Spatial Database Development for Estimation of Emission of Greenhouse Gases Using Remote Sensing and GIS in Sumatra Island, Indonesia

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Abstract

Deforestation, conversion of forest into non-forest land, especially in tropical forest areas has been a cause for concern worldwide. Since forests hold most of the carbon in terrestrial ecosystems, such changes exert a significant impact on the net increase of atmospheric carbon. In addition, land cover changes affect the greenhouse gas dynamics. The final objective of this study was to construct a database for storing various types of information about the intake and uptake of the greenhouse effect gasses (GHG). We are developing a system for the construction of databases of GHG in the Pasir Mayang area and Jambi Province in Sumatra. The Pasir Mayang area is a small area and Jambi Province is a middle-sized area.

Using LANDSAT/TM data, we determined the land cover of the Pasir Mayang area in 1992 and 1995. Due to the land cover changes, aboveground carbon stock of the area decreased by 6%. Comparison of the total GHG flux determined in the studies carried out over the period 1992-1995 based on the land cover shows that there was an increase in the flux of nitrous oxide and carbon dioxide and reduction in the absorption of methane.

In Jambi Province, comparison of the results of land cover data collected in 1986 and 1992 shows that the loss of aboveground carbon due to the land cover changes amounted to 8 million tons annually.

Introduction

Deforestation, conversion of forest into non-forest land use/land cover, especially in tropical forest areas has been a cause for international concern. It was estimated that 6 - 16.8 million hectares per year of tropical forest were lost (Grainger, 1993; Barbier *et al.*, 1991; Myers, 1994). Since forests hold most of the carbon in terrestrial ecosystems, such changes exert a significant impact on the net increase of atmospheric carbon. In addition, changes in land use and land cover result in changes in greenhouse gas dynamics.

GHG (CO_2, N_2O, CH_4) emission from the soil surface is influenced by several factors such as land use/land cover types as well as climatic, biological and physical environment factors. Since emission measurements usually are conducted at a point location, problems arise when emission estimation is used for scaling up into broader areas. The current research aimed at the development of a database to contribute to the regional estimation of aboveground carbon stock loss and soil surface greenhouse gas emission changes caused by land use/land cover changes using GIS and Remote Sensing. As a case study, land use/land cover changes between 1992 and 1995 in Pasir Mayang area and 1986 to 1992 in Jambi Province, Indonesia will be described.

Research objective

Since the measurements of the flux or emission of greenhouse gases are usually conducted at a point

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location, problems arise when emission estimation is used for scaling up into national or regional areas where biophysical variations occur. The current research aimed at developing a database for the estimation of regional emissions based on the measurement of emissions at several points using GIS.

Research methodology

1 Development of GHG database in Pasir Mayang area, Sumatra

Using LANDSAT/TM data, we determined the land cover of the Pasir Mayang area in 1992 and 1995. The Pasir Mayang area extends over 35 km (east to west) and 25 km (north to south) as shown in Fig. 1. In the area, the estimation of the total aboveground carbon stock was calculated by multiplying the number of ha by the total area of each land cover type. The same method was applied for calculating the total emission of greenhouse gases.

2 Development of GHG database in Jambi Province, Sumatra

The study area is located in Jambi Province, between 0° 45' and 2° 45' latitude south and 101° and 104° 55' longitude east (Fig. 1). The total area covers 48,715 sq. km. It ranges from swampy coastal plains in the east to areas at an elevation of more than 1,000 meter above the sea level in the western part. According to statistical data, in 1995 the population of Jambi which numbered 2.18 million had increased more than twofold compared to 1971 data (Bappeda Jambi, 1985 and 1998).

The research was initiated by the development of land use/land cover maps, followed by field measurements. Spatial database (land use/land cover) construction was conducted at the Forest Ecology and Remote Sensing Lab. of the Regional Center for Tropical Biology (Biotrop), and Remote Sensing Laboratory of the National Institute of Agro-Environmental Sciences, Japan. Field measurements (above ground biomass, and greenhouse gas flux) were conducted by Biotrop, Impact Center of South East Asia and National Institute of Agro-Environmental Sciences, Japan.

1) Land use/land cover map construction

Spatial database of land use/land cover was developed based on land use/land cover maps constructed by BIOTROP in 1986 and 1992 on a scale of 1 : 250,000. These two maps were made based on the visual interpretation of various remotely sensed imagery photographs obtained by LANDSAT and SPOT.

2) Biomass estimation (aboveground carbon stock)

Weight of sample components of the trees i.e. stems, branches, twigs, leaves and roots in the primary forest, secondary forest and logged-over forest was estimated by using the equation developed by Kira and *et al.* (1967). Stem weight included stem bark, while weight of branches included twigs. For the saplings and seedlings, the calculation of biomass per individual was obtained from the average weight of several saplings and seedlings collected as samples at each study site. The total weight of the sapling and seedling components was separated into leaf weight, stem weight and root weight. Tree biomass for one hectare plot was calculated by multiplying the biomass of each tree by the number of trees per hectare. The same method was applied for saplings and seedlings. Aboveground biomass of the other land use/land cover types was determined based on the literature. To obtain the aboveground carbon stock, the biomass weight was multiplied by a factor of 0.5.

3) Measurement of soil greenhouse gas flux

Flux of carbon dioxide, nitrous oxide and methane from the soil surface was measured for various land use/land cover types in order to obtain the estimates of GHG emissions by the ground survey group of the project.

4) Combined field data measurement and GIS spatial data

Data on the aboveground carbon stock and soil surface greenhouse gas flux were combined using a look-up table of Arc/Info. The total aboveground carbon stock was estimated by multiplying the unit value by the total area of each land use/land cover type. The same method was applied for calculating the total emission of greenhouse gases.

Results and Discussion

1 Development of GHG database in Pasir Mayang area, Sumatra

The land cover maps of the Pasir Mayang area constructed in 1993 and 1995 are depicted in Fig. 2. The aboveground carbon stock was calculated by multiplying the unit value by the total area of each land cover type using the land cover maps of the Pasir Mayang area constructed in 1993 and 1995. The same method was applied for calculating the total emission of GHG. The results are shown in Tables 1 and 2.

Logged forest was the predominant land cover type in Pasir Mayang, followed by rubber plantations and secondary vegetation (rubber jungle), fallow land (bush/shrubs), grassland and bare land (clear-cut area) (Table 1). Between 1993-1995, the logged forest area decreased to about 5,300 ha, while the rubber jungle and fallow land area increased to 4,872 ha and 225 ha, respectively. As a result, the aboveground carbon stock of the area decreased from 11.1 million ton to 10.4 million ton, corresponding to a loss of about 0.7 million ton.

Table 2 summarizes the greenhouse gas emissions from soil in 1993 and 1995. Comparison of the total greenhouse gas flux in the studies carried out over the period 1993-1995 based on land cover types showed that there was an increase in the flux of nitrous oxide and carbon dioxide and reduction of absorption of methane.

Table 1 Land cover type and aboveground carbon stock changes in Pasir Mayang area between 1993-1995

Land cover	Carbon stock per ha (ton/ha)	Area in 1993 (ha)	Total aboveground carbon stock in 1993 (ton)	Area in 1995 (ha)	Total aboveground carbon stock in 1995 (ton)
Logged forest	155.2	68,529.5	10,634,270.8	63,235.5	9,812,758.4
Bush/Shrubs	15.0	10,224.8	153,372.0	10,450.3	156,754.5
Rubber and Secondary vegetation	35.5	6,541.8	232,233.9	11,414.3	405,207.7
Grassland	6.0	3,156.5	18,939.0	3,468.3	20,809.8
Bare land	0.0	986.3	0.0	870.5	0.0
Total in 1993		89,438.9	11,038,815.7	89,438.9	10,395,530.4

Note: Aboveground biomass was estimated by Biotrop using allometric equation

Table 2 Soil greenhouse gas emission changes in Pasir Mayang area between 1993 and 1995

Land cover	Carbon dioxide (ton/hour)		Nitrous oxide (kg/hour)		Methane (kg/hour)	
	1993	1995	1993	1995	1993	1995
Logged forest	241.4	222.8	7.343	6.776	-9819.3	-90607.7
Fallow land	59.4	60.7	2.041	2.086	-4.5	-4.6
Rubber and Secondary vegetation	31.0	54.0	1.328	2.317	-1.3	-2.2
Grassland	19.1	20.9	0.347	0.381	0.0	0.0
Bare land	6.1	5.4	0.326	0.117	-73.2	-64.6
Total	357.0	363.8	11.194	11.679	-9898.3	-9132.1

Note : Calculation was made based on mean value of 10-month (10 times) measurements conducted by Dr. Tsuruta. The measurements were made in Jan., Feb., March, June, July, Aug., Sept., Oct., Nov. and Dec.

2 Development of GHG database in Jambi Province, Sumatra

1) Land use/ land cover changes

Fig. 3a and 3b show the land use/land cover patterns in 1986 and 1992. Quantitative comparison of the changes is presented in Table 3. Proportion of primary forest decreased from 33.9 % in 1986 to 25.8 % in 1992. Fallow land area (shrubs) decreased from 19.3 % to 12.5 % in 1992. Further analysis of each land use/land cover type is presented in Fig. 4 which shows that about 24 % of the primary forest area was converted into logged forest, shrubs (fallow lands), cash crop plantations, cultivated and settlement areas. About 30 % of the logged forest was converted into shrubs, cash crop plantations, a mixture of cultivated land and settlements. In the case of shrubs, most of them were converted into a mixture of cultivated land and secondary vegetation (40.3 %), cash crop plantations (7.9 %), logged forest (20.2 %) and secondary forest. About 73 % of the grasslands became fallow land (48.8 %), as well as a mixture of cultivated land and secondary vegetation (20.7 %).

2) Aboveground carbon stock changes

Aboveground carbon content for each land use/land cover type was estimated by multiplying the area of each land use/land cover type by the carbon stock per unit area. Table 3 shows the changes in the aboveground carbon content associated with the changes in the land use/land cover types. Total aboveground carbon stock decreased from 6.16 x 10^8 tons in 1986 to 5.66 x 10^8 tons in 1992 corresponding to a loss of about 0.50 x 10^8 tons within 6 years (equivalent to 8.3 million tons per year). The loss of the aboveground carbon content was mainly due to primary forest conversion. IPCC has divided the loss of aboveground carbon content into on-site and off-site release. These two categories were classified further into direct burning (fuel wood and slash and burn agriculture) and release of unburned biomass through decomposition process (Houhton *et al.*, 1996).

Thus the amount of carbon and greenhouse gas released to the atmosphere depended on these processes. Estimation of the amount of carbon and greenhouse gas release requires yearly time series of spatial data and information on commercial wood and fuel wood harvest, as well as burning efficiency data of each land use/land cover type.

Table 3 Land use/land cover type and aboveground biomass changes between 1986 and 1992

LAND USE/LAND COVER	1986			1992		
	Area (sq. km)	% of total area	Total carbon (10^6 ton)	Area (sq. km)	% of total area	Total carbon (10^6 ton)
Primary forest	16521.20	33.91	416.89	12569.86	25.80	317.19
Secondary forest	0.00	0.00	0.00	1274.34	2.62	7.40
Logged forest	10022.39	20.57	155.53	12448.65	25.55	193.18
Fallow land	9401.68	19.30	14.10	6072.66	12.47	9.11
Grassland	535.99	1.10	0.32	523.19	1.07	0.31
Bare land	3.67	0.01	0.00	3.67	0.01	0.00
Cash crop plantation	912.78	1.87	2.56	3303.17	6.78	9.25
Paddy fields	1002.78	2.06	0.75	649.16	1.33	0.49
Upland fields	0.00	0.00	0.00	235.84	0.48	0.18
Cultivated land and Secondary vegetation	7036.29	14.44	24.97	7933.39	16.29	28.16
Cultivated land and Settlement	1339.84	2.75	0.50	1630.68	3.35	0.61
Urban area	0.00	0.00	0.00	132.17	0.27	0.00
Water surface/lake	42.41	0.09	0.00	42.27	0.09	0.00
No data	1896.60	3.89	-	1896.6	3.89	-
Total	48715.65	100.00	615.62	48715.65	100.00	565.88

Note: Aboveground biomass was estimated by Biotrop using allometric equation

Table 4 Greenhouse gas flux changes between 1986 and 1992

Land use/ Land cover class	Total flux of CO_2 (mg/day)		Total flux of N_2O (mg/day)		Total flux of CH_4 (mg/day)	
	1986	1992	1986	1992	1986	1992
Primary forest	$1.69x10^{14}$	$1.28x10^{14}$	$3.2x10^{9}$	$2.43x10^{9}$	$-1.45x10^{10}$	$-1.10x10^{10}$
Secondary forest	0.00	$5.75x10^{12}$	0.00	$7.03x10^{8}$	0.00	$-3.36x10^{9}$
Logged forest	$1.24x10^{14}$	$1.54x10^{14}$	$2.48 x10^{9}$	$3.08x10^{9}$	$1.04x10^{10}$	$-1.29x10^{10}$
Fallow land	$1.31x10^{14}$	$8.46x10^{13}$	$4.51 x10^{9}$	$2.91x10^{9}$	$-1.00x10^{10}$	$-6.47x10^{9}$
Grassland	$7.76x10^{12}$	$7.58x10^{12}$	$1.42 x10^{8}$	$1.38x10^{8}$	0.00	0.00
Bare land	$2.44x10^{10}$	$2.44x10^{10}$	$5.67x10^{5}$	$5.67x10^{5}$	$-6.25x10^{5}$	$-6.25x10^{5}$
Cash crop plantation *	$1.87x10^{13}$	$6.75x10^{13}$	$4.68x10^{8}$	$1.69x10^{9}$	0.00	0.00
Paddy fields	-	-	$9.63x10^{7}$	$6.23x10^{7}$	$7.22x10^{8}$	$4.67x10^{8}$
Upland fields	0.00	$2.41x10^{12}$	0.00	$4.03x10^{7}$	0.00	0.00
Cultivated land and Secondary vegetation	$8.00x10^{13}$	$9.02x10^{13}$	$3.43 x10^{9}$	$3.87x10^{9}$	$-3.33x10^{9}$	$-3.75x10^{9}$
Cultivated land and Settlement	$6.85x10^{12}$	$8.33x10^{12}$	$1.16 x10^{8}$	$1.41x10^{8}$	0.00	0.00
Total flux	$536.5x10^{12}$	$548.3 x10^{12}$	$14.4 x10^{9}$	$15.1x10^{9}$	$-37.5x10^{9}$	$-37.0x10^{9}$

Note: Calculations were made based on field measurements, conducted by IC-SEA in November 1997
*Assumed flux of CH_4 and CO_2 of cash crop plantations is equal to that of upland, while flux of N_2O is equivalent to three times the upland field flux due to intensive fertilizer application

3) Soil greenhouse gas emission changes

Greenhouse gas flux from soil varies depending on the site conditions and season. The comparison below was made based on flux measurement conducted in November 1997 at several sites in Jambi Province. The results of calculation of the total flux based on 1986 and 1992 land use/land cover data for major land use/land cover types are presented in Table 4. Comparison of the total greenhouse gas flux in the studies carried out over the period 1986-1992 could not be performed since information on greenhouse gas flux from the soil surface under cash crop plantations and secondary forest was not available. However, it is assumed that the conversion of natural forest may lead to the decrease of methane gas absorption and increase of nitrous oxide and carbon dioxide flux emissions.

Concluding remarks

There are two problems in the development of a spatial database and scale up of the emission estimation: a) variability of sources (materials) in terms of scale/accuracy, and data generation methodology used, b) limited field measurements or availability of unit/value of greenhouse gas emission/flux in terms of ecosystems and seasonal variability.

These two problems may affect the accuracy of the estimation results. Accuracy of the measurements is also another important problem.

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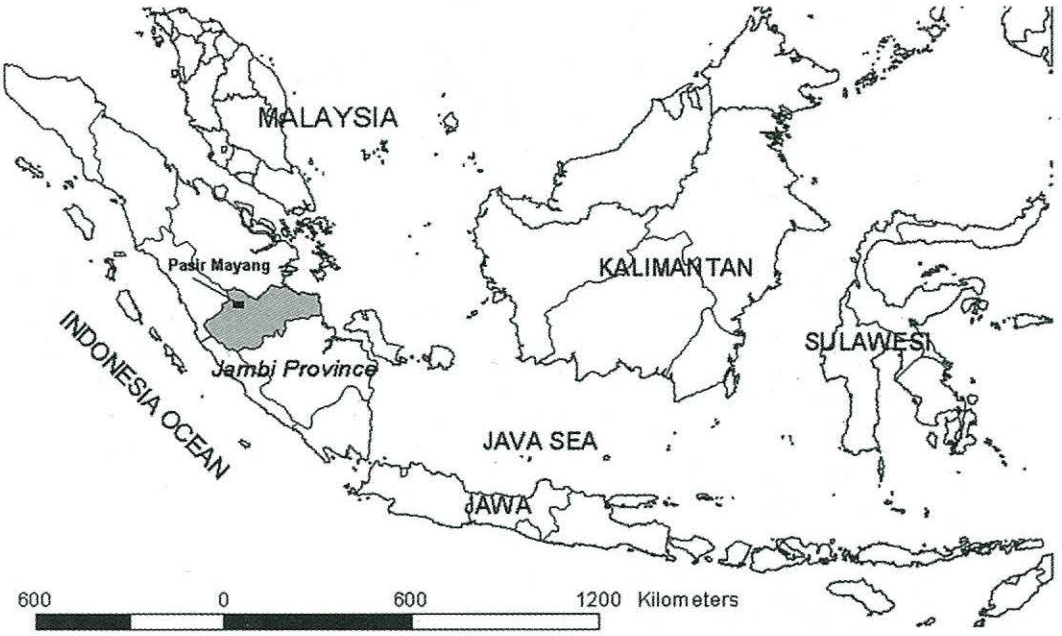
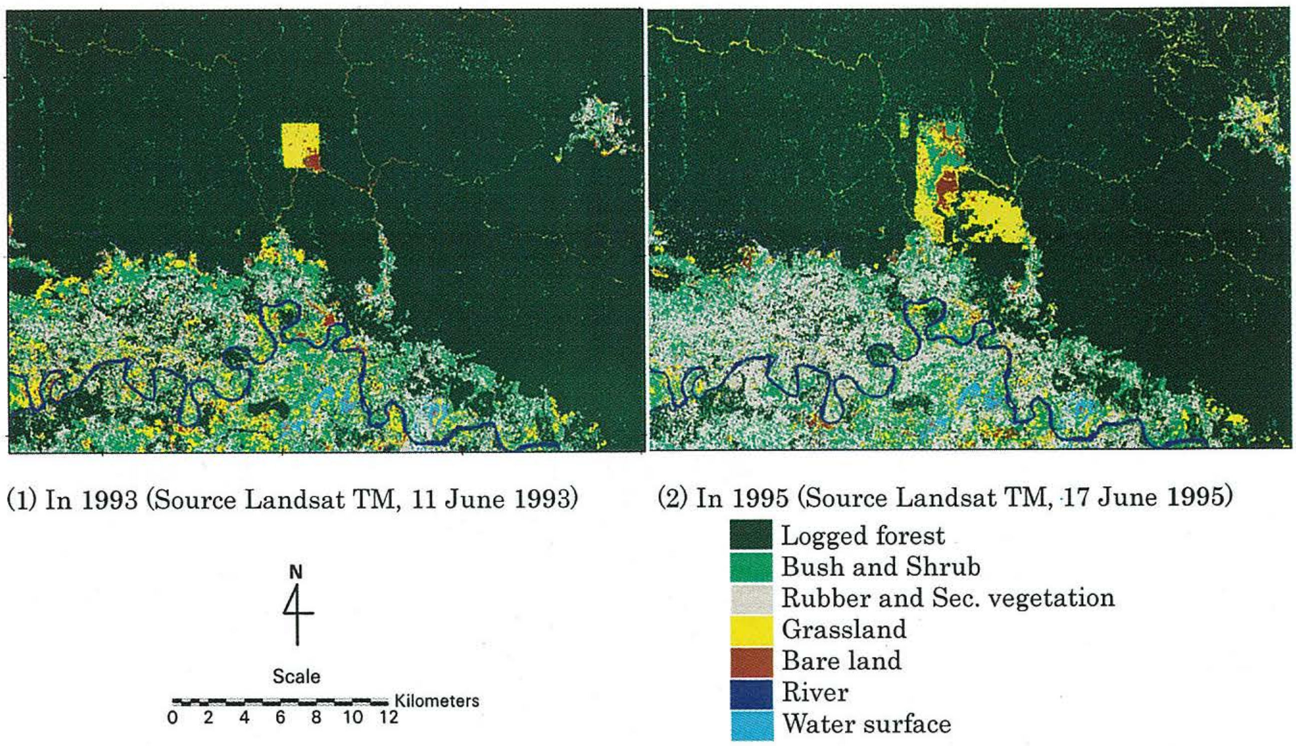


Fig. 1 Pasir Mayang area and Jambi Province



(1) In 1993 (Source Landsat TM, 11 June 1993)

(2) In 1995 (Source Landsat TM, 17 June 1995)

Fig. 2 Land use changes in Pasir Mayang area

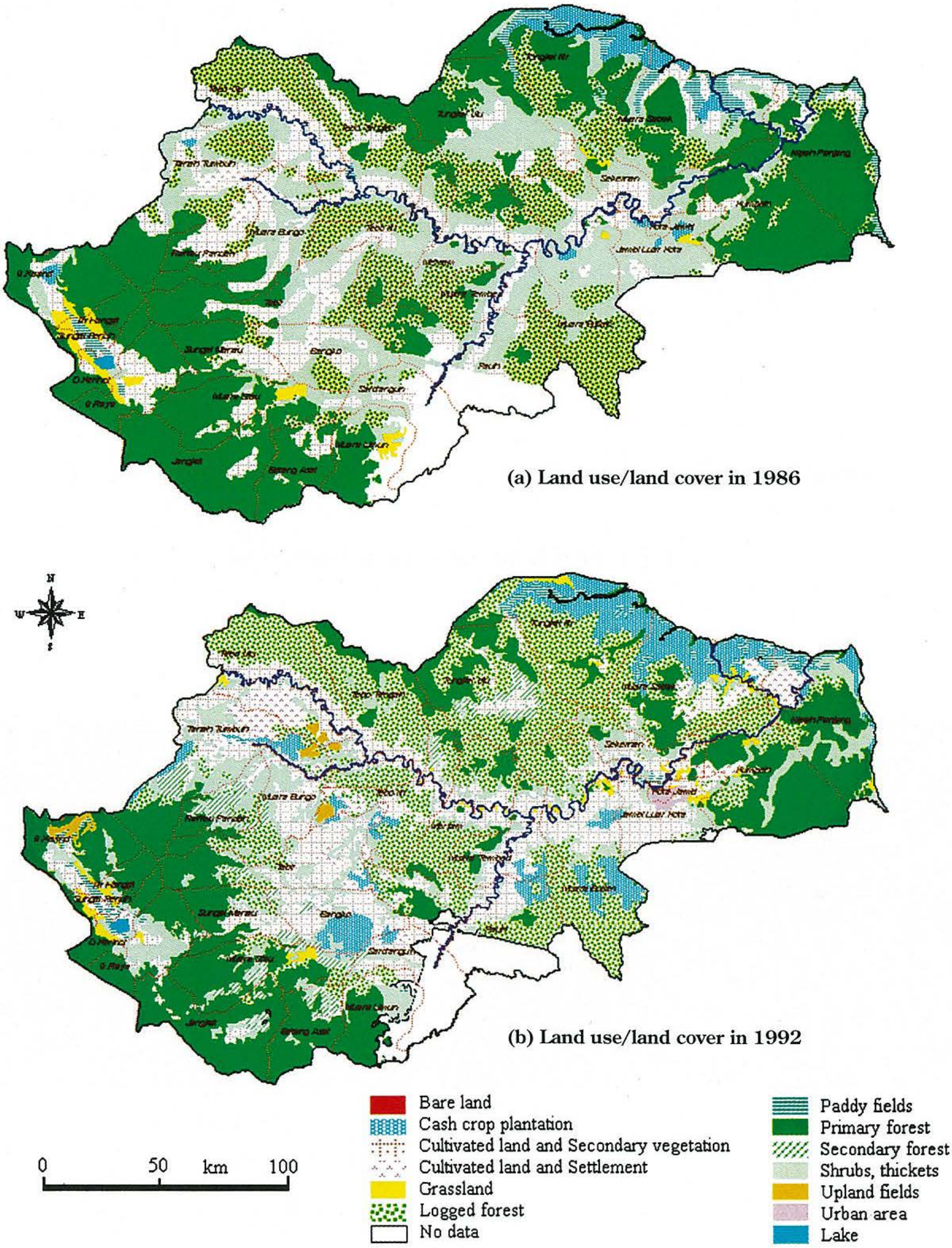


Fig. 3 Land use/ land cover changes in 1986 and 1992 in Jambi Province

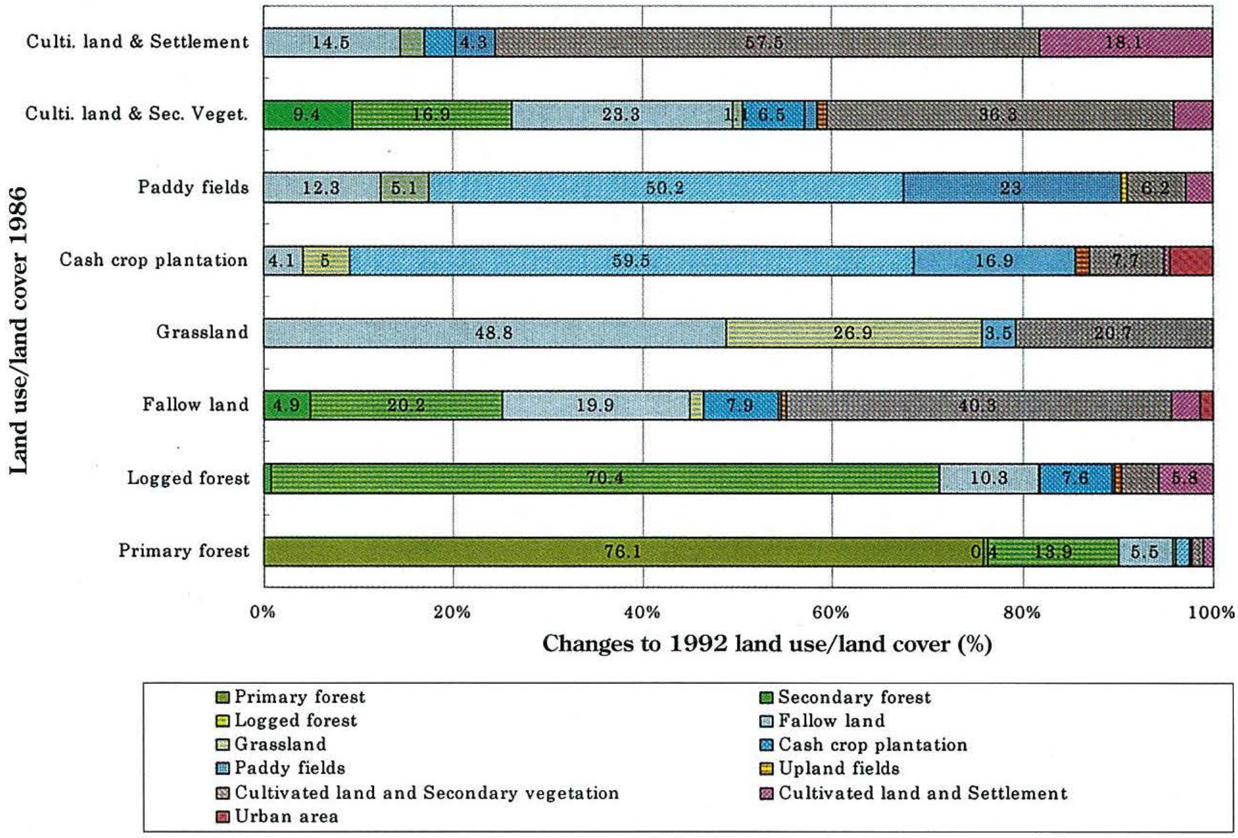


Fig. 4 Land use/land cover changes from 1986 to 1992