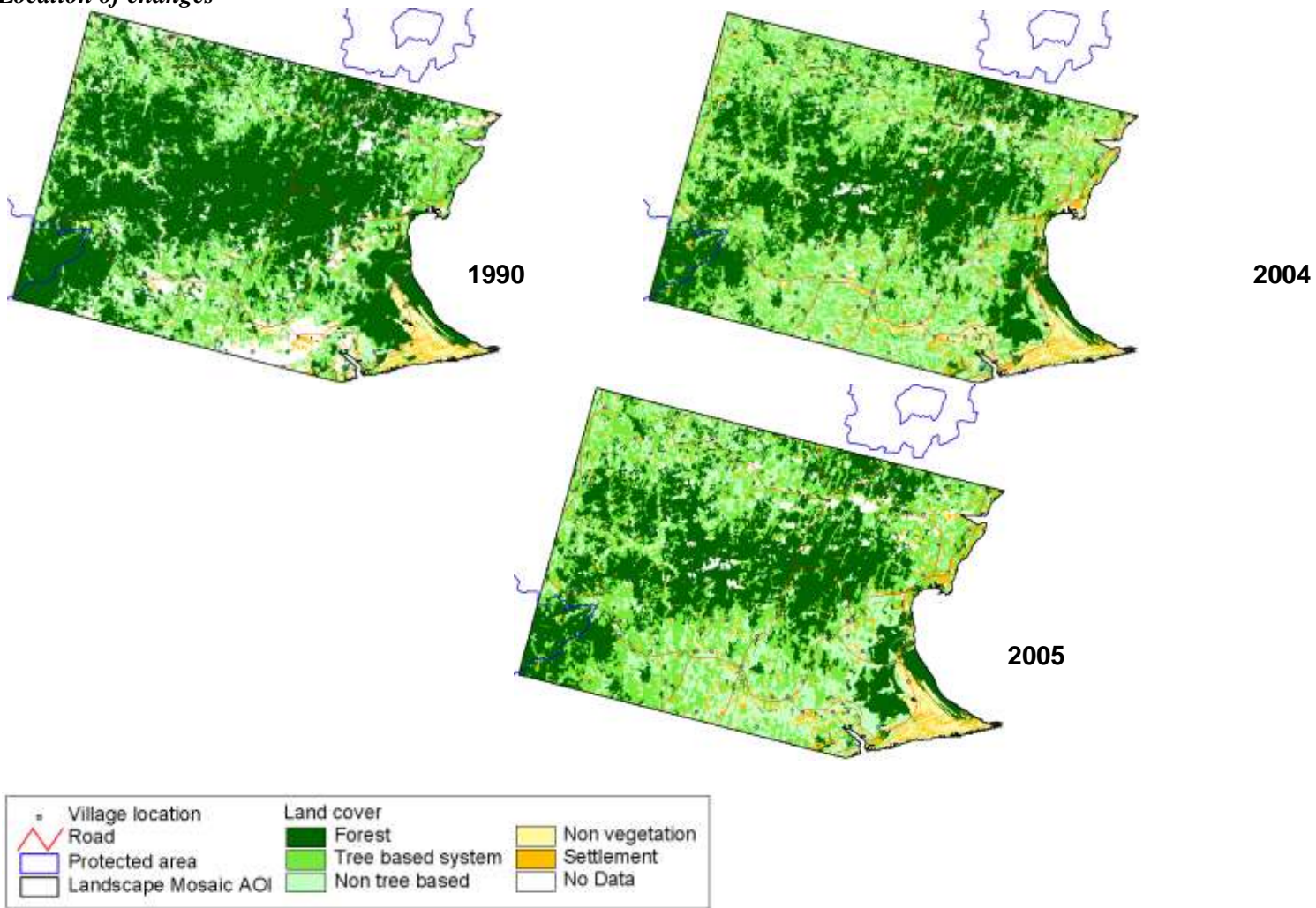
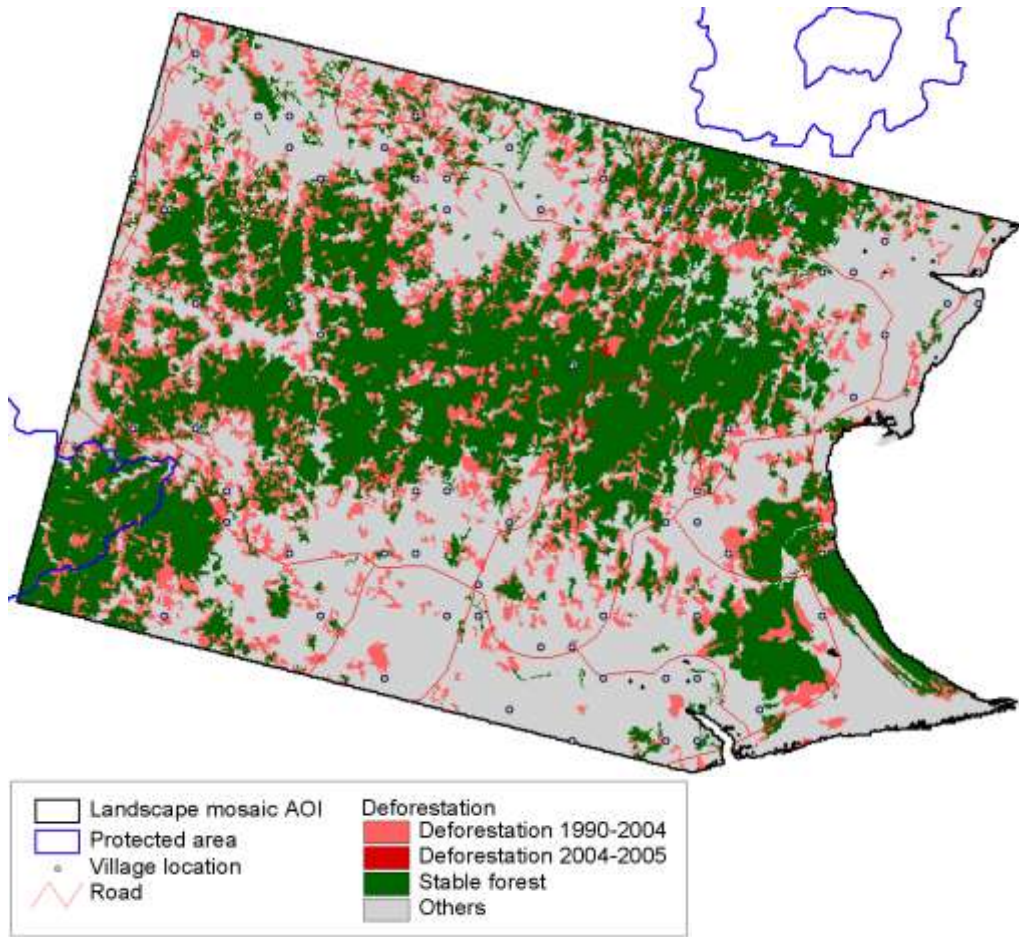**Figure 19.** Time series, land-cover maps of Manompana site

Figure 20. Location of deforestation at the Manompana site

Figures 19 and 20 show that forest loss mostly happened as encroachment from the edges of primary forest blocks from 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 and hinterland populations 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 for upland rice or cash crops is the dominant land-use system and is believed to be the major threat to the remaining forest. The national estimation in 2003 suggested that 60% of commercialised wood came from illegal logging. How this figure manifested within this particular landscape in Manompana is yet to be explored.

The fallow system is the dominant land-use system in Manompana. Most deforestation is believed to be driven by this type of agricultural expansion. Around villages, home gardens of banana, papaya and other fruit trees are commonly managed in mixed agroforestry systems 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 classes is comparable to the existing forest, which suggests that there is no particular tendency for forest loss to be associated with topography.
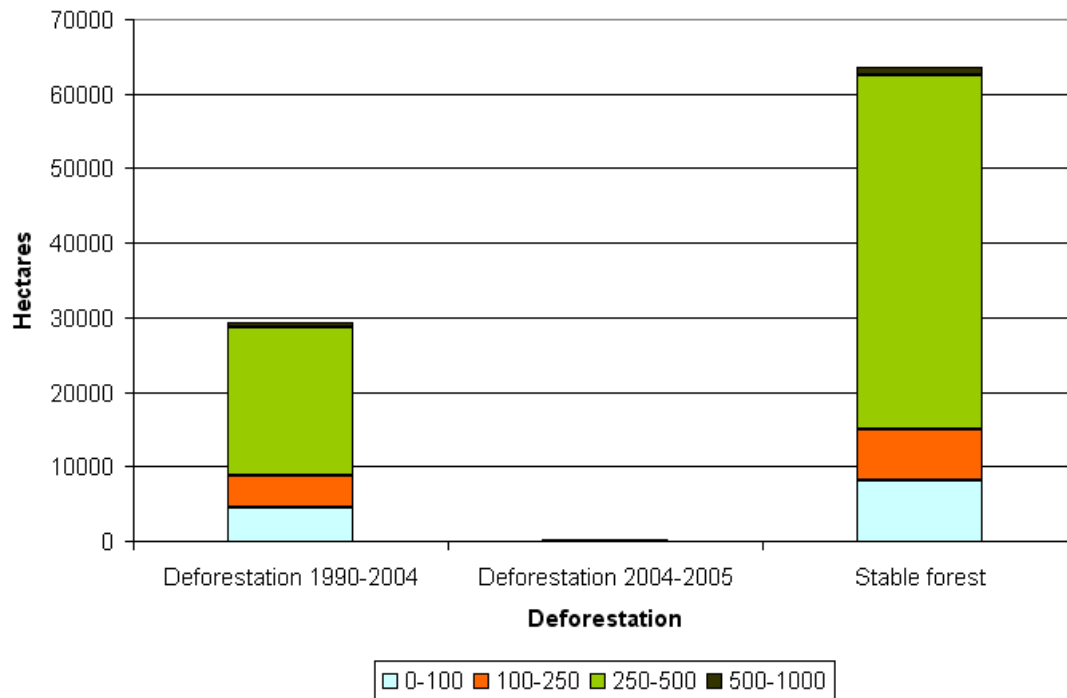
Figure 21. Forest loss (in hectare) in each period by elevation class

Access

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

Cameroon (Takamanda-Mone)

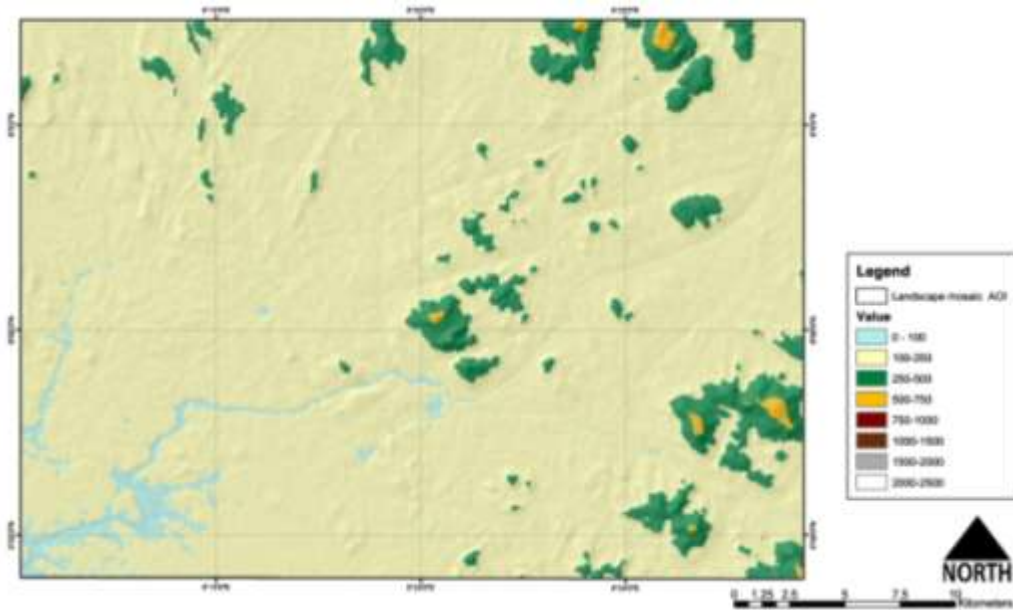*Topography, current land cover and description*

Figure 22. Elevation of Takamanda-Mone site ranges from 0 to 650 metre 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 extent is
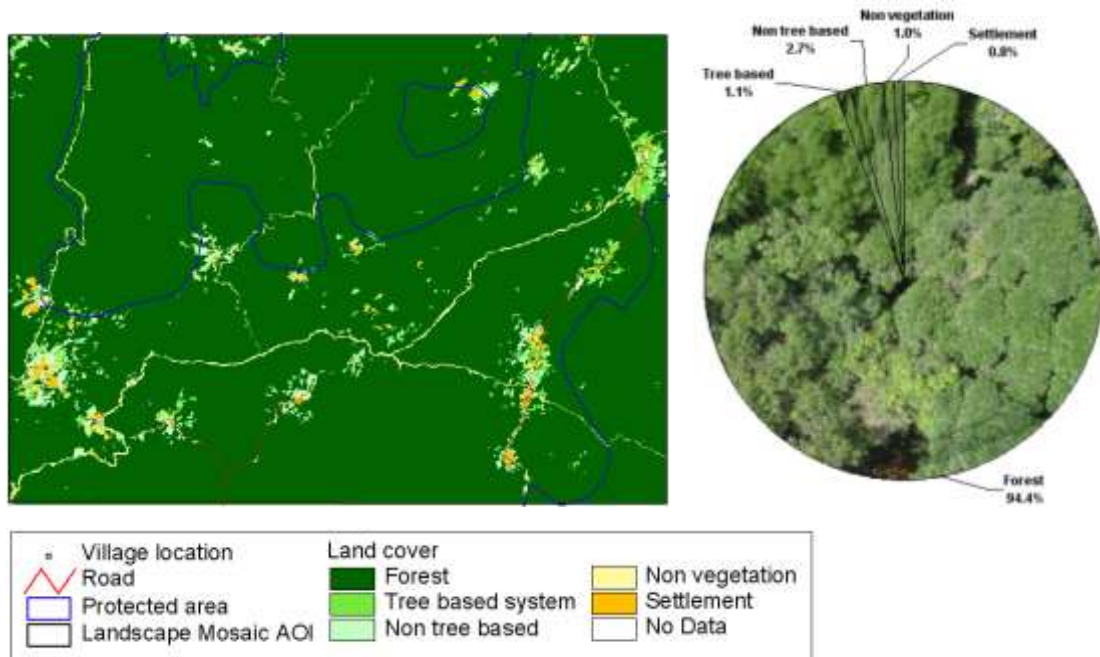small. River networks cover the landscape.

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 cover (Figure 22). Most of the areas are under protected status.
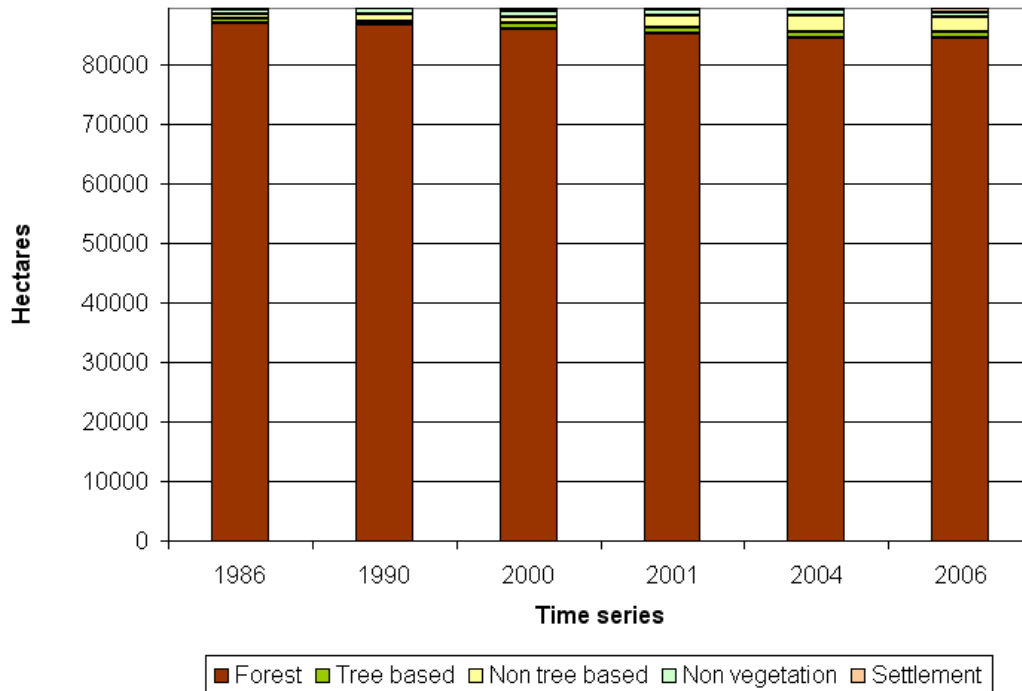
Temporal pattern

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

Within the time series, forest loss has been relatively small 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 is the increase of area of settlement (Figure 24). This perhaps indicates either population increases (due to in-migration) or resettlement. Interchange from tree-based to non-tree-based cover and vice versa is also high.

	Forest	Tree based	Non tree based	Non vegetation	Settlement
Forest					
Tree based					
Non tree based					
Non vegetation					
Settlement					

(a)

	Forest	Tree based	Non tree based	Non vegetation	Settlement
Forest					
Tree based					
Non tree based					
Non vegetation					
Settlement					

(b)

	Forest	Tree based	Non tree based	Non vegetation	Settlement
Forest					
Tree based					
Non tree based					
Non vegetation					
Settlement					

(c)

Figure 24. Pattern of changes in Takamanda-Mone for three 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
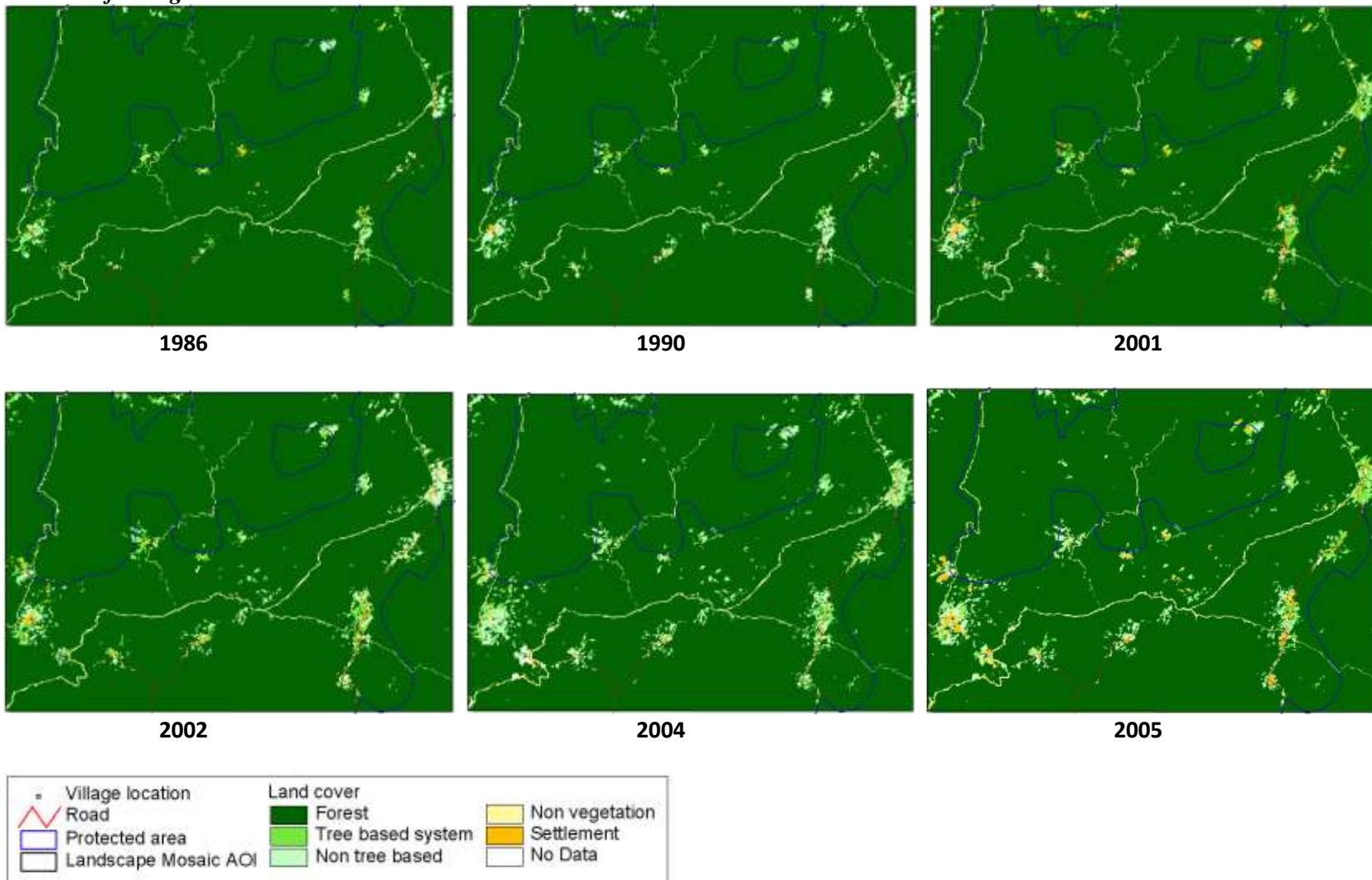
Location of changes

Figure 25. Time-series, land-cover maps of Takamanda-Mone site

- 32 -

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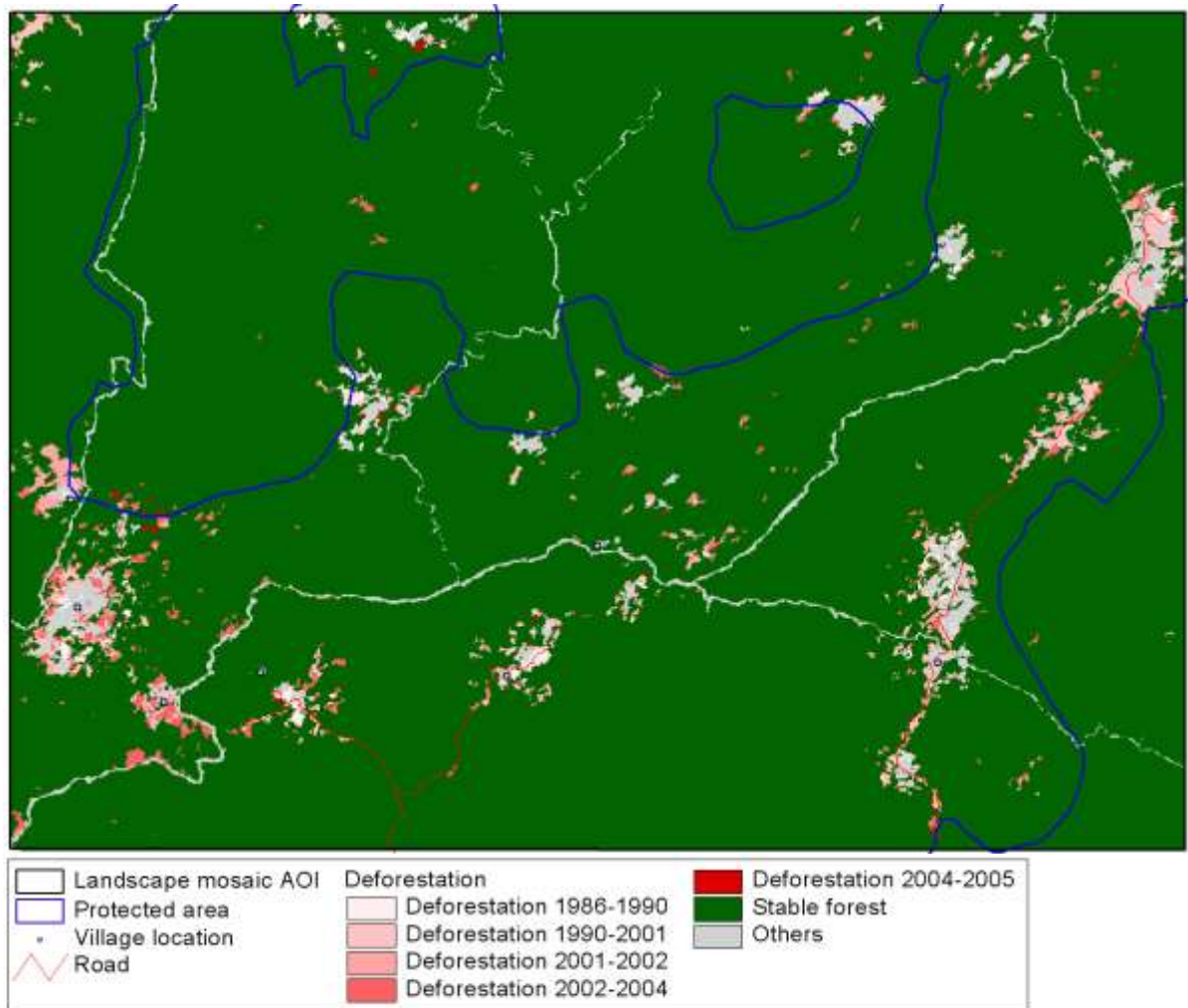

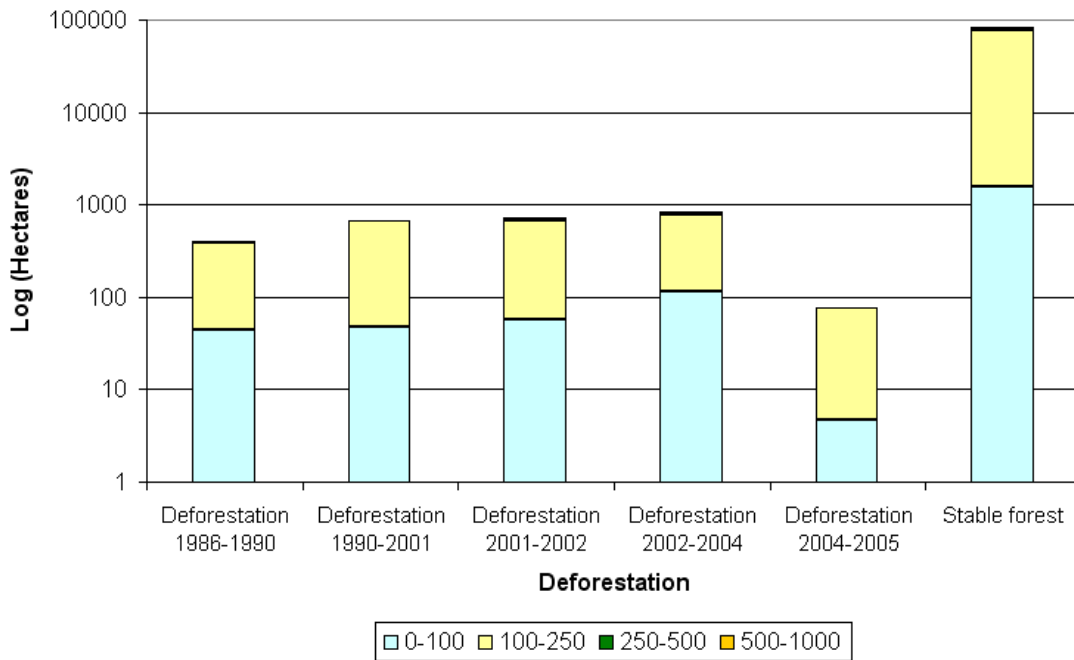**Figure 26.** Location of deforestation at Takamanda-Mone site

Figure 27. Forest loss over time by elevation class

Whilst the earlier period showed comparable forest loss in the lower and moderate elevation classes in relation to the existing forest, the most recent forest loss revealed a new pattern: forest loss at elevations of 100–250 m is higher compared to those in the lower altitudes (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, that is, 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 roads have increased recently owing to market access. Small-scale oil palm plantations have been introduced and developed in the secondary forests as well as 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)

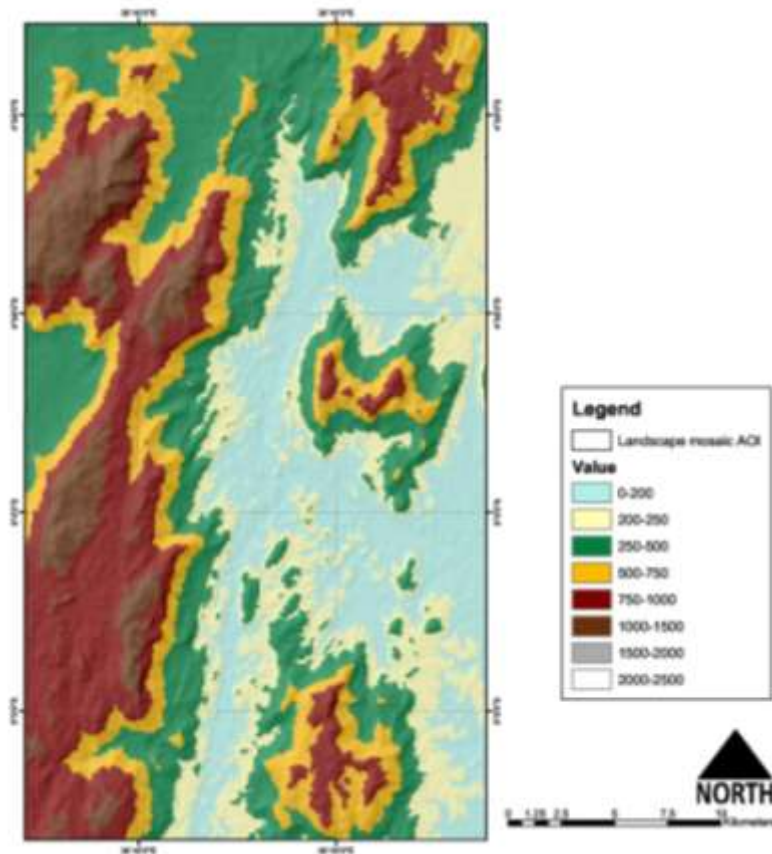*Topography, current land cover and description*

Figure 28. Elevation of East Usambara site ranges from 100 to 1500 metre above sea level

The landscape of East Usambara is the second highest and roughest in terms of topography among the five sites. Topographically, the landscape consists of one big island of montane ecosystems and three other smaller islands; two 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 submontane areas and to a lesser extent in the lowlands.
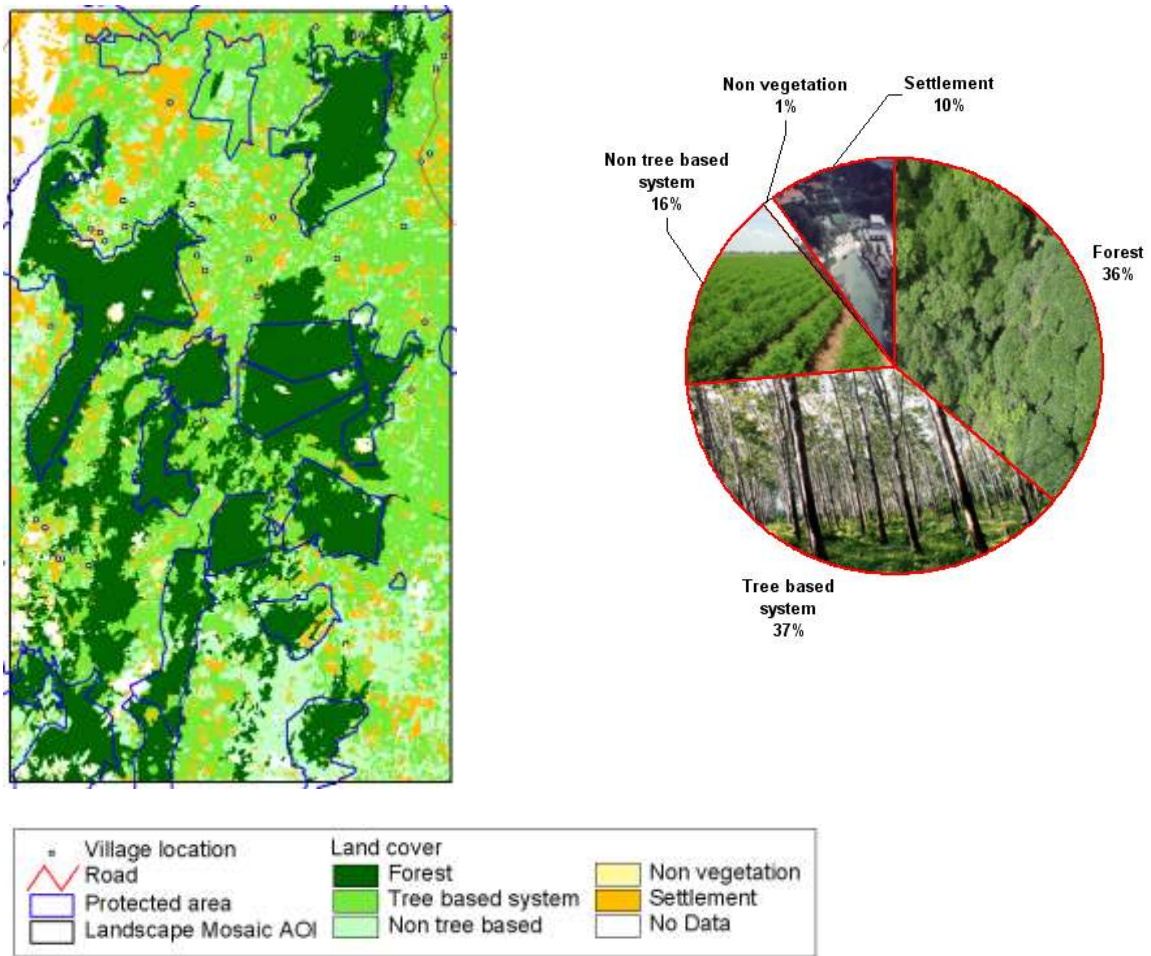
Figure 29. (a) Land-cover map of East Usambara site in 2007 (interpreted from SPOT 2007); (b) Landscape composition in 2007

Temporal pattern

Forest continues to decline over time. The proportion of tree-based to non-tree-based cover interchanges over time, whilst settlement areas show steady increases in size. Most recently, tree-based cover dominates the landscape.
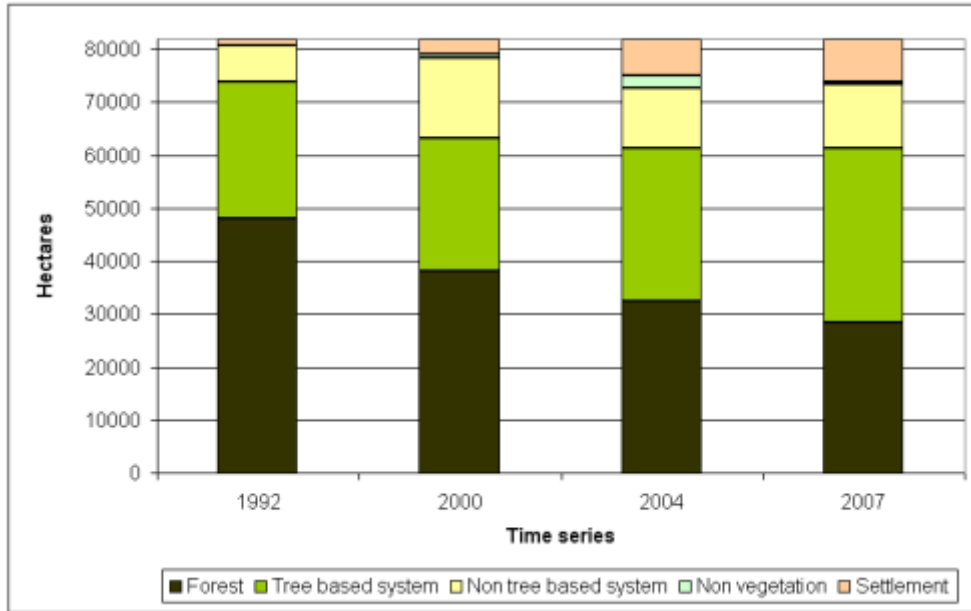
Figure 30. Time-series, land-cover composition of East Usambara site

(a)

(b)

Figure 31. Pattern of changes in East Usambara for two 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 increased over time; the deforestation pattern over time is in the form of encroachment from the long edges of the forest core (Figure 33).
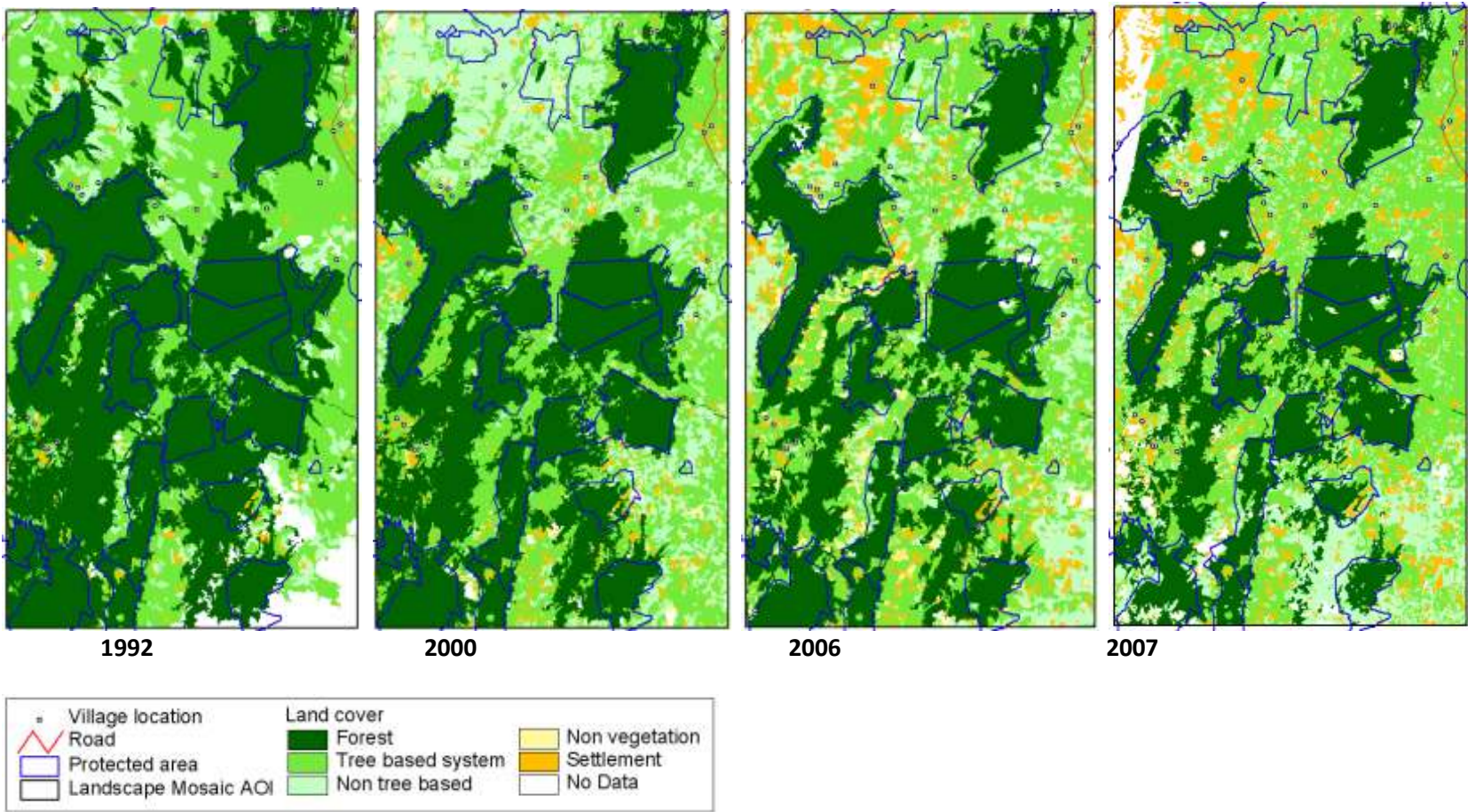
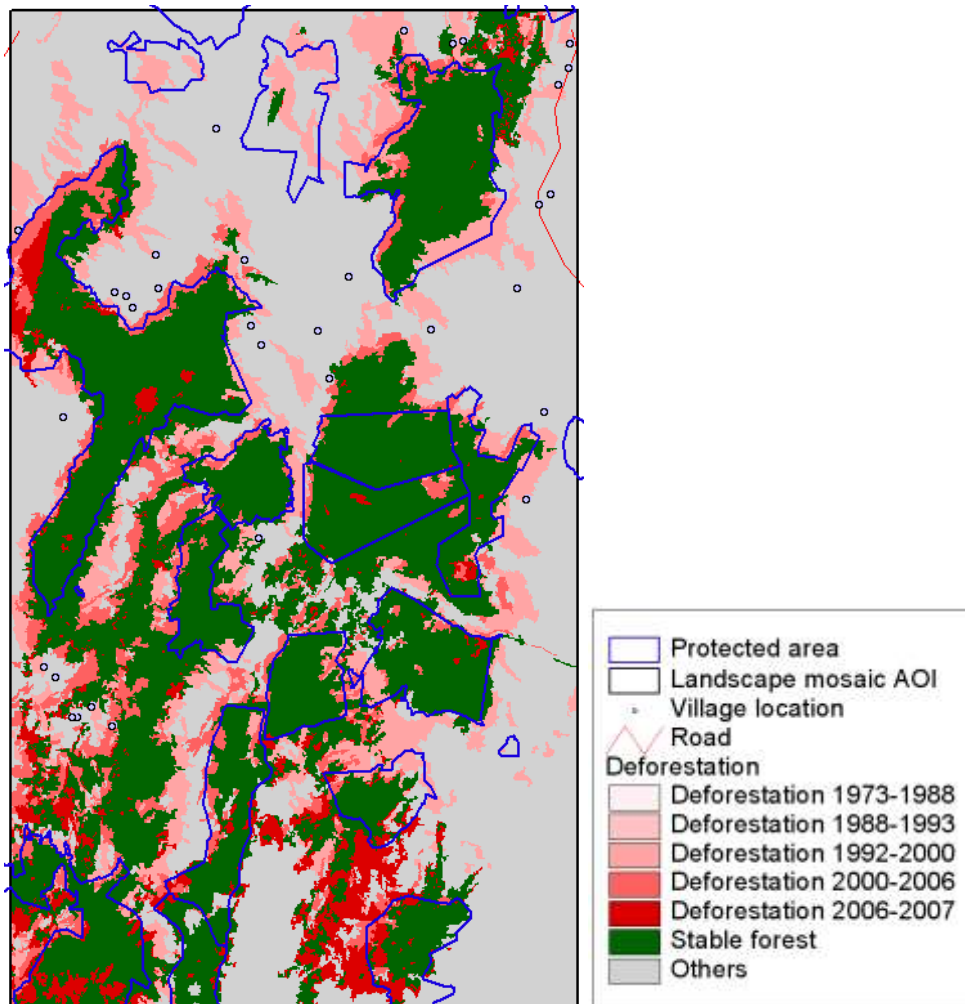**Figure 32.** Time-series land-cover maps of East Usambara site

Figure 33. Location of deforestation at East Usambara site

Drivers

Agents

Some remnant forest can be found on village land that is available for conversion to farmland through the villages' 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 cultivation 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 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 an 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 owing 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 owing 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 (for tea curing) is becoming more significant and new forest areas are cleared for fuel wood without a strategy for regeneration.
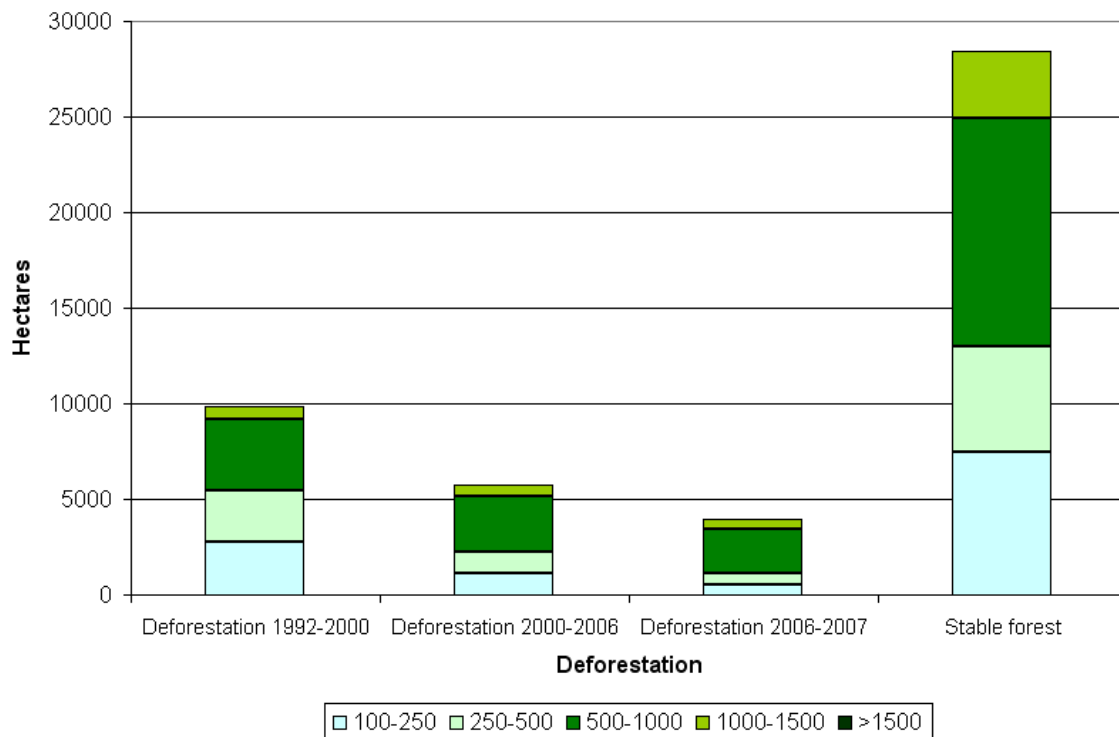
Topography

Figure 34. Forest loss over time by elevation class

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