Working Paper

Land Cover Changes, Forest Loss and Degradation in Kutai Barat, Indonesia

Mukhammad Thoha Zulkarnain, Chandra Irawadi Wijaya and Atiek Widayati

World Agroforestry Centre

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Abstract

As part of efforts on Reducing Emissions from Deforestation and Degradation (REDD+) and low CO_2 emission development planning for Kutai Barat district, East Kalimantan, Indonesia, it is important to obtain estimates of the land cover changes and the change trajectories. The information is useful for further assessments on CO_2 emissions, trade-off as well as for inputs in land use planning. The objectives of the study are to produce four time series of land cover data, to analyze land cover changes and trajectories in the district, and to analyze forest deforestation and degradation in Kutai Barat District. Four time series Landsat Imageries (1990, 2000, 2005 and 2010) were utilised, and herarchichal object-based classification method was employed for the map production. The result demonstrates that most of forest loss in Kutai Barat during 1990 – 2010 was caused by changes from degraded forest (especially open and closed *Tree.Evergreen-broadleaved*) to rubber agroforests, rubber plantations and shrub land; this latter change implying forest degradation due to timber extraction. Most forest loss and forest degradation occur in Production Forest zones (*Hutan Produksi*) where tree cutting is legal. However, there is as well degradation taking place in Protection Forest zone *(Hutan Lindung)* which implies illegal activities. For a district where natural resources still play a major role in the development and economic growth, locally appropriate strategies on land-use planning and its implementation should be comprehensively designed in order to maintain good environmental practices.

Keywords

Land cover changes, forest degradation, deforestation, trajectories, hierarchical object-based classification

Acknowledgements

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Contents

1. Introduction

Kutai Barat District is located at 113° 45’ 05” – 116° 31’ 19” East and between 1° 31’ 35” North and 1° 10’ 16” South (Figure 1). The total area of Kutai Barat District is 31629 km^2, with altitudes ranging 0-1500 m asl. The topography of Kutai Barat is dominated by sloping lands with more than 50% of it mountainous, mostly in the Northwestern part of the District. The mountainous parts of Kutai Barat are located upstream of Mahakam River, especially in the Long Bagun district, Long Pahangai district and Long Apari district.

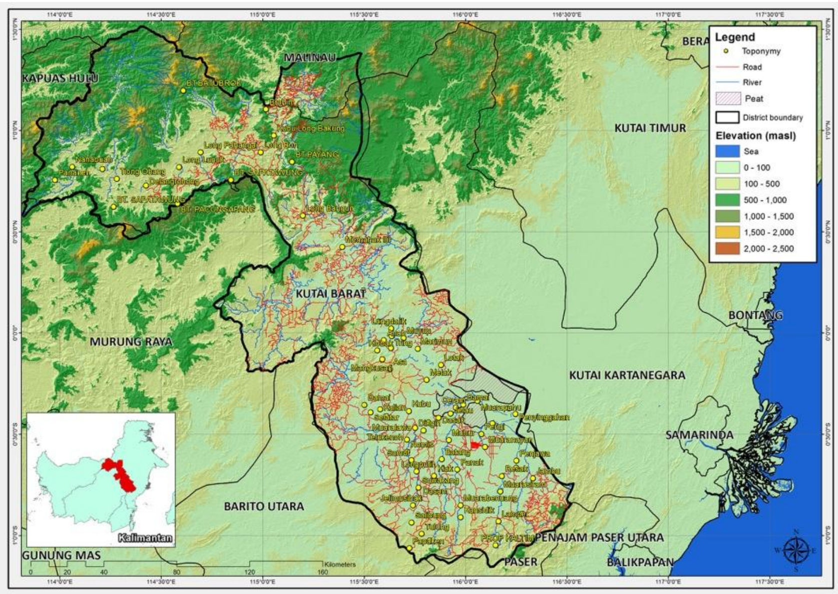

Figure 1. Location of Kutai Barat Regency in East Kalimantan, Indonesia

As part of the various ongoing work in Kutai Barat related to Reducing Emissions from Deforestation and Degradation plus conservation (REDD+) and Land Use Planning for Low Emission Development Strategies (LUWES) (Dewi *et al*, 2013), it is important to obtain estimates of the Land-Cover changes and the change trajectories, especially for tropical forest deforestation and forest degradation domains. Tropical deforestation accounted for approximately 12% of global anthropogenic CO_2 emissions in 2008 (Van der Werf *et al*, 2009). Forest degradation from fire, logging and fuel wood collection represents an additional source of carbon emissions from Land-Use activities in tropical forest regions (Morton DC *et al*, 2011). According to Ekadinata *et al*, 2011, forest cover in Indonesia decreased from 128.72 million hectares in 1990 to 99.6 million hectares in 2005. The 2005 Land-Cover maps shows that 40% (38.5 million hectares) of forest cover is logged-over forest, demonstrating the decrease of forest cover caused by logging and other timber extraction activities.

Remote Sensing and Geographic Information Systems are the most efficient and effective tools to map and monitor Land-Cover changes and trajectories. Medium-resolution Landsat Imageries, which

are publicly available, serve as cost-effective data to generate Land-Cover data at the district level and thus, is used as the main data source. However, common with optical remote sensors, loss of information due to cloud cover has become a major problem, especially when affecting large areas and/or it affects the precisely specific areas of interest. Active remote sensors such as the Synthetic Aperture Radar (SAR) has became one of the best solutions due to its ability to penetrate cloud cover. The capability to penetrate clouds is a major advantage of radar systems, with respect to optical systems. Furthermore, radar sensor provides information that is complementary to that of visible infrared imagery (Riedel *et al*, 2008). Zulkarnain *et al*, 2013, added that Land-Cover generated from fusion of Landsat and Alos Palsar image has a higher accuracy of about 3% compared to Landsat imaging only.

The objectives of the study in this report are: (1) to produce four time series of Land-Cover data (1990, 2000, 2005 and 2010) of the Kutai Barat District, (2) to analyze Land-Cover changes and trajectories in the district, and (3) to analyze forest deforestation and degradation in the study site.

2. Data and Methods

This study made use of four time series (1990, 2000, 2005 and 2010) of Land-Cover data derived from satellite imageries to identify Land-Cover changes and forest cover changes (forest deforestation and degradation) in Kutai Barat. The general framework used to identify Land-Cover changes and forest cover changes is Analysis of Land-Use/cover Changes and Trajectories (ALUCT) (Dewi, 2010), which consists of three major stages: 1) image pre-processing, 2) image classification, 3) post-classification (Figure 2).

Before implementing this method, it is required to conduct inventories and to define classes of Land-Use/cover in the study area. The classes are designed in such a way so that they are recognizable from the satellite imageries and cover all the dominant land-use/cover types that exist in the study area. A list of relevant land-use classes was developed based on the Land-Cover Classification System (LCCS) (Di Gregorio, 2005) with the exception of a few cases that were not possible to match with the LCCS classification scheme. The datasets intend to include, at least, the level of detail in the legend hierarchies (1) Land-Cover and (2) Land-Use (3) Hydrology (4) Disturbance history and 5) Additional Land-Cover characteristics and through field work in the study area.

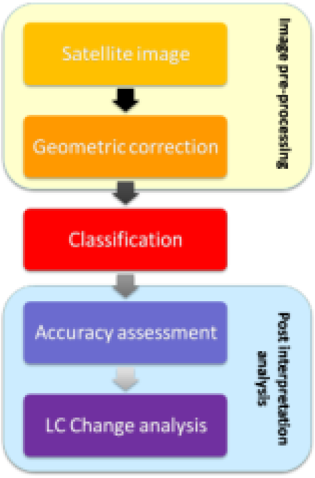

Figure 2. Overall flow of ALUCT framework

2.1. Data

2.1.1. Satellite Imageries

This study made use Landsat imageries that cover Kutai Barat with a spatial resolution of 30 meters. In addition, ALOS Palsar imageries with spatial resolution of 50 meters were also used as auxiliary imageries to produce land cover data of 2010. List of satellite imageries used for land cover mapping is shown in Table 1.

2.1.2. Ground Truth Data

Ground truth data is required to assist classification of satellite imagery as well as a reference to assess the accuracy of land cover 2010 produced in image classification. The ground truth data were taken from field survey that was conducted in 2012. The plan of field survey was designed by generating random point data which then was visualized in the form of maps together with spatial data of Kutai Barat in particular maps, such as Landsat imageries, road networks, river networks, and point locations. In the implementation stage, 358 ground were successfully obtained with GPS during the field survey, with 314 of these ground truth points qualified to be used as reference for accuracy assessment. Most ground truth points taken from field surveys may represent land cover classes that were derived from satellite imageries.

In addition, secondary data was also used to support the classification of satellite imagery. The data was obtained from various sources such as forest maps, road maps, river maps, administrative maps, and SRTM DEM.

Table 1. List of satellite imageries

Satellite imagery	Time series	Path/ Row	Acquisition date	Spatial resolution	Source
Landsat 5 TM	1990	117/60	August 28, 1992	30 m	USGS - NASA
		117/ 61	August 28, 1992		
		118/ 59	December 28, 1990		
		118/ 60	Jube 30, 1991		
		119/ 59	July 25, 1992		
Landsat 7 ETM+	2000	117/60	August 26, 2000	30 m	USGS - NASA
		117/ 61	August 26, 2000		
		118/ 59	September 02, 2000		
		118/ 60	September 02, 2000		
		119/ 59	July 10, 2001		
Landsat 7 ETM+	2005	117/60	August 21, 2004	30 m	USGS – NASA
		117/ 61	June 05, 2005		
		118/ 59	April 09, 2005		
		118/ 60	April 09, 2005		
		119/ 59	August 19, 2004		
Landsat 7 ETM+	2010	117/60	December 12, 2010	30 m	USGS – NASA
		117/ 61	August 03, 2009		
		118/ 59	April 26, 2011		
		118/ 60	March 25, 2011		
		119/ 59	January 27, 2011		
ALOS Palsar Mosaic	2010	A03	June 12 – August 19, 2009	50 m	EORC, JAXA
		A04	June 12 – August 19, 2009		

2.2. Methods

2.2.1. Image pre-processing

Image pre-processing was needed in order to correct errors caused by interference from the atmosphere at the time of image recording, which consist of two activities: radiometric and geometric corrections. We used the ATCOR method for radiometric correction. The Atmospheric and

Topographic Correction for Satellite Imagery (ATCOR) is a method used to reduce atmospheric and illumination effects on remotely sensed data to retrieve physical parameters of the earth's surface such as atmospheric conditions (emissivity, temperature), thermal and atmospheric radiance and transmittance functions in order to simulate the simplified properties of a 3D atmosphere (http://www.satimagingcorp.com/svc/atcor.html). Geometric correction aims to correct errors or geometric positions during the recording of satellite imagery, we also used 20 ground control points (GCPs) collected from reference datasets, in this case, Orthorectified Landsat 2000 image form the United States Geological Survey (USGS). We imposed geometric precision of 0.5 pixels (15m) for each image.

2.2.2. Image classification

Image classification is the core processing method containing interpretations of spectral information in satellite images into land-use classes. The Hierarchical object-based classification (HOBC) approach (Blumberg and Zhu, 2007) is applied in producing the time series Land-Cover maps. In the HOBC approach, the procedure begins with an image segmentation process, which aims to produce image objects. An object is defined as a group of pixels with a similar level of homogeneity for their spectral and spatial characteristics (Figure 3). The determination for an image object has to meet the need to represent the actual earth landscape features on the satellite images. For this study, the smallest object size was determined to be 1 ha. Several phases of segmentation were conducted in order to obtain the required quality of detail at the different levels. The outputs of these phases are called multi-resolution image segments, which serve as a basis for the hierarchical classification system.

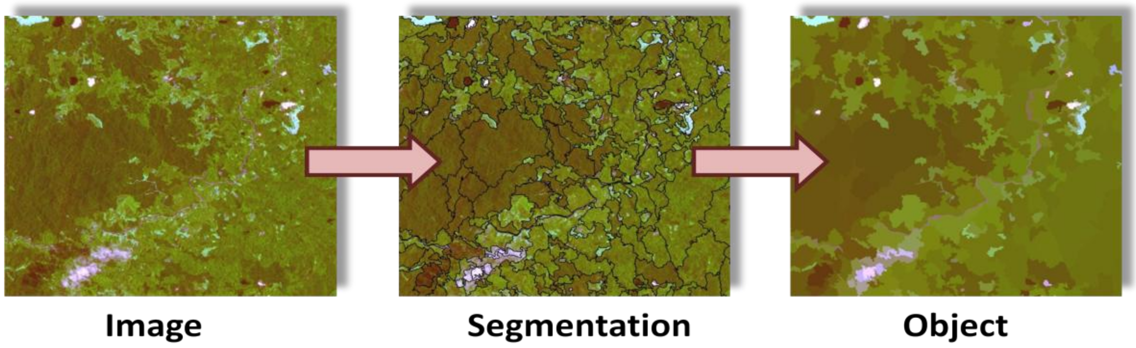

Figure 3. Segmentation process

Image classification was conducted using the hierarchical structure, shown in Figure 4. The hierarchy is divided into four levels, and in each level, land cover types are interpreted using spectral and spatial rules. A Land cover class scheme is developed as a combination of categories based on the criteria of: land cover type, forest classification, soil type, hydrology, crop system type and disturbance history. Details and complexity of land cover types increase in each level, therefore, each of them has different sets of rules applied.

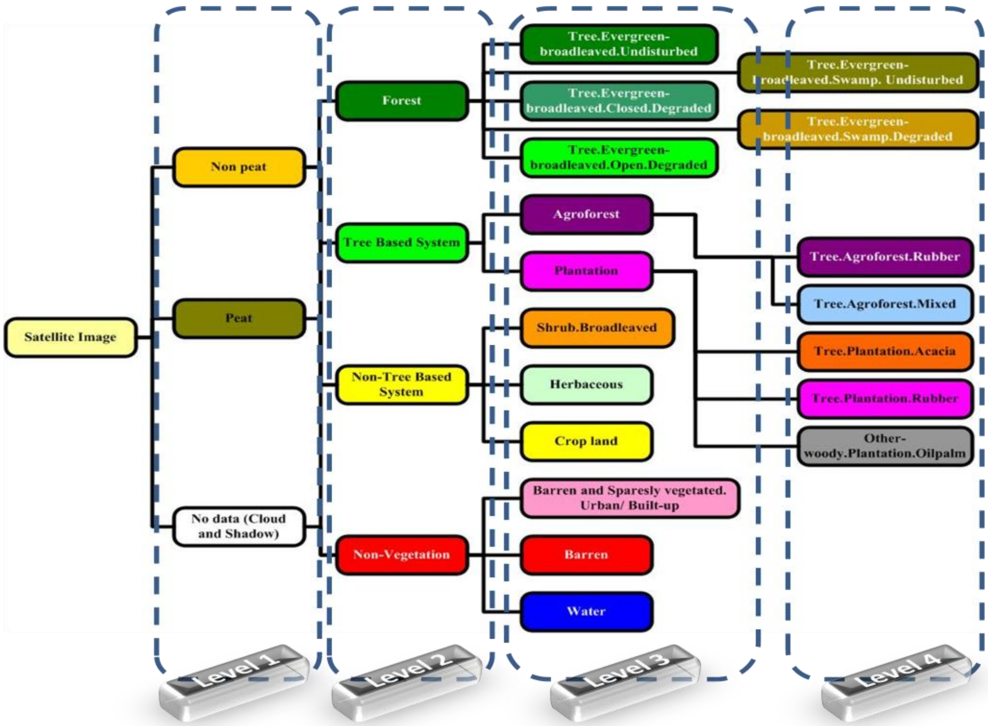

Figure 4. Hierarchical classification scheme

- *Level 1* consists of general classes such as: Peat, Non peat and No Data (Cloud and Shadow). These classes can be easily distinguished using visual inspections, simple spectral landsat bands and peat map. The result of *Level 1* is further classified in *Level 2*.

- *Level 2* consists of general classes such as: *Forest, Tree-based system, Non tree based system and Non vegetation.* These classes can be easily distinguished using visual inspections and a simple vegetation index. The Vegetation index is a ratio of spectral value between a vegetation-sensitive channel (near infra red spectrum) and a non vegetation-sensitive channel (visible spectrum) in the satellite image. The result of *Level 2* is further classified in *Level 3.*

- In *Level 3*, spectral value is not the only parameter using spatial characteristics such as oil palm maps, field references and *Nearest Neighborhood* algorithm is also used as a rule in classification. *Nearest Neighborhood* algorithm in object-based hierarchical classification is conducted in two steps: (1) Feature space optimization and (2) Classification (Definiens, 2007). The first step is conducted to calculate the combination of object features that produces the largest average minimum distance between the samples of the different classes. The combination of object features is used in the second steps to classify all objects into Land-Cover classes in level 3. Level 3 consists of 15 Land-Cover types such as[1]: *Tree.Evergreen-broadleaved.Unditurbed, Tree.Evergreen-broadleaved.Closed.Degraded, Tree.Evergreen-broadleaved.Open.Degraded, Tree.Evergreen-broadleaved.Swamp.Unditurbed, Tree.Evergreen-broadleaved.Swamp.Degraded, Tree.Evergreen-broadleaved.Peat swamp.Unditurbed, Tree.Evergreen-broadleaved.Peat swamp.Degraded, agroforest, monoculture plantation, Shrub.Broadleaved, Crop land, Herbaceous, Barren, Urban/ Built-up and Water.* Typically, for *agroforest and monoculture plantation classes* in *Level 3,* they are classified in more details in *Level 4.*

- In Level 4, similar parameters were applied to the smaller-size objects. Level 4 consists of 5 Land-Cover types such as: Tree.Agroforest.Rubber, Tree.Agroforest.Mixed, Tree.Plantation.Rubber, Other-woody.Plantation.Oilpalm and Tree.Plantation.Acacia. No data class (cloud and shadow) in the upper level are classified in level 4. In this level, backscatter value, field reference and nearest neighborhood algorithm was used as a rule in classification. ALOS Palsar image sampling is based on the appearance of a cloud-free Landsat imagery, or based on field references, while using with the value of backscatter from ALOS Palsar imagery as the parameter.

2.2.3. Post interpretation analysis

Post interpretation analysis consists of two stages: accuracy assessment and land cover change analysis. The accuracy assessment is to test the quality of the information derived from the image classification process by comparing field reference data with the most recent land-cover map. Furthermore, the land cover change analysis aims to get an overview of land cover changes and trajectories which may be analyzed further to derive the rate of deforestation and forest degradation in Kutai Barat.

[1] Following classification system defined under I-REDD project

2.2.4. Accuracy assessment

Accuracy assessment was conducted by cross-tabulating the GPS points as reference data to the corresponding pixels in the output land cover map in a matrix, with the resulting percentage of correctly classified pixels were then used as the value for accuracy. To observe the consistency of the accuracy value, accuracy assessment was conducted by incorporating an increased number of sample points: 50%, 60%, 70%, 80% and 100 % of the total number of collected 314 GPS points. The increasing sample points also considered a larger number of samples for each class, although spatial dependence across sample points was not considered.

2.2.5. Land cover changes analysis

Land cover changes analysis was done by overlaying four time series of land cover data to produce land covers changes and trajectory data during three periods (i.e. 1990-2000, 2000-2005, and 2005-2010) in Kutai Barat. Furthermore, the land cover changes data produced in three periods were overlaid with logging concession boundaries and state forest land designation maps from the Ministry of Forestry to capture the changes that occur at each zone. There are five designation zones in the state forest land in Kutai Barat: Production Forest (Hutan Produksi – HP), Limited Production Forest (*Hutan Produksi Terbatas – HPT*), Protection Forest (*Hutan Lindung – HL*), Natural Reserve (*Cagar Alam*) and Non-Forest Land (*Area Penggunaan Lain –APL*).

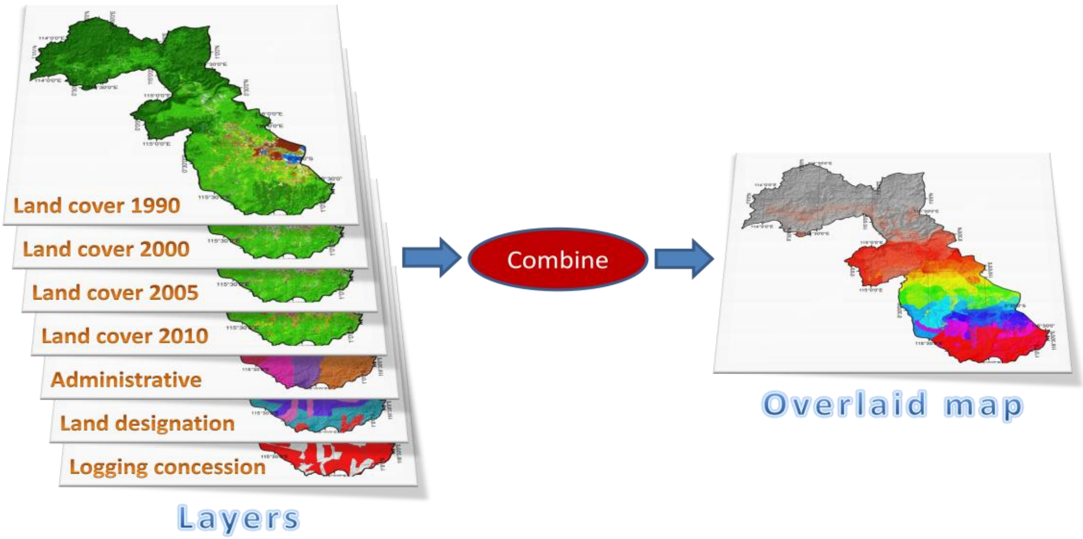

Figure 5. Illustration of overlay process

2.2.6. Rate of deforestation and forest degradation

Deforestation is defined as the conversion of forest to other Land-Uses or a long-term reduction of tree canopy cover below 10%, whereas forest degradation is the reduction of the capacity or quality of forest to provide goods and services (FAO, 2010). To estimate forest deforestation and degradation from the detailed Land-Cover time series, we first grouped the Land-Cover types into three main classes: undisturbed forest, degraded forest, and non-forest.

In practice, we distinguished between three natural forest types: evergreen-broadleaved forest on 1) mineral soil, 2) peat soil, and 3) swamps, with each of these forest types were then further classified as either undisturbed or degraded. Degraded forests on mineral soils were further separated into open canopy and closed canopy forests. Finally, we mapped a total of three undisturbed forest classes and four degraded forest classes, plus non-forest classes (see Table 2 and Table 3 in Chapter 3).

Based on the definitions from the FAO (2010) above, deforestation was estimated from the loss of undisturbed and degraded forest area, i.e. area of undisturbed forest changed to non-forest, plus the area of degraded forest that changed to non-forest. For forest degradation, the evaluation was based upon the changes from undisturbed forest to degraded forest. The annual rate of deforestation was estimated by applying Compound Interest Law (CIL) formula below (FAO, 1995):

$$q = (A_2/A_1)^{1/(t2-t1)} - 1$$

where, A_1 and A_2 are the forest area at time t_1 and t_2.

CIL was also applied to estimate the annual rate of forest degradation by taking into account the residual undisturbed forest from the changes into degraded/disturbed forest. Forest degradation rate (*r*) is calculated based on deforestation formulation which was modified by considering only forest classes.

$$r = ((A_{i1}-A_{j2})/A_{i1})^{1/(t2-t1)} - 1$$

Where, A_{i1} is the undisturbed forest at time 1 (t_1) and A_{j2} is the degraded forest during time 1 (t_1) to time 2 (t_2).

3. Results

3.1. Image classification accuracy

We collected a total of 358 ground truth points representing the various Land-Cover types in Kutai Barat (Figure 6) using GPS, of which as many as 314 ground truth points were used as reference for accuracy assessment.

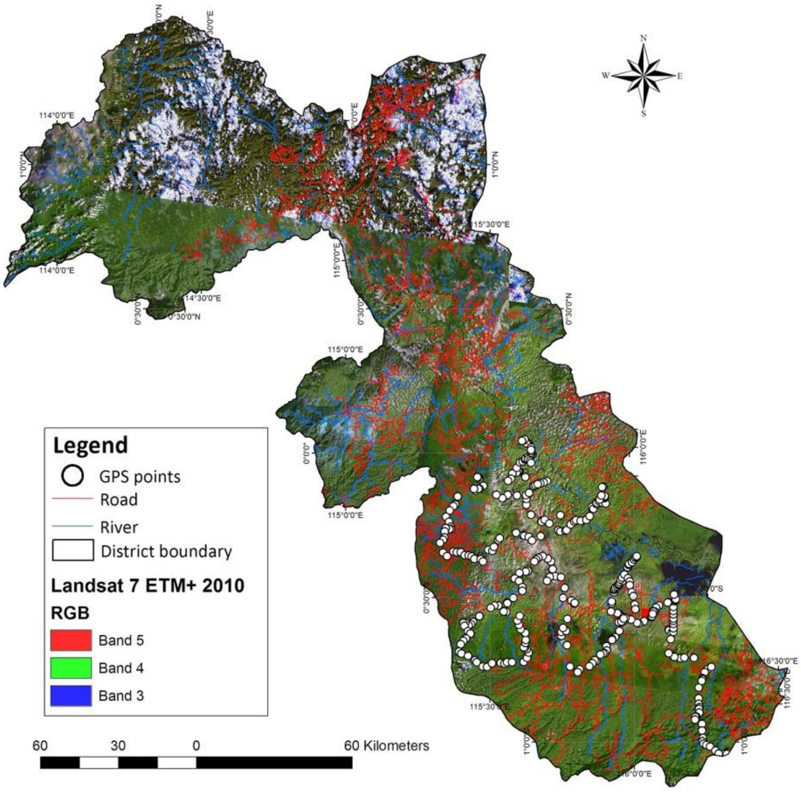

Figure 6. Distribution of ground truth points collected in 2012 in Kutai Barat

The accuracy assessment results demonstrate that overall accuracy of 2010 Land-Cover map is 76.11%. The lowest accuracy (73%) occurred when 50% of sample points were tested, and the highest (79%) was when 60% of sample points were tested. These values indicate that the range of accuracy values is 73%-79%, with an average of 76% (Figure 7).

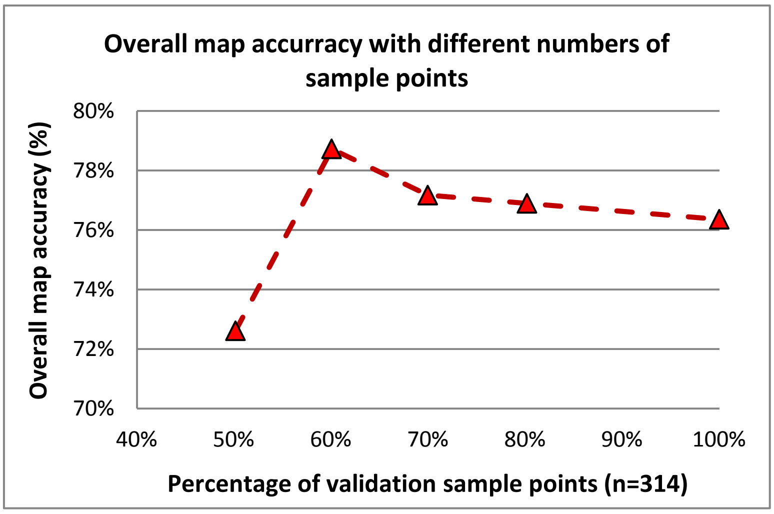

Figure 7. Variation of accuracy values for 2010 Kutai Barat Land Cover Map

Misclassification occurs in rubber agroforests and rubber monocultures mostly due to the similar response shown by these two Land-Cover types in the satellite imagery. In the field, some vegetation cover in rubber agroforests is dominated by rubber plants and understory shrub, while the canopy cover was captured similarly as that of a monoculture system, although this only appears in small areas. Misclassification occurs also for logged-over forest and shrubs. This misclassification occurs as an impact of the vegetation variation in the field being segmented into objects.

3.2. Land Cover Changes

Majority of land cover changes take place in the southern part of Kutai Barat, while only small areas in the northern parts experiencing changes during the last 20 years (Figure 8).

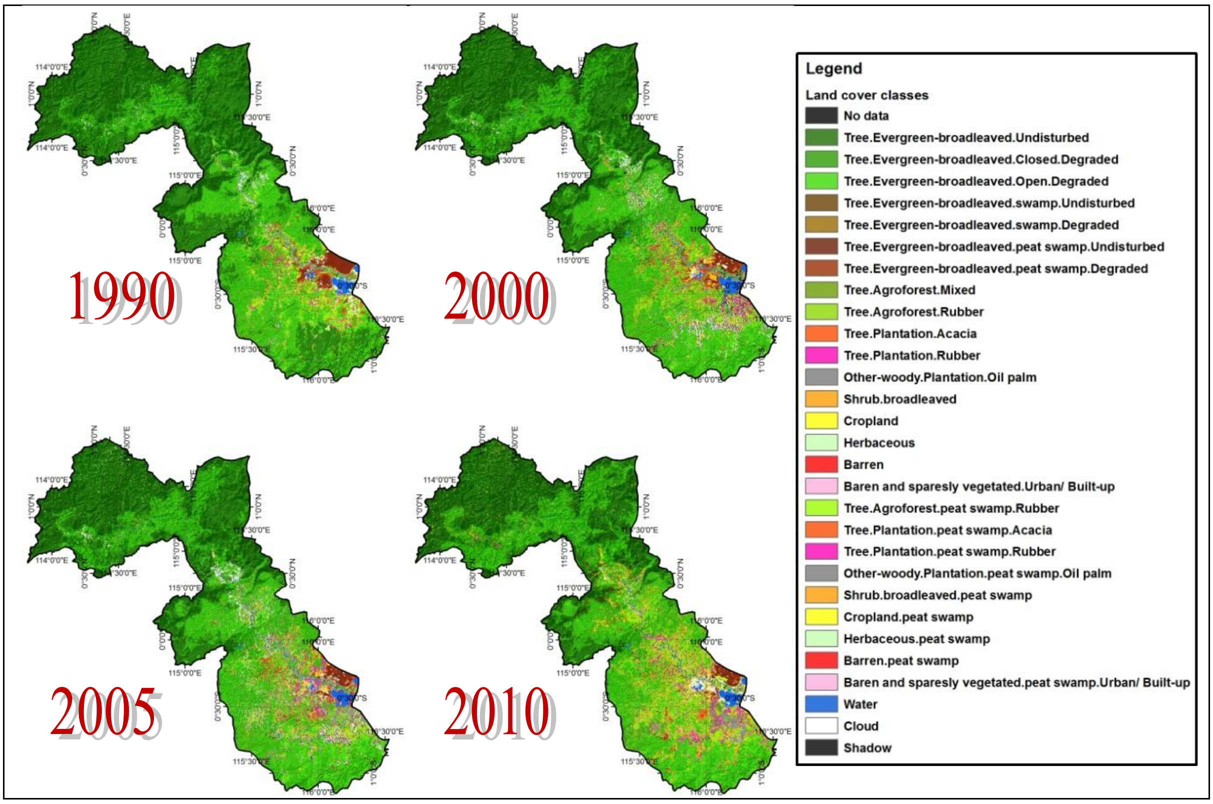

Figure 8. Land cover maps 1990, 2000, 2005 and 2010 of Kutai Barat

In the beginning of the observation period (1990), the undisturbed forest type of *Tree.Evergreen-broadleaved* in mineral soils area was the largest Land-Cover, occupying a total area of 1.6 M ha, which is about 50% of the district area. However, it persistently decreased in the last two decades, with an area of 1.24 M ha in 2000, 1.1 M Ha in 2005 and 952 000 Ha in 2010. In other words, at the end of the observation period in 2010, this Land-Cover type had decreased to about 42% of its initial area, either deforested or degraded by 2010. In the same period, other Land-Cover types that decreased substantially in 1990-2010 were undisturbed and degraded *Tree.Evergreen-broadleaved* in the swamp area. The total area of these Land-Cover classes in 1990 was 74 292 ha and 65% of it

changed into other Land-Cover types with the remaining area of these classes being 26 000 ha in 2010. The undisturbed and degraded *Tree.Evergreen-broadleaved* in the peat swamp area also decreased by 44% from 28 271 ha in 1990, to 15 832 ha in 2010.

The closed-degraded and open-degraded types of *Tree.Evergreen-broadleaved* in mineral soils area increased constantly from the total area of 1.1 M Ha in 1990 to only 1.5 M Ha in 2010. Substantial increase in the area also occurred due to shrub-dominated lands and oil palm plantations which increased approximately five times (400-560%) from 1990 to 2010. Similarly, the areas of agroforests and rubber monocultures increased from 2.2% to 4.4% and 0.5% to 1.2% of the district area, respectively. Changes in Land-Cover areas can be seen in more detail in Figure 9 and Table 2 below.

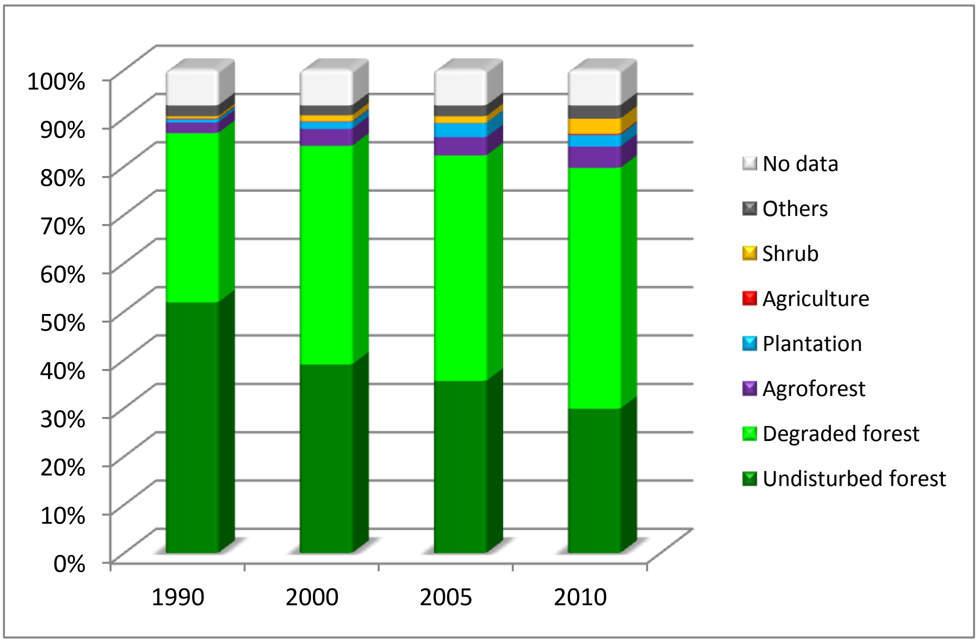

Figure 9. Land cover changes of Kutai Barat 1990-2010

Table 2. Land cover changes in Kutai Barat 1990-2010 (in hectares)

I-REDD Land cover classes	1990	2000	2005	2010
Tree.Evergreen-broadleaved.Undisturbed	1,646,258	1,241,547	1,139,017	952,043
Tree.Evergreen-broadleaved.Closed.Degraded	988,876	1,263,943	1,291,643	1,347,074
Tree.Evergreen-broadleaved.Open.Degraded	108,666	182,032	221,142	277,589
Tree.Evergreen-broadleaved.swamp.Undisturbed	29,404	22,389	13,557	13,148
Tree.Evergreen-broadleaved.swamp.Degraded	44,888	33,585	18,193	13,116
Tree.Evergreen-broadleaved.peat swamp.Undisturbed	36,480	24,210	23,169	20,808
Tree.Evergreen-broadleaved.peat swamp.Degraded	14,269	14,031	8,789	7,463
Tree.Agroforest.Mixed	13,769	42,484	54,260	11,768
Tree.Agroforest.Rubber	57,169	70,590	67,611	115,009
Tree.Plantation.Acacia	83	1,392	4,735	5,424
Tree.Plantation.Rubber	16,940	30,241	42,133	38,709
Other-woody.Plantation.Oil palm	6,100	15,305	41,184	49,014
Shrub.broadleaved	14,495	32,762	37,567	92,963
Cropland	3,904	2,745	873	6,175
Herbaceous	19,672	3,254	1,151	20,268
Shrub/Herb/Barren	7,930	13,799	19,610	12,437
Baren and sparesly vegetated.Urban/ Built-up	574	2,660	6,039	3,981
Tree.Agroforest.Peat swamp.Rubber	595	2,126	2,712	3,836
Tree.Plantation.Peat swamp.Acacia	0	12	381	14
Tree.Plantation.Peat swamp.Rubber	344	1,106	3,219	2,038
Other-woody.Plantation.Peat swamp.Oil palm	33	841	4,589	6,707
Shrub.broadleaved.Peat swamp	307	7,852	8,372	6,037
Cropland.Peat swamp	5	119	0	202
Herbaceous.Peat swamp	4,468	5,666	4,549	8,690
Shrub/Herb/Barren.Peat swamp	293	829	382	323
Baren and sparesly vegetated.Peat swamp.Urban/ Built-up.	16	19	648	693
Water	41,977	41,977	41,988	41,988
No data	242,589	242,589	242,589	242 589
Grand total	**3 300 104**	**3 300 104**	**3 300 104**	**3 300 104**

3.3. Deforestation and forest degradation

The reclassification of land cover classes into undisturbed forest, degraded forest and other land cover types are shown in Table 3 below.

Table 3. Reclassification of land cover classes into forest cover classes

I-REDD Land cover classes	Forest cover classes	1990	2000	2005	2010
Tree.Evergreen-broadleaved.Undisturbed	Undisturbed Forest	1 646 258	1 241 547	1 139 017	952 043
Tree.Evergreen-broadleaved.Closed.Degraded	Degraded Forest	988 876	1 263 943	1 291 643	1 347 074
Tree.Evergreen-broadleaved.Open.Degraded	Degraded Forest	108 666	182 032	22 1142	277 589
Tree.Evergreen-broadleaved.Swamp.Undisturbed	Undisturbed Forest	29 404	22 389	13 557	13 148
Tree.Evergreen-broadleaved.Swamp.Degraded	Degraded Forest	44 888	33 585	18 193	13 116
Tree.Evergreen-broadleaved.Peat swamp.Undisturbed	Undisturbed Forest	36 480	24 210	23 169	20 808
Tree.Evergreen-broadleaved.Peat swamp.Degraded	Degraded Forest	14 269	14 031	8 789	7 463
Forest in total		**2 868 842**	**2 781 738**	**2 715 511**	**2 631 240**
Other land cover classes	Non-forest	188 673	275 777	342 004	426 274
No data	No data	242 589	242 589	242 589	242 589
Grand Total		**3 300 104**	**3 300 104**	**3 300 104**	**3 300 104**

During the period of 1990-2010, the total forest area decreased from 2.86 M ha (87% of total district area) to 2.78 M ha (84%), 2.71 M ha (82%), 2.63 M ha (80%). Thus, in the last 20 years, the loss of forest in Kutai Barat was approximately 8% of the initial forest area in 1990. In average, forest area loss in the three change periods were 8 710 ha per year in 1990-2000, 13 245 ha per year (2000-2005), and 16 854 ha per year (2005-2010). The proportion of undisturbed forest, degraded forest and non-forest of Kutai Barat during 1990-2010 is shown in Figure 10.

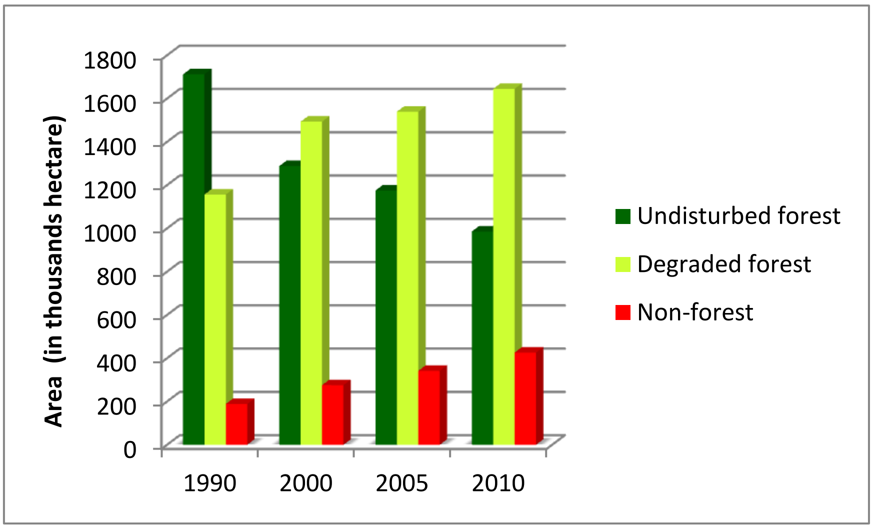

Figure 10. Proportion of undisturbed forest, degraded forest and non-forest of Kutai Barat 1990-2010

Forest degradation in the period of 1990-2000 reached 411 833 Ha with an average area increase of degradation 41 183 Ha per year. During 2000-2005, forest degradation decreased to 110 689 Ha, or an average of 22 138 Ha per year. In 2005-2010 forest degradation increased again to 178 900 Ha, or 35 780 Ha per year. Deforestation and forest degradation maps of Kutai Barat during 1990-2000, 2000-2005 and 2005-2010 can be seen in Figure 11.

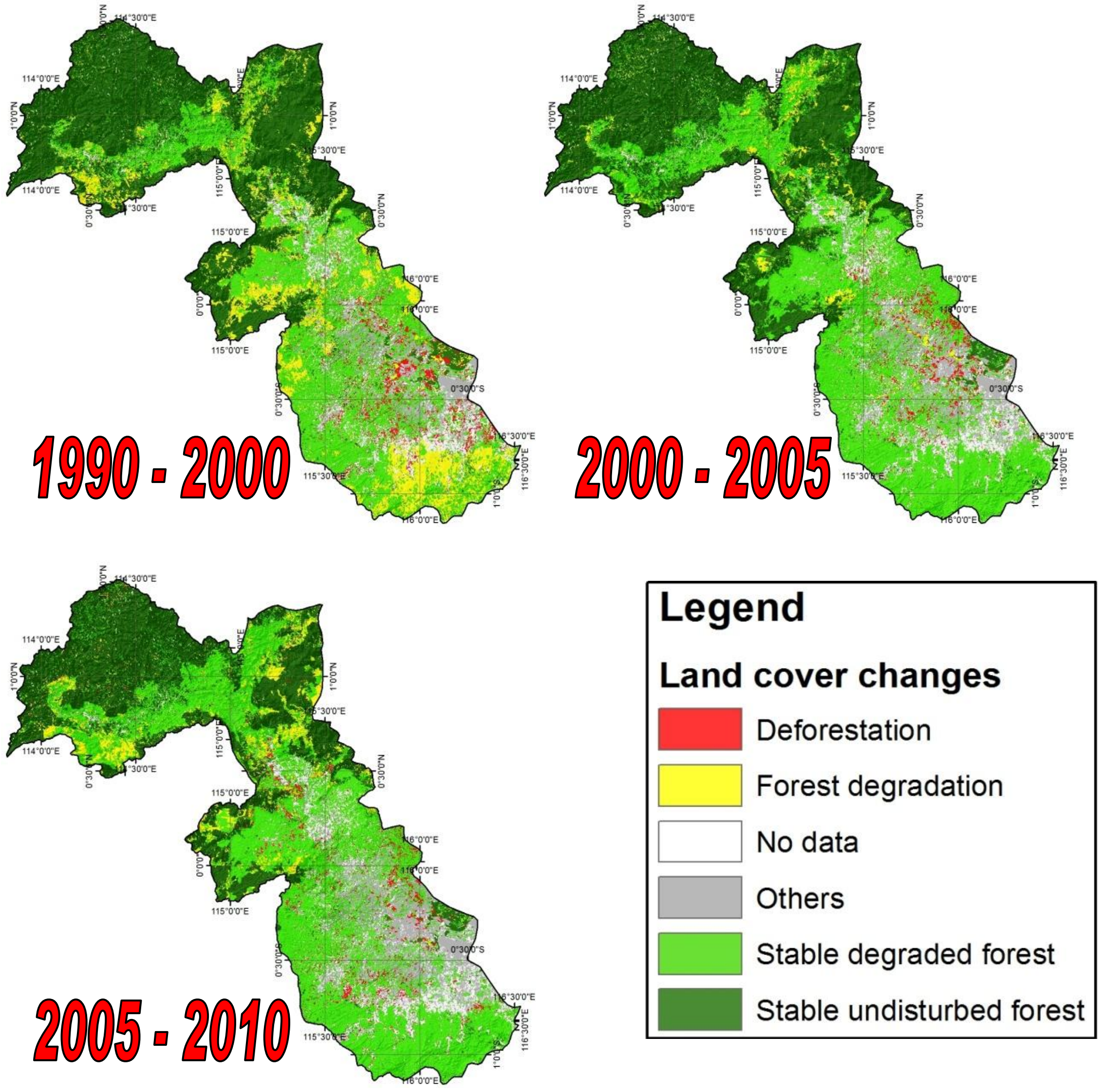

Figure 11. Deforestation and forest degradation maps of Kutai Barat

3.4. Deforestation and forest conversion

The annual rates of deforestation in Kutai Barat for the three periods are 0.31% (1990-2000), 0.48% (2000-2005) and 0.63% (2005-2010). Large areas of forest loss took place in the areas classified as non forest land (APL) and Production Forest (HP). Nevertheless, despite the smaller areas, forest loss and conversions also occurred inside the Protection Forest with the amount of 1.89 ha per year in 1990-2000, 27.8 ha per year (2000-2005) and 863.4 ha per year (2005-2010). Deforestation occurrence based on forest land designation in Kutai Barat during 1990-2010 is shown in Figure 12.

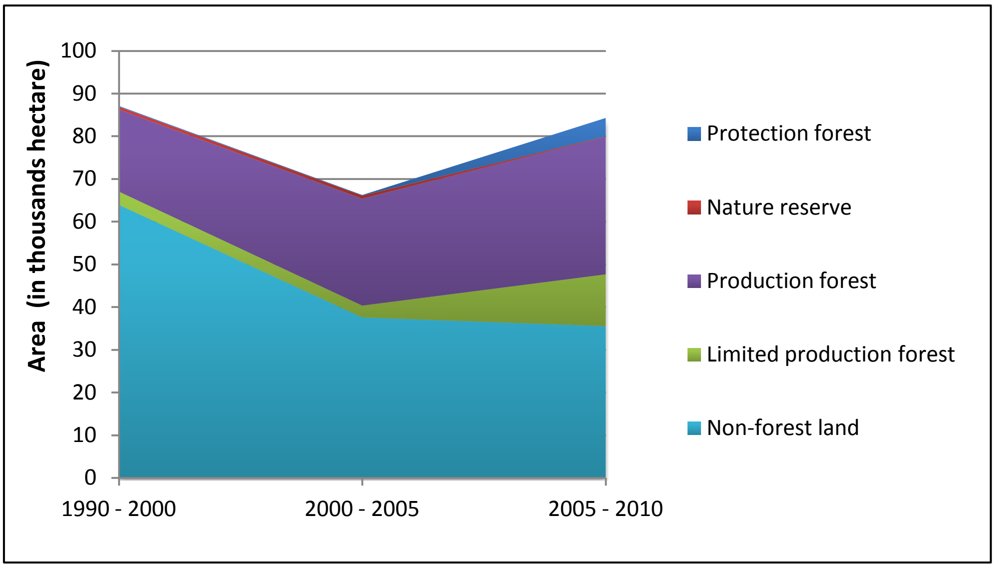

Figure 12. Deforestation occurrence based on forest land designation in Kutai Barat during 1990-2010

On the major trajectories of forest loss in 1990-2000, the largest area was shown by changes from forest to agroforest and to shrub, which contributed to 43% and 23% of total forest loss area of 87 104 ha in 1990-2000 (Figure 13). In addition, forest was also converted to plantations (21%) and, to a much smaller extent, to agriculture (1%).

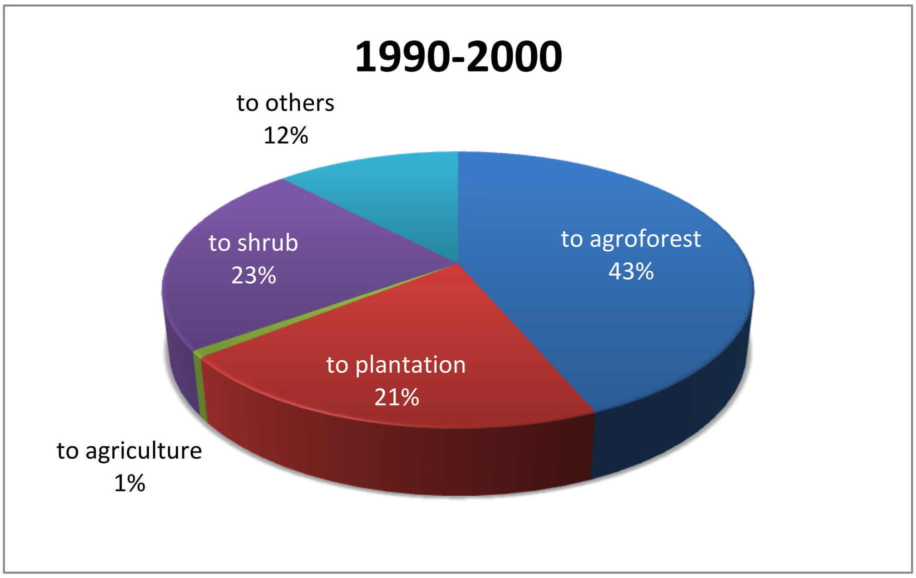

Figure 13. Trajectories of forest conversions for 1990-2000

For the forest loss in 2000-2005 (66 227 ha), the major trajectories shared 40% and 42% contributions as changes from forest to agroforest and to plantation (Figure 14).

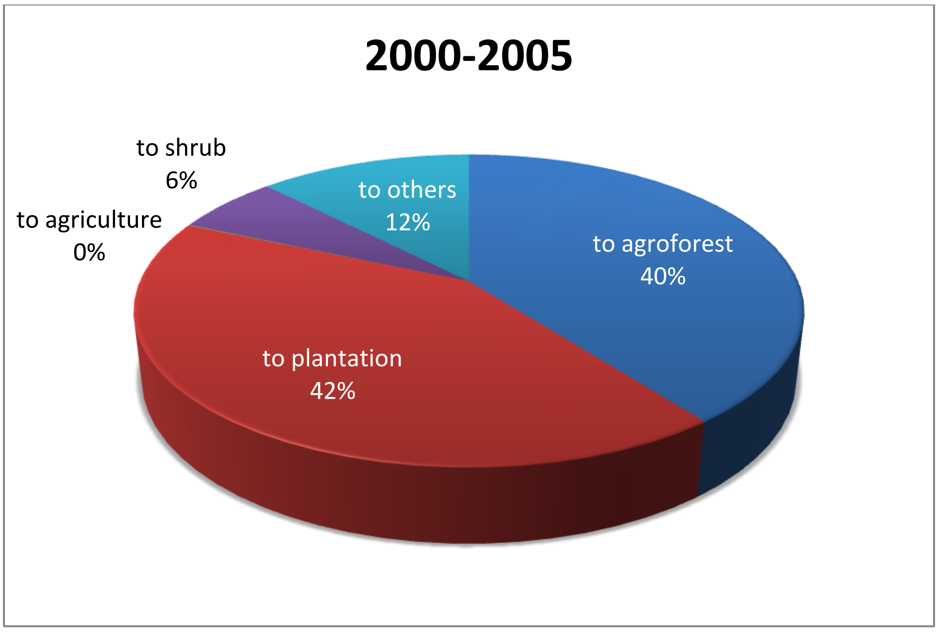

Figure 14. Trajectories of forest conversions for 2000-2005

In 2005-2010, the largest trajectories were changes from forest to agroforests and to shrubs, which contributed 36% and 31% of forest loss area of 84 271 ha (Figure 15).

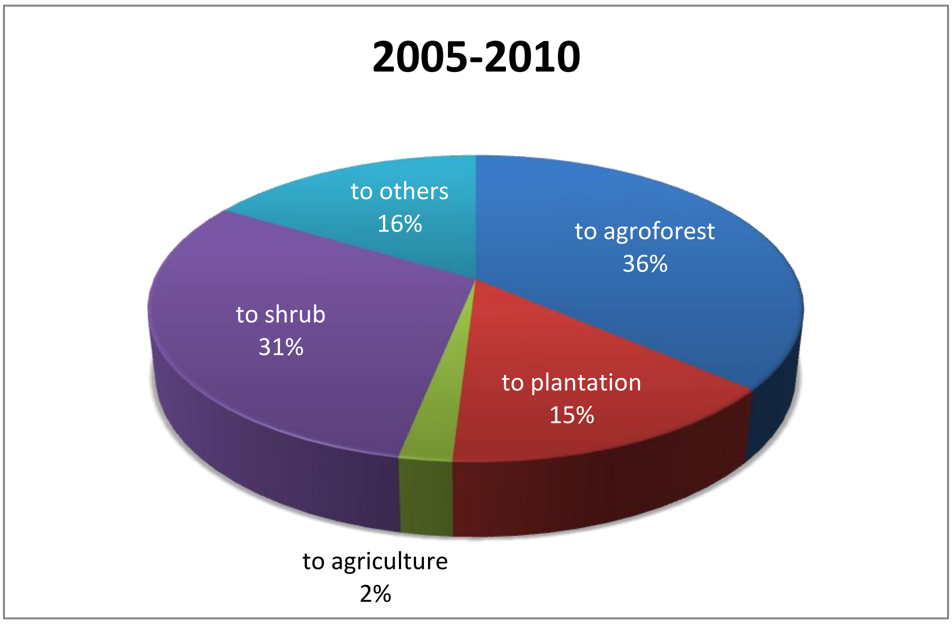

Figure 15. Trajectories of forest conversions for 2005-2010

3.5. Forest degradation

The annual rates of forest degradation in Kutai Barat for the three periods were 2.74% (1990-2000), 1.78% (2000-2005), and 3.28% (2005-2010). Most of the forest degradation occurred in areas designated as Production Forest (HP) and Limited Production Forest (HPT). Nevertheless, forest degradation also occurred largely in Protection Forests was an average of 6 611 Ha per year in 1990-2000, 5 961 Ha per year (2000-2005) and 11 555 Ha per year (2005-2010).

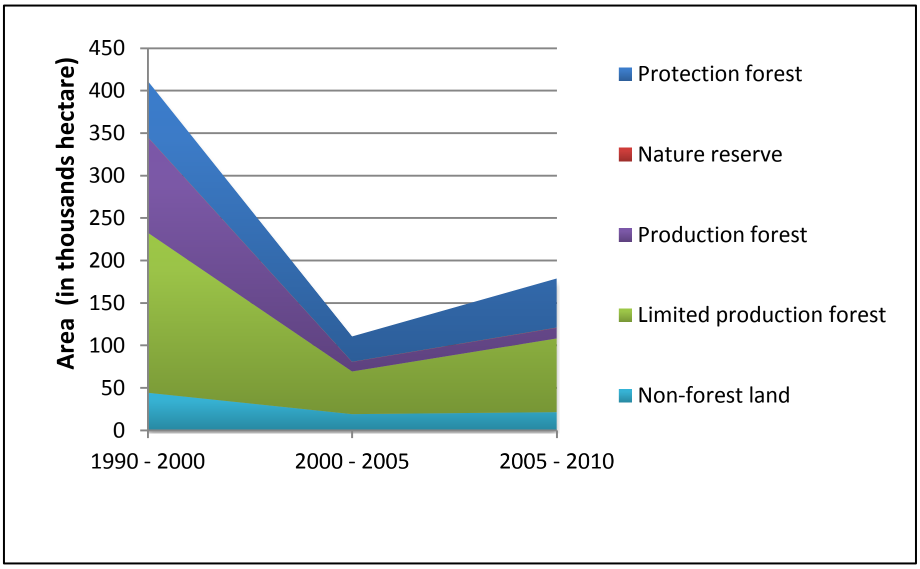

Figure 16. Forest degradation based on forest land designation in Kutai Barat during 1990-2010

4. Discussions

Between 1990 and 2010, deforestation in Kutai Barat took place largely in the areas categorized as Non-forest Land (APL) and Production Forest (HP). For APL areas, forest conversions are indeed legal, where the forest is extracted of its resources and the lands were developed for the interests of economic development and other production and livelihood needs. In the Production Forest areas, forest timber extraction is legal, although conversions for agricultural commodities are not, unless the forest land status is transformed into another status where conversions are allowed.

The study found that most of forest loss in Kutai Barat during 1990 – 2010 was caused by changes from degraded forest (especially open and closed *Tree.Evergreen-broadleaved*) to rubber agroforests, rubber plantations and shrub land. Anecdotal information showed that the increase of rubber agroforests and rubber plantations, which are mostly developed by local communities, might be driven, or at least supported, by government programs of providing rubber seeds to communities. This Land-Use development mostly takes place in the non-state forest land (APL) areas, and thus is inevitable for the economic development, population growth and people’s livelihood. Changes to shrub land normally refer to effects of logging concessions which leave the land with secondary

regrowth. The constant increase of shrubland for 1990-2010, should alarm the district stakeholders in managing the lands to improve their livelihoods and the environment.

Similar to deforestation, most of the forest degradation occurred in the area designated as Production Forest and Limited Production Forest where tree cutting is legal, as long as the logging companies hold concession permits from the Ministry of Forestry and the local government. However, to reduce logging impacts to the environment, it is imperative that the companies obey and implement regulations that promote sustainable forest management (e.g. not exceeding annual logging quotas, conducting land rehabilitation and replanting after logging, protecting high conservation value areas). Aligned with such enforcements, the Ministry of Forestry and the local government, as regulator bodies, should conduct monitoring and evaluation efforts to make sure that forest management practices are implemented properly.

Forest degradation in Kutai Barat occurred not only in Production Forest areas, but also in Protection Forest, where logging is illegal, but nonetheless showed a steady increase of degradation throughout the study period. This practice occurs mostly around the forest boundaries and is most likely due to the adjacency of the Protection Forest with logging concession areas and/or villages. The reason might be due to unclear boundaries, while in some instances illegal logging might be done deliberately. In the core zone of Protection Forests with less accessibility, forest degradation is very low.

5. Conclusion/recommendations

Forest deforestation and degradation in Kutai Barat mostly took place in the southern parts of the district, where according to the land designation, some of them are legal (and necessary) while some are illegal. In answer to the illegal, the role of forest monitoring and law enforcement is key, and it should be reinforced optimally, while alternative livelihood options for communities living around the forest should also be promoted in order to reduce encroachments in the protection areas.

For a district where natural resources still play a major role in the development and economic growth, strategies on Land-Use planning and its implementation, which accommodate environmental protection and community development, should be comprehensively designed in order to ensure good environmental practices as well as to improve community livelihood. This latter notion should be well captured in the various strategies to mitigate climate change such as REDD+ and Land-Use planning for low (CO_2) emission development.

6. Appendix

6.1. Appendix 1. Description of land cover classes

No	I-REDD LC classes (ICRAF)	Descriptions
1	**Tree.Evergreen-broadleaved.Undisturbed**	Undisturbed forest is natural forest cover with a dense canopy, highly diverse species of trees and basal areas. It has no logging roads, indicating that it has never been logged, at least not on a large scale, and is usually located in areas with a rough topography. Canopy cover of undisturbed forest is usually >80%. In satellite images it is indicated by high value of vegetation index and infrared spectrum channels and lower value in visible spectrum channels.
2	**Tree.Evergreen-broadleaved.Closed.Degraded**	Natural forest area having been disturbed by logging, or other timber extraction activities, or fire but still has a relatively dense tree cover and dense canopy. Canopy cover is around 20–60%. Large trees with diameter >30 cm may still be found.
3	**Tree.Evergreen-broadleaved.Open.Degraded**	Natural forest area having been disturbed by logging or other timber extraction activities, or fire, but already has relatively rare tree cover and rare canopy. Large trees with diameter > 30 cm cannot be found.
4	**Tree.Evergreen-broadleaved.swamp.Undisturbed**	Similar to no.1, but located in swampy areas and generally with lower vegetation size / shorter and lower density than lowland forests and forests in the mountainous region.
5	**Tree.Evergreen-broadleaved.swamp.Degraded**	Similar to No. 3, but is located in a swampy area.
6	**Tree.Evergreen-broadleaved.peat swamp.Undisturbed**	A swamp forest is a wetland featuring temporary or permanent inundation of large areas of land by shallow bodies of water with natural vegetation cover, has never been logged in the past and has also not been degraded or affected by any human activities.
7	**Tree.Evergreen-broadleaved.peat swamp.Degraded**	Logged-over swamp forest is swamp with natural forest cover that has been logged or degraded.
8	**Tree.Agroforest.Mixed**	Mixed garden is an agroforest or tree-based system with more than 30% of the area consisting of various species of trees. Mixed garden is usually located in 0.5-1km distance to settlement or road.
9	**Tree.Agroforest.Rubber**	Rubber agroforest is characterized by the presence of rubber trees mixed with other tree species and shrub, which form a stand structure similar to secondary forest. Rubber trees usually account for less than 70% of the population of trees above 10 cm dbh. When the presence of non-rubber trees is dominant, and the plot is old enough, the area will be very hard to differentiate from a natural forest.
10	**Tree.Plantation.Acacia**	Monoculture plantation of acacia.
11	**Tree.Plantation.Rubber**	Monoculture plantation of rubber, usually has a spacing by 3 x 3 m.
12	**Other-woody.Plantation.Oil palm**	Monoculture plantation of oil palm planted by private companies and local communities.
13	**Shrub.broadleaved**	Area dominated by non-woody vegetation, which is usually a former forest clearing area undergoing natural secondary regrowth. For old shrubs, there is a low cover of trees, around 5% cover; but no trees with a diameter >20 cm.
14	**Cropland**	Area used to grow crops other than rice. For example: potato, chili, cabbage, maize and etc.
15	**Herbaceous**	Area dominated by grass, usually an abandoned area.

No	I-REDD LC classes (ICRAF)	Descriptions
16	**Shrub/Herb/Barren**	Area where trees have been cleared, which includes ex-logging areas or slashed-and-burned areas prepared for agriculture; vegetation cover is usually herbaceous vegetation and/or grass.
17	**Baren and sparesly vegetated.Urban/ Built-up**	Settlement refers to built area (city or village), which includes road; main road and/or logging road; for rural settlement this includes home gardens immediately located near the houses.
18	**Tree.Agroforest.peat swamp.Rubber**	Similar to no. 9, but in a peat area.
19	**Tree.Plantation.peat swamp.Acacia**	Similar to no. 10, but in a peat area
20	**Tree.Plantation.peat swamp.Rubber**	Similar to no. 11, but in a peat area.
21	**Other-woody.Plantation.peat swamp.Oil palm**	Similar to no. 12, but in a peat area.
22	**Shrub.broadleaved.peat swamp**	Similar to no. 13, but in a peat area.
23	**Cropland.peat swamp**	Similar to no. 14, but in a peat area.
24	**Herbaceous.peat swamp**	Similar to no. 15, but in a peat area.
25	**Shrub/Herb/Barren.peat swamp**	Similar to no. 16, but in a peat area.
26	**Baren and sparesly vegetated.peat swamp.Urban/ Built-up**	Similar to no. 17, but in a peat area.
27	**Water**	Water body refers to an area covered with water, for example: stream, lake, pond.

6.2. Appendix 2. Error matrix of land cover map 2010

Classification data \ Reference data	Tree.Evergreen-broadleaved.Undisturbed	Tree.Evergreen-broadleaved.Closed.Degraded	Tree.Evergreen-broadleaved.Open.Degraded	Tree.Evergreen-broadleaved.swamp.Undisturbed	Tree.Evergreen-broadleaved.swamp.Degraded	Tree.Agroforest.Mixed	Tree.Agroforest.Rubber	Tree.Plantation.Acacia	Tree.Plantation.Rubber	Other-woody.Plantation.Oil palm	Shrub.broadleaved	Cropland	Herbaceous	Shrub/Herb/Barren	Baren and sparesly vegetated.Urban/ Built-up	Water	Total
Tree.Evergreen-broadleaved.Undisturbed	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Tree.Evergreen-broadleaved.Closed.Degraded	0	44	3	0	0	0	5	0	1	1	12	0	0	0	0	0	66
Tree.Evergreen-broadleaved.Open.Degraded	0	2	24	0	0	1	2	0	1	2	5	0	0	0	0	0	37
Tree.Evergreen-broadleaved.swamp.Undisturbed	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Tree.Evergreen-broadleaved.swamp.Degraded	0	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0	4
Tree.Agroforest.Mixed	0	0	1	0	0	2	0	0	1	0	0	0	0	0	0	0	4
Tree.Agroforest.Rubber	0	1	0	0	0	0	34	0	6	1	1	0	0	2	0	0	45
Tree.Plantation.Acacia	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	4
Tree.Plantation.Rubber	0	0	0	0	0	0	2	0	19	0	1	0	0	0	0	0	22
Other-woody.Plantation.Oil palm	0	0	0	0	0	0	2	0	0	25	0	0	0	0	3	0	30
Shrub.broadleaved	0	0	0	0	0	0	1	0	4	0	45	0	1	1	1	1	54
Cropland	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2
Herbaceous	0	0	0	0	0	0	0	0	0	1	1	0	16	0	2	1	21
Shrub/Herb/Barren	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	4
Baren&sparesly vegetated.Urban/Built-up	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	15
Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4
Total	0	49	29	0	2	3	46	3	32	30	67	2	17	7	21	6	314

6.3. Appendix 3. Accuracy of each land cover category in land cover map 2010

Land cover classes	Correctly classified pixels in map	GPS points from the field	Accuracy Assessment (%)
Tree.Evergreen-broadleaved.Closed.Degraded	44	49	89.80%
Tree.Evergreen-broadleaved.Open.Degraded	24	29	82.76%
Tree.Evergreen-broadleaved.swamp.Degraded	2	2	100.00%
Tree.Agroforest.Mixed	2	3	66.67%
Tree.Agroforest.Rubber	34	46	73.91%
Tree.Plantation.Acacia	3	3	100.00%
Tree.Plantation.Rubber	19	32	59.38%
Other-woody.Plantation.Oil palm	25	30	83.33%
Shrub.broadleaved	45	67	67.16%
Cropland	2	2	100.00%
Herbaceous	16	17	94.12%
Shrub/Herb/Barren	4	7	57.14%
Baren and sparesly vegetated.Urban/ Built-up	15	21	71.43%
Water	4	6	66.67%
Total	239	314	**76.11%**

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