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RUBBER AGROFORESTS IN A CHANGING LANDSCAPE: ANALYSIS OF LAND USE/COVER TRAJECTORIES IN BUNGO DISTRICT, INDONESIA

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ABSTRACT

Land cover has changed dramatically in Sumatra Island, Indonesia over the last decades. Rampant deforestation has drawn a lot of attention due to the potential global impact of the associated carbon stock loss on climate warming and the erosion of biodiversity. The various land uses which replace natural forest are not equally benign to the environment. Rubber agroforests (jungle rubber) are extensive traditional cropping systems. They have been singled out by previous studies as the best land use option for biodiversity conservation once forest is cleared, while allowing farmers to make a living from the deforested land. But how sustainable are complex agroforestry systems themselves? Are they not just a transient stage in the overall process of land use intensification?

We studied land cover change in the Bungo district, in Jambi, Sumatra (Indonesia), a 4,550 km^2 area. Large forest tracks have been cleared since the early seventies and replaced by rubber plantations, oil palm plantations and other agricultural land-uses. Landsat images taken between 1973 and 2005 were used to quantify the trends of land cover changes in the area. During that period forest cover fell from more than 75% to 30%. Simultaneously monoculture plantations increased from 3% to over 40%, while rubber agroforests, decreased from 15% to 11%. Strikingly most of the rubber agroforests present in 2005 where absent in1973 while most of the rubber agroforests present in 1973 had been replaced by more intensive agricultural systems by 2005.

Rubber agroforests are now the ultimate reservoir of the original lowland forest biodiversity since natural forest has almost completely disappeared from the peneplain. They are however under growing pressure themselves and have incurred an accelerated conversion rate to more intensive agricultural systems in the period 2002–2005.

Key words: land cover change, drivers of deforestation, rubber agroforests, Indonesia

INTRODUCTION

In a single human generation time the landscape in Sumatra Island, Indonesia has been completely transformed. Within only a few decades, the island has lost 12 million ha of natural forest (Laumonier *et al.* 2010). Even though millions of hectares of lowland natural forest have been logged over and converted into large scale tree crop plantations, a traditional extensive cultivation system referred to as rubber agroforest has persisted in the landscape despite the otherwise rapid changes in land use. Rubber agroforest, locally referred as *hutan karet* (literally

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"jungle rubber"), are characterized by the presence of rubber trees mixed with other tree species, which form a stand structure similar to secondary forest (Gouyon *et al.* 1993). Rubber tree typically account for less than 70% of the population of trees above 10 cm dbh (Vincent *et al.* 2010). Agroforests appear as a land use option that can provide multiple types of environmental services while ensuring farmer livelihoods (Schroth *et al.* 2004, Tomich *et al.* 2004). Rubber agroforests have notably become a major reservoir of the original forest biodiversity in the Sumatran peneplain as they provide a refuge for numerous forest species (Rasnovi 2006, Rasnovi *et al.* 2008). But how do agroforest areas evolve over time? Are they just a transient stage in the gradual process of intensification of land use? Circumstantial pieces of evidence from field observations suggest that such traditional systems may be losing ground (authors' personal obs.). In many places rubber agroforests are being replaced by more intensive, shorter lived, less environmentally friendly agricultural systems.

We studied the case of Bungo district, in Jambi province, Indonesia, a 4550 km^2 area where large natural forest stands have been converted over the past four decades into intensive tree crops and agriculture. Bungo district is quite representative of the land use change scenarios which are developing at the scale of Sumatra Island. Rapid land conversion to rubber and oil palm, coal and gold mining, logging of forest concessions, and illegal logging inside protected areas are common throughout Sumatra, and also in Bungo district. In the study period population increase has been rapid due in particular to active transmigration programs which affected many parts of Sumatra (Levang 1997). Two successive waves occurred in the Bungo District in 1977 and 1984 (Anonymous 1980, Anonymous 1990).

Using multi-temporal remote sensing data, we studied the changes in land cover which have occurred in the Bungo district over 32 years, with special focus on rubber agroforest. We use wall-to-wall mapping from 1973–2005 to analyze land cover changes and trajectories in Bungo district. The integration of land cover maps with various thematic maps provides some new insights on the status of rubber agroforest within the changing landscape.

METHODOLOGY

We conducted an *analysis of landuse/cover change and trajectories* (ALUCT) to produce spatial datasets on land cover change in Bungo district. ALUCT was based on a set of 6 Landsat images recorded in 1973, 1988, 1993, 1999, 2002, and 2005 (Table 1).

ALUCT workflow can be classified into three stages: (1) *Image pre-processing*, (2) *Image classification*, and (3) *Post interpretation analysis*. The first stage, *Image pre-processing,* aims to rectify geometric distortion in satellite images using ground control point (GCP) collected from reference datasets. In this case, orthorectified Landsat ETM 2002 from the United States Geological Survey (USGS) was used as reference data. Minimum of 30 GCP were used in

TABLE 1

Description of time series Landsat images used for the land use change analysis in Bungo district, Sumatra, 1973–2005

Sensor/Platform	Scene ID	Description of data acquisition
Landsat 1/MSS	135–061	Acquisition date: June, 25th 1973, 3% cloud cover, image size 1571×1122 pixel, pixel size 79m, sun elevation 30 d.
Landsat 4/TM	126–061	Acquisition date: June, 13th 1988, 7% cloud cover, image size 4136×2954 pixel, pixel size 30m, sun elevation 33 d.
Landsat 5/TM	126–061	Acquisition date: September, 16th 1993, 5% cloud cover, image size 4136×2954 pixel, pixel size 30m, sun elevation 30.7 d.
Landsat 7/ETM+	126–061	Acquisition date: April, 9th 1999, 10% cloud cover, image size 4136×2954 pixel, pixel size 30m, sun elevation 31.7 d.
Landsat 7/ETM+	126–061	Acquisition date: May, 24th 2002, 12% cloud cover, image size 4136×2954 pixel, pixel size 30m, sun elevation 29.7 d.
Landsat 7/ETM+	126–061	Acquisition date: May, 7th 2005, 15% cloud cover, image size 4136×2954 pixel, pixel size 30m, sun elevation 31.2 d.

geometric correction, ensuring geometric precision of 0.5 pixel (<15m) for all images (Welch and Usery 1984).

The second stage of ALUCT is *image classification*. The objective is to produce time series land cover maps through satellite image interpretation. The first step at this stage is to define land cover types that can be identified through satellite image. Six vegetation types were identified through extensive field work and matched on the satellite images. A brief description of each one is given below.

- **Natural forest** typically varies in species composition, stem diameter distribution and total basal area. These include logged over forest.
- **Rubber agroforests** are characterized by the presence of rubber trees mixed with other tree species forming a stand structure similar to secondary forest.
- **Rubber plantations** are pure or almost pure stands of rubber trees. This land cover type covers intensively managed large scale plantations as well as smallholdings. The latter are usually less intensively managed and may include a significant proportion of non-rubber tree species. Rubber plantations are the dominant land cover in the lowland peneplain area of Bungo in 2005.
- **Oil palm plantations** are characterized by a homogeneous canopy structure when mature (single dominant species), a regular network of roads and clear-cut boundaries with the neighbouring vegetation. Oil palm plantations in the

younger age were classified into a separate class due to significant difference in spectral signature.

- **Shrubs:** any low stature woody vegetation usually less than 5-6 m tall, typically a young fallow resulting from swidden agriculture.
- **Rice fields** include irrigated and non irrigated (upland) rice fields. They are most often located near settlements or rivers.

Object-based hierarchical classification approach was then used to interpret satellite images. In this approach, image classification begins with a series of image *segmentation* processes. The purpose is to produce *image objects*, i.e. groups of pixel with a certain level of homogeneity in term of spectral and spatial characteristics. The result of these phases is called *multiresolution image segments* which serves as a basis for the hierarchical classification system (Definiens 2007). The same segmentation parameters were applied at each date.

Following the segmentation process, image classification was conducted using the hierarchical structure shown in Figure 1 (Blumberg and Zhu 2007). The hierarchy was divided into three levels, where objects were classified into land use/cover types based on spectral characteristics and spatial rules. Moving from the simplest legend (higher level) to finer and more detailed legends (lower level), the spectral characteristics became more homogeneous and less discriminating, and therefore spatial rules played an increasingly important role. *Level 1* differentiated between forest and non-forest classes, which was achieved by using visual inspections and a simple vegetation index. The vegetation index is a ratio of spectral value between vegetation-sensitive channel (near infra-red spectrum) and non vegetation-sensitive channel (visible spectrum) in the satellite image. Result of *Level 1* was further classified in *Level 2,* in which non-forest areas were differentiated into tree, non-tree and non-vegetation. We used Nearest Neighborhood classification for this level. The approach consisted of two steps: first, spectral signatures of the land cover classes were identified with the help of ground truth data collected during a field survey. We used the signatures to select the combination of spectral features that would best separate those classes. Optimal combination of features was used in the second step to classify all objects into land cover classes.

Some of the classes in *Level 2* were further sub-classified in *Level 3*. In this level, spectral value was combined with spatial characteristics such as distance to settlement, proximity to logging road, forest concession maps, and plantation maps to build classification rules. The field knowledge about land use/cover types and changes obtained from ground-truthing was used as supplementary information during the interpretation. GPS points collected by the authors and compiled from other sources were the main data used to help with the interpretation and to assess accuracy of the results.

Post classification analysis process is the last stage of ALUCT. It consists of two steps, *accuracy assessment* and *land cover change analysis.* The objective

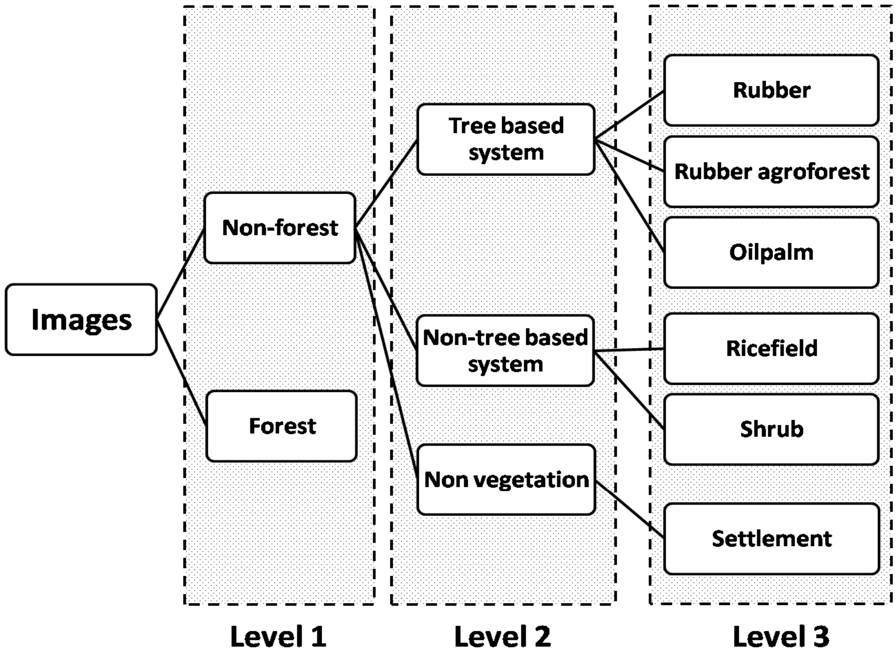

Figure 1. Hierarchical land use/cover classification scheme for satellite image interpretation

of *accuracy assessment* is to test the quality of information derived from the image classification process. It is conducted by comparing field reference data with the contemporary land cover map. The last step in ALUCT is the land cover change analysis. Two final forms of output are produced by ALUCT: (i) *area-based changes analysis* and (ii) *trajectories analysis. An area-based change* analysis is a simple analysis conducted by comparing total area of land cover types in each time period. *Trajectory analysis* summarizes sequences of changes in land use/cover of each pixel in the map within the study period (Mertens and Lambin 2000). The extent or area of each occurrence or sequence of changes can then be quantified.

LAND USE/COVER CHANGES ANALYSIS RESULT

Time series land cover maps produced through interpretation of Landsat images are shown in Figure 2 The accuracy of the 2005 land cover map, was assessed by 426 GPS reference points (table 2). The overall accuracy was 89.3%, which is considered sufficient to be used in land cover change analysis (Mas *et al*. 2010). Accuracy of the various land cover classes varied between 77.8% for settlement to 90.8% for forest class. The classification accuracy of rubber agroforest was 80.7%, most of the misclassification in this class occurred between rubber agroforest, forest and monoculture rubber. This is understandable considering the degree of similarity in their vegetation structure.

In 1973, natural forest covered an area of 342,795 ha or 75% of Bungo district area. This figure gradually decreased to only 135,697 ha or 30% of total Bungo district area in 2005 (table 3). Almost all forested land in the peneplain

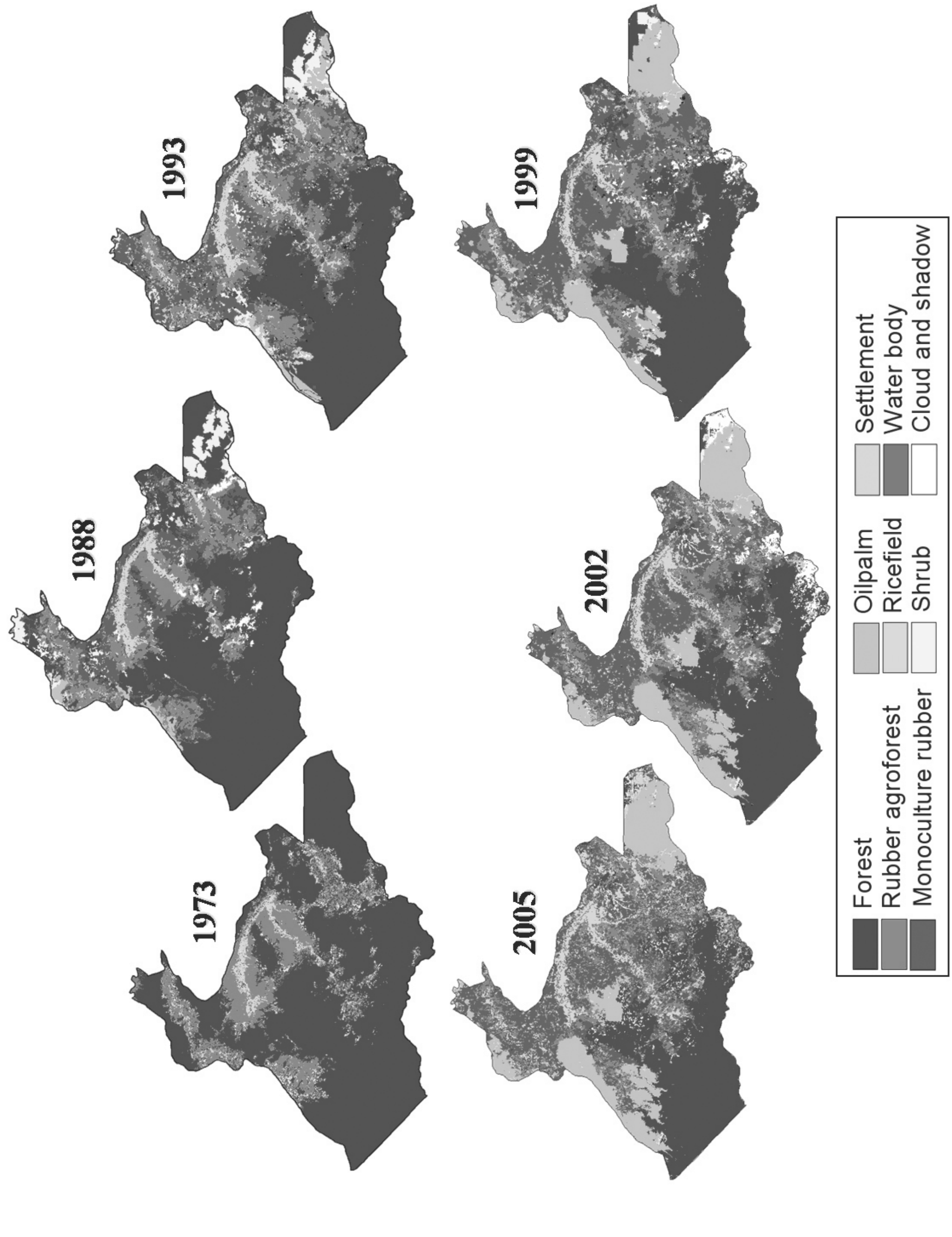

Figure 2. Time series land cover map of Bungo district, Sumatra, 1973–2005

TABLE 2

Accuracy matrix of the 2005 land cover map of Bungo district, Sumatra

	Reference								
Classified	Forest	Rubber agroforest	Monoculture rubber	Oil palm	Shrub	Rice-field	Cleared land	Settle-ment	Total GCP
Forest	73	1	1	0	0	1	0	0	76
Rubber agroforest	8	39	1	0	0	0	0	1	49
Monoculture rubber	0	2	158	0	0	0	0	0	160
Oil palm	1	0	0	65	0	0	0	0	66
Shrub	0	0	0	0	9	2	0	0	11
Ricefield	0	0	0	0	0	20	0	0	20
Cleared land	0	0	1	0	2	1	16	0	20
Settlement	0	0	1	0	1	0	1	21	24
Total	82	42	162	65	12	24	17	22	426

zone had disappeared, the last remnants of forest being located in the mountain area located in the southern part of the district. In marked contrast, intensive tree crop plantations such as rubber and oil palm dominated the area in 2005. Monoculture rubber, which only covered 9,525 ha or 2% of the area in 1973, dramatically increased to 120,880 ha or 27% of the area in 2005. The largest conversion to rubber occurred during the period 1973–1988, where rubber area increased almost eight folds within 15 years (table 3). Similarly rapid growth occurred with oil palm although it happened a few years later. From only 6259 (1%) in 1988, oil palm increased to 88,355 ha in 2005 or 19% of total Bungo district area. The largest conversion to oil palm occurred between 1993 and 1999. In this period, oil palm area increased three-fold from 19,535 ha (4%) in 1993 to 59,575 ha (14%) in 1999. Unlike other dominant types of land use in Bungo, rubber agroforest area remained relatively stable. The area of rubber agroforest increased from 66,370 ha (15%) in 1973 to 70,755 ha (16%) in 1988. However, it later declined to reach 48,137 ha (11%) in 2005.

Forest loss, changes to intensive tree crops and agroforest transition

Time series land cover maps of Bungo district reveal three major types of land cover changes: (1) natural forest loss, (2) increase in the area of intensive tree crops, and (3) decrease in the area of rubber agroforest. The pattern and speed of changes for each of those classes are different (Figure 3). Forest cover decreased most rapidly in the period of 1988–1993, when the average rate of forest loss was 9,964 ha/years. The rate of forest loss gradually decreased to 6,531 ha/year

TABLE 3

Land cover changes in Bungo district, Sumatra, 1973–2005

	1973		1988		1993		1999		2002		2005	
Land cover	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Forest	342795.1	75%	238845.7	53%	189024.6	42%	158926.6	35%	139331.5	31%	135697.1	30%
Rubber agroforest	66370.6	15%	70755.7	16%	66791.5	15%	61986.3	14%	56247.7	12%	48137.7	11%
Rubber	9525.3	2%	88940.5	20%	119516.5	26%	123198.5	27%	119936.2	26%	120880.2	27%
Oilpalm	0.0	0%	6259.1	1%	19535.8	4%	59575.5	13%	75583.4	17%	88355.9	19%
Agriculture	4662.5	1%		0%		0%		0%		0%		0%
Ricefield		0%	173.0	0%	248.0	0%	385.6	0%	464.1	0%	564.8	0%
Shrub	10449.3	2%	18285.0	4%	26553.5	6%	4351.3	1%	5719.8	1%	6167.8	1%
Settlement	12521.7	3%	14724.5	3%	22513.9	5%	29027.3	6%	34111.2	8%	46557.4	10%
River	8273.0	2%	8273.0	2%	8273.0	2%	8273.0	2%	8273.0	2%	8273.0	2%
Total	454657	100%	454657	100%	454657	100%	454657	100%	454657	100%	454657	100%

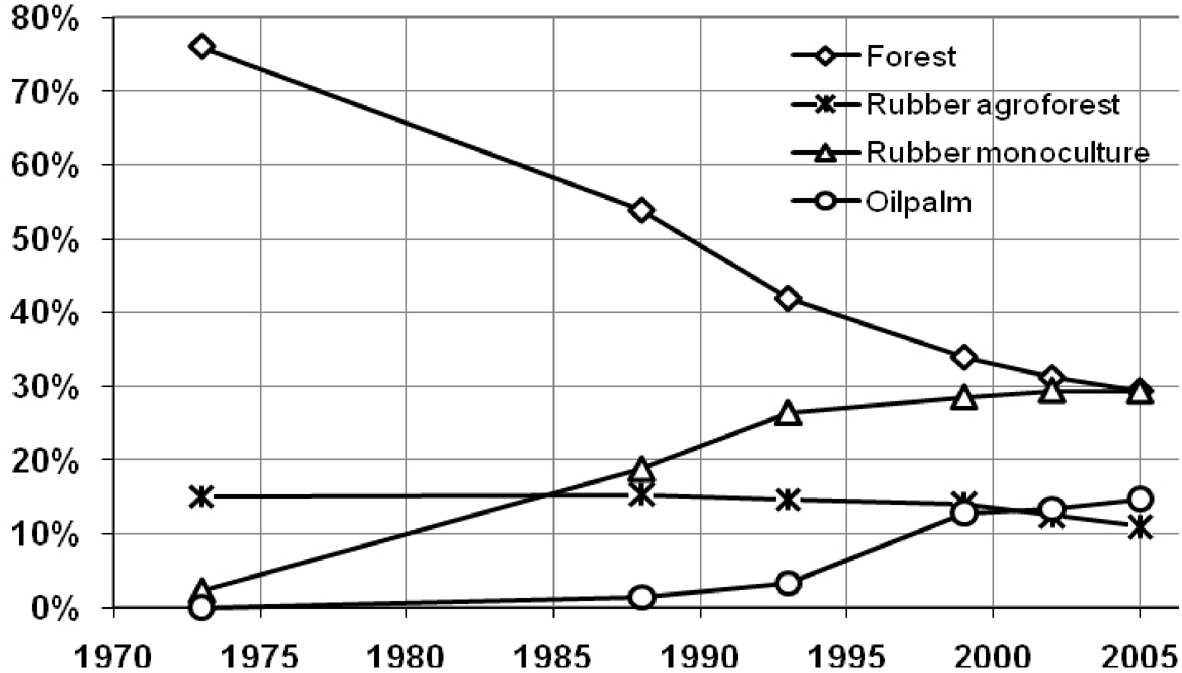

Figure 3. Area-based land cover changes of Bungo district, Sumatra, 1973–2005

between 1999 and 2002 and slowed down to 1,211 ha/year in the 2002–2005 period.

During the 1988–1993 period, when forest loss rate was highest, establishment rate of intensive tree crops such as rubber and oil palm increased to 8,770 ha/year. Within this period the Bungo district started to host government transmigration programs. The primary transmigration program was conducted in the period 1977–1984 where three primary sites for transmigrants were chosen: Bukitsari and Muliasari in Jujuhan sub-district, Rimbo Bujang in the northern part of Bungo district, and Kuamang Kuning in the eastern part of Bungo district (Anonymous 1980, Anonymous 1990). Rubber and oil palm crops in Bungo are clearly the two land uses which have increased the most at landscape scale. Even in the latest period, the conversion rate to rubber or oil palm remained high (4,572 ha/year).

While the rate of forest loss tended to slow down, the conversion rate of rubber agroforest to other type of land uses seemed to increase gradually (Figure 2). In the 1973–1988 period, rubber agroforest increased at a rate of 292 ha/year. After that, area of rubber agroforest slowly decreased and its conversion rate increased in the latest years. In the latest period of analysis, conversion rate of rubber agroforest reached 2,703 ha/year, which was higher than the rate of forest loss. At that time rubber agroforest rather than forested land had become the primary target of land use intensification.

Trajectories of land use/cover

As an overall summary of the changes, we analyzed the trajectories of change based on the time series land cover maps. Four major trajectories were considered: (1) Natural forest conversion, (2) Rubber agroforest conversion (3) Conversion to non agricultural land, and (4) Stable area. The dominant trajectory is natural forest conversion to rubber and oil palm which affected almost 40% of Bungo area (Figure 4). Conversion to non agricultural land such as settlements and roads affected 10% of the area, while conversion from rubber agroforest to oil palm and rubber monocrop plantations was smaller (7%).

Stable forest cover, which corresponds to land which has remained covered by natural forest over the period 1973–2005 amounted to 30.4% of the area, while stable rubber agroforest covered a much smaller area (1%). This last figure means that most of the area under agroforest in 1973 had been converted to another land use type in 2005. We further analyzed how those trajectories were affected by two factors: (1) Accessibility level derived from existence of road access. Road density in 2002 (road length per square kilometer) was used as a proxy of accessibility. We classified accessibility level based on the road density into three classes: low access (0–25 km/sq.km), medium access (25–50 km/sq.km) and high access (>50 km/sq.km). (2) elevation classes were derived from the Digital Elevation Model (DEM).

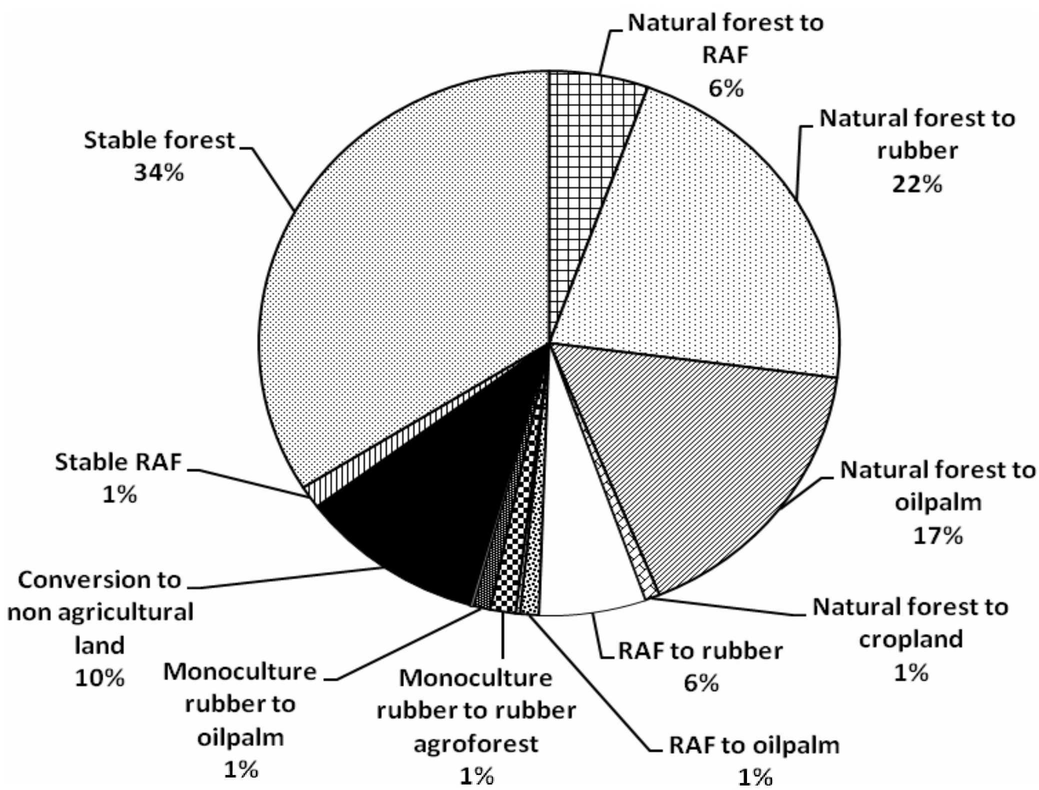

Figure 4. Land cover trajectories of Bungo district, Sumatra, over the 1973–2005 period

Most of the remaining forest was found to be located in low accessibility areas. More than 50% of the remaining natural forest cover had little to no road access and c. 85% was above 500 m asl. This may explain why the rate of forest loss declined in the latest period. In sharp contrast, more than 95% of the remaining patches of rubber agroforest were located below 250 m a.s.l. with medium to high level of accessibility. These easily accessible areas are more likely to be converted to intensive tree crops or agriculture than less accessible forest in the near future. Faster rate of rubber agroforest conversion in the period of 2002–2005 illustrated this growing pressure exerted on those extensive agricultural systems. Since natural forest in Bungo district in 2005 was largely restricted to high elevation areas, rubber agroforest constituted the last remaining forest-like vegetation cover of ecological value in the peneplain area of Bungo.

CONCLUSION

Three major types of change dominated the landscape in Bungo district in the period 1973–2005: forest loss, conversion to intensive tree cropping systems and simultaneous conversion and establishment of rubber agroforest. In 2005 remaining natural forest covered 30.4% of Bungo area, while rubber agroforest covered only 11% of the area. In the 2002–2005 period the rate of rubber agroforest loss was higher than that of forest. Rubber agroforest appears to be a predominantly transient type of land use with high likelihood of conversion. Difficult access to the remaining forested land adds more pressure to rubber agroforest conversion into more intensive agricultural systems. On the other hand rubber agroforests play a unique role in the landscape since almost all natural forest land in the peneplain area has disappeared. Our data alarmingly suggest that the current trend is to further reduction of the area of rubber agroforest in the near future. Maintaining a significant portion of the landscape under rubber agroforest in Bungo district would therefore require putting in place specific schemes to reward agroforest farmers for the environmental services they provide.

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