Evaluation of Recent Forest Cover Change in Savannakhet Province, Lao PDR, Using AVNIR-2 and MODIS Satellite Images

Bumpei TOJO[1*], Akihiko KOTERA[2], Koji NAKAI[2], Takanori NAGANO[2], Shigeo KOBAYASHI[3] and Kazuhiko MOJI[1]

[1]*Research Institute for Humanity and Nature*
457-4 Kamigamo Motoyama, Kita-ku, Kyoto 603-8047, Japan
[2]*Graduate School of Agricultural Science, Kobe University*
1-1 Rokkodai-cho, Nada-ku, Kobe 657-8501, Japan
[3]*Graduate School of Asian and African Area Studies, Kyoto University*
46 Shimoadachi-cho, Yoshida, Sakyo-ku, Kyoto 606-8501, Japan
**e-mail: bumpeitj08@chikyu.ac.jp*

Abstract

In this study we analyzed the rate of change of forest coverage in Savannakhet Province, in central south Lao PDR (People's Democrotic Republic), and the causes of this change. In considering reasons for the transition of forest coverage, we took into account human activities such as large-scale development, expansion of agricultural land and shifting cultivation as well as effects of changes in rainfall. To survey changes in land coverage, including forests, we used AVNIR-2 images with high spatial resolution and MODIS images with high time resolution. To supplement the insufficient network of rainfall gauges in the study area, data from the APHRODITE Project were used for analysis. As a result of this analysis, we estimated that the total forest coverage decreased by nearly 40,000 ha in Savannakhet Province, in the ten years between 2000 and 2009. Deforestation occurred both in the open forest in the plains (dry dipterocarp forest) and in isolated masses of dense forest (mixed deciduous forest) as the result of expansion of agricultural areas, mainly in the western part of the province. We could find no long-term trend in rainfall, but recently there has been a tendency of rainfall to decline where deforestation has occurred.

Key words: APHRODITE, deforestation, land cover and land use change, NDVI, object-based classification, satellite remote sensing

1. Introduction

In Southeast Asia, the forested area of the Lao PDR is second largest after that of Cambodia, accounting for 50% to 60% of the country's total area. This is a much larger number compared to that of neighboring countries such as Thailand, Vietnam and Myanmar where forests cover 20% to 40% of the land. However, the forests of the Lao PDR are said to be in decline. In the severest estimate, the forest coverage in the Lao PDR in 1997 is said to have fallen to as low as 39% (Chanthirath, 1998). Some of the reasons for this deforestation are said to be shifting cultivation, expansion of grazing and agricultural fields, and inappropriate commercial logging (Pheng, 1995; Chanthirath, 1998; Vajpeyi, 2001; MAF, 2005a). In the Lao PDR, a large part of the nation's foreign currency acquisition relies on the export of forest resources (54% in 1991) and the lives of many people also depend on the use of forests (Chanthirath, 1998). As such, forest preservation is a crucial issue not only for the Lao PDR, but also for the preservation of forests and biodiversity of all of continental Southeast Asia.

In the Lao PDR, an accurate understanding of forest cover change is essential in order to establish an accurate forest preservation scheme. However, in developing countries including the Lao PDR, the statistics used to understand changes in forest cover are often inaccurate (Fairhead, 1998). The use of remote sensing (satellite images) and Geographic Information System (GIS) technology is required to promote research into large-scale and quantitative analysis of forest coverage change and its causes. As the target area for this study, we selected Savannakhet Province in central south Lao PDR, known for its large area and the highest forest coverage in the Lao PDR, and estimated the rate of forest cover change and its causes in the period between 2000 and 2009.

To verify changes in forest coverage, we used the object-based supervised classification results of Advanced Visible and Near Infrared Radiometer type 2

(AVNIR-2) images and the Normalized Difference Vegetation Index (NDVI) time-series analysis results of the Terra Moderate Resolution Imaging Spectroradiometer (MODIS) images. AVNIR-2 images have a spatial resolution of 10 m/pixel, excellent for a detailed investigation of land coverage. However, as the satellite takes 46 days to return to the area, AVNIR-2 images are disadvantageous in tropical areas with long rainy seasons for capturing cloudless images over large areas every year to observe changes in forest coverage. The satellite was not in operation until 2006 so it cannot be used to verify the forest coverage before 2006. MODIS images, on the other hand, have a spatial resolution of 250 m/pixel, generating a variety of mixed pixels. In areas with successions of tiny land coverage, it is difficult to compare the classification results with the actual land coverage. However, as the MODIS images can be obtained every eight days from the targeted area, they have the advantage of minimizing the effects of cloudiness, while being able to track changes in land coverage with a high time resolution. In this study, we combined the classification results of AVNIR-2 images and unsupervised classification of MODIS images with low spatial resolution.

We also analyzed rainfall trends in the province to determine if they might have caused or triggered the changes in forest coverage. Since rain gauge stations were sparsely distributed and not all data were accessible, we used an established precipitation data product of the Asian Precipitation Highly Resolved Observational Data Integration towards the Evaluation of Water Resources (APHRODITE) project (Yatagai *et al.*, 2009).

2. Study Area

The study site was Savannakhet Province in central south Lao PDR (Fig. 1A). Savannakhet is one of the largest provinces in the Lao PDR and has 70% to 80% of its area covered by forests. The total area of forests within the province was the largest in Lao PDR as of 1981 (Pheng, 1995). These large forests are seen in the mountainous area and around the rivers as they approach the Mekong River, significantly contributing to the maintenance of ecological services in the peripheral area, including the climate regulation, water quality regulation and biodiversity. The average annual rainfall is approximately 1,500 mm, 80% of which occurs in the five-month rainy season between May and September.

According to the classification by the Ministry of Agriculture and Forestry (MAF), the forest coverage of the Lao PDR is primarily categorized into three types: Current Forests; Potential Forest Areas; and Other Wooded Areas. Current Forests are further categorized by the type of tree species as dry evergreen forests (DEF); mixed deciduous forests (MDF); and dry dipterocarp forests (DDF). Potential Forest Areas include bamboo and unstocked forest, comprising less than 20% tree crowns due to human intervention such as logging and slash-and-burn farming. Other Wooded Areas include a variety of forests such as savannah, heath and scrub forest.

The total area of all these forest types between 1992 and 2002 was 86.9% (1,855,853 ha) of Savannakhet Province (MAF, 2005b). The National Geographic Department created a digital map (NGDD map) for all kinds of land use and land coverage up to 1998 (Fig. 1B). The ratio of forests in Savannakhet Province calculated using this map is 84.1% (1,795,948 ha), almost equal to the figure shown by the MAF.

Looking at the NGDD map (Fig. 1B), the province's forest type distribution is divided by a border around 105.7°east longitude, into the western half (the Thailand side) dominated by dry dipterocarp forest and the eastern half (the Vietnam side) dominated by MDF, unstocked

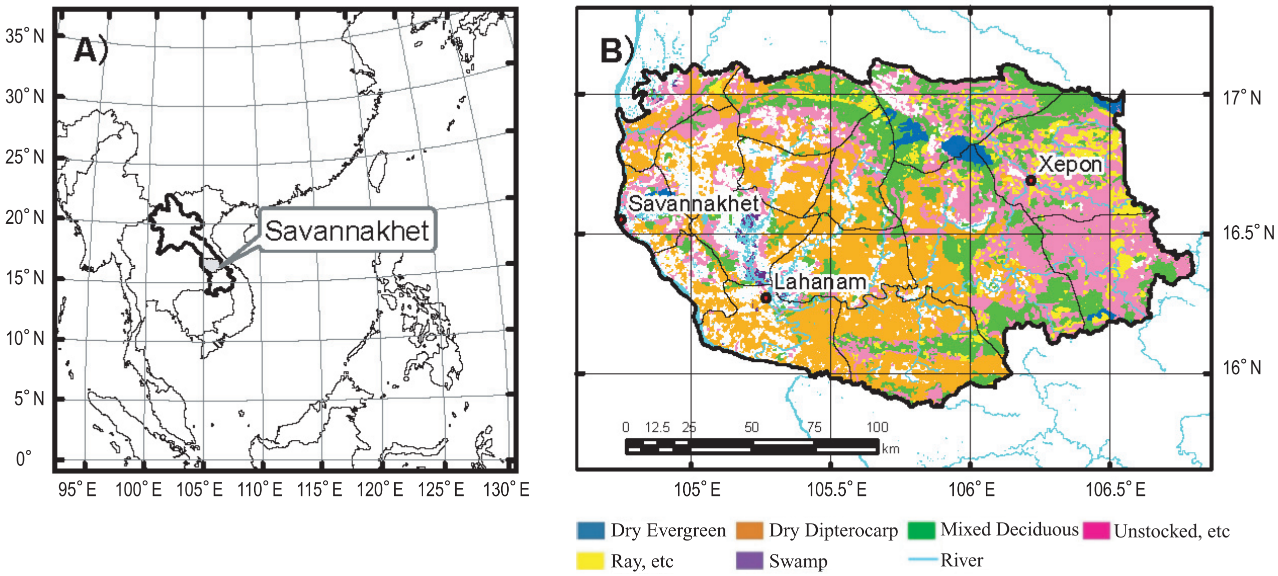

Fig. 1 Location and forest distribution of Savannakhet Province.
A) Location of Savannakhet Province, Lao PDR.
B) Forest distribution by digital map of the Lao PDR. (1987-1998) and rain gauge station locations in Savannakhet (1967-2005), Lahanam (1994-2005), and Xepon (1988-2002).

forest and shifting cultivation (Ray). The distribution of forest types clearly reflects the geographic condition of the province. DDF consists of open forest stands which are established on the plains. MDF, on the other hand, is established on hill slopes, thus it occurs in the eastern part of the province. It is also seen as isolated patches across the small hills generated by the rivers in the plains of the western part of the province. A large part of the unstocked forest in the mountainous area is said to be under the influence of human intervention, such as slash-and-burn farming and large-scale logging (MAF, 2005b). DEF is scarcely seen, occurring in limited areas such as deep in the mountains of the eastern part of the province.

3. Materials and Methods

3.1 Detection of forest distribution using high spatial resolution satellite imagery

Using AVNIR-2 satellite images and the NGDD map, we quantified the actual distribution of all types of forests. A total of ten AVNIR-2 images were used, mosaicked for each time batch (three from 9/13/2006, two from 3/1/2008, two from 2/15/2009, two from 2/20/2009 and one from 03/07/2010) without histogram matching. Each of five mosaicked images was subdivided into segmentations called "objects" using eCognition8™ Software (Trimble Germany GmbH, 2011).

An "object" is defined as a group of pixels of spectral homogeneity. Compared to a single pixel, the object has additional values like texture and morphology. The object-oriented approach enables exploration of the full value of satellite images and extraction of GIS-ready information from images (Benz *et al*., 2004). The segmentation procedure starts with one pixel and repeatedly merges other pixels into a larger unit as long as an upper threshold of homogeneity is not exceeded locally. All these processes run automatically on the eCognition. The user can control the segmentation results by setting the Scale Parameter (SP). The smaller the SP, the smaller the object becomes, making it possible to extract more micro- evenness (Fig. 2 A).

We tested all numbers of SP from 100 to 10, and selected SP=10 for this study. If the SP is too small (*e.g*., 8) it causes sudden interruption of the segmentation procedure by program error. After the segmentation procedure, some objects are selected from the whole image as training samples by visual interpretation. In this study we adopted three classification categories (water, bare land, and wooded areas) and applied a supervised method of maximum likelihood analysis using the object mean value of each band (band 1: 0.42-0.50μm, band 2: 0.52-0.60μm, band 3: 0.61-0.69μm, band 4: 0.76-0.89μm) for classification.

The classification result "wooded areas" was exported as vector data (Fig. 2B), which were intersected with NGDD map vector data (Fig. 2C) on ArcGIS™ software to generate the wooded area map with forest type (DEF, MDF, DDF, unstocked, ray, swamp, others)

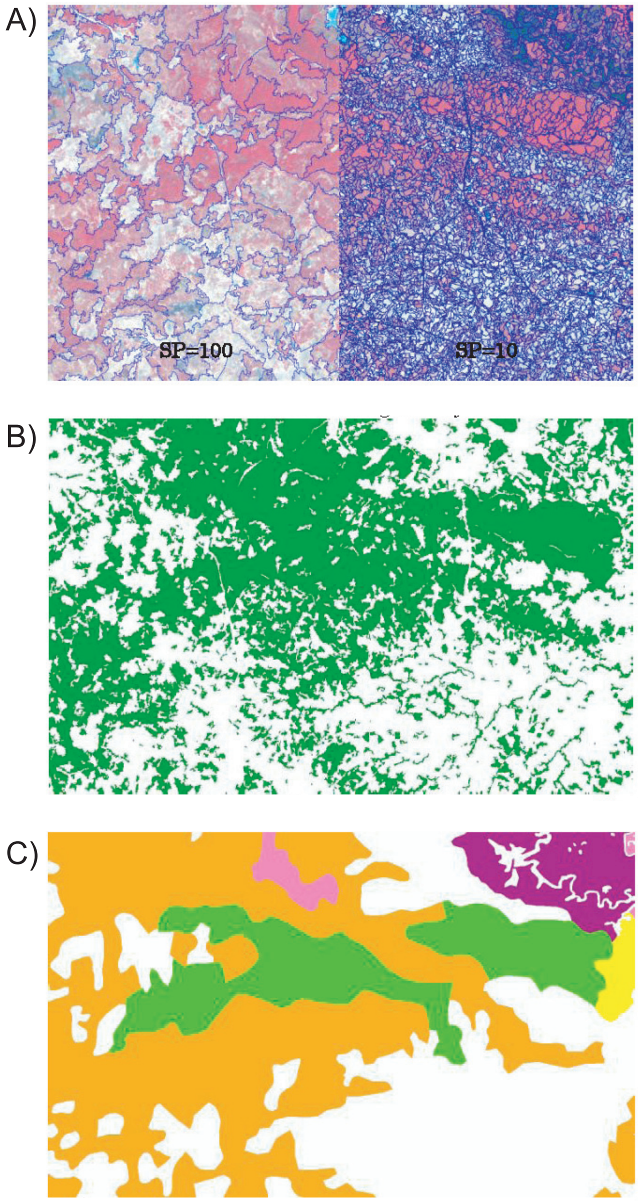

Fig. 2 Example of object-based (object-oriented approach) classification of an AVNIR-2 image.
A) Influence of SP setting on object sizes.
B) "Wooded area" converted to vector data.
C) Vector data of the National Geographic Department digital map.

information (Fig. 3). In this manner, spatial resolution of the final product (shown in Fig. 3) became much higher than that of Fig. 1.

3.2 Detection of land cover changes using time-series satellite imageries

The Terra MODIS surface reflectance data (MOD09Q1: 8-day composite, spatial resolution: 250 m) covering the area of Savannakhet Province (tile h28v07) from April 2000 to March 2010 were used for the time-series vegetation analysis in this study. The data were obtained via the Warehouse Inventory Search Tool (WIST) website <https://wist.echo.nasa.gov/~wist/api/imswelcome>. As for vegetation signatures, NDVI was

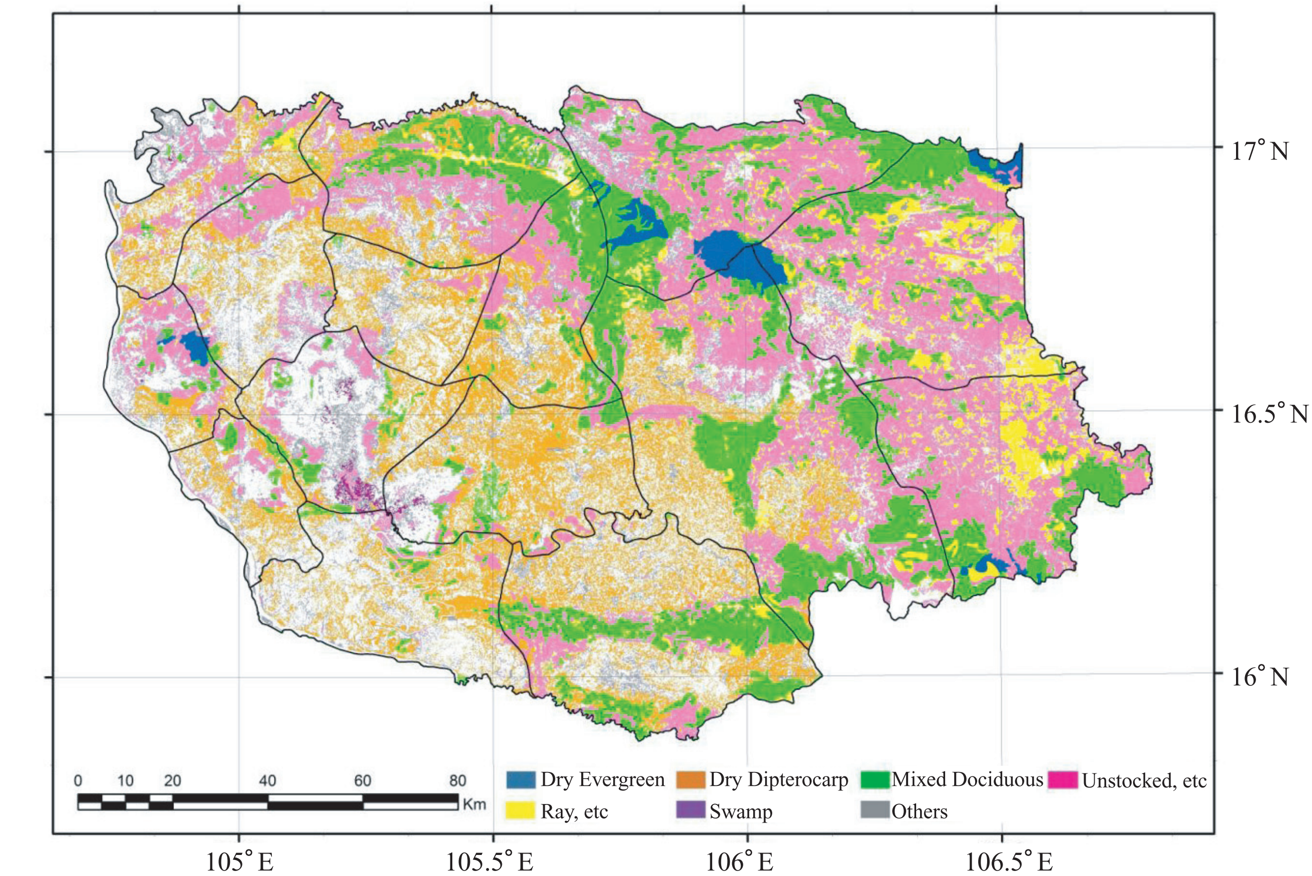

Fig. 3 Actual distribution of wooded areas by forest type, Savannakhet Province, generated from intersecting mosaicked AVNIR-2 satellite imageries and the National Geographic Department's digital map.

This classification was based on an object-base classification of ALOS/AVNIR-2 satellite imageries, using ten satellite images obtained from 2006/9/13 (3 images), 2008/3/1 (2), 2009/2/15 (2), 2009/2/20 (2) and 2010/03/07 (1). Information on the seven forest types (Dry Evergreen, Mixed Deciduous, Dry Diptercarp, Unstocked, Ray, Swamp, Others) was added to the generated Wooded Area layer (Fig. 2B) by intersecting it with the National Geographic Department's digital map (Fig. 1B).

derived from band 1 (620-670 nm) and band 2 (841-876 nm) reflectance data.

In order to reduce the cloud noise effect and to extract characteristics of the vegetation dynamics, the Harmonic Analysis of Time Series (HANTS) algorithm (Roerink *et al.*, 2000) was performed on time-series NDVI data. The advantage of the HANTS algorithm is that the output can be obtained as a smoothed time-series data. The algorithm captures only the most significant frequencies expected to be present in the time profiles determined by Fast Fourier Transform (FFT) analysis, and applies a least squares curve fitting procedure based on harmonic components. In this study, number of frequencies (NOF), suppression flag (SF) and fit error tolerance (FET) were set as 2, low, 26 and 18, respectively, as control parameters of the algorithm. Since the majority of the vegetation categories in Savannakhet Province have seasonal growth cycles between rainy and dry seasons, in this study, the annual vegetation dynamics was analyzed over a period of twelve months between April and the subsequent March.

To detect land cover changes, an unsupervised classification was performed on the cloud-free time-series images. Unsupervised classification identifies clusters by their time-series pattern similarities and allows the feature space to segment into similar pattern clusters (Cheema & Bastiaanssen, 2010). The K-means clustering method was used in this study. To avoid variation of clustering criteria among different years, the algorithm was performed on a single mosaic image which was synthesized by merging images of all years. The image was classified into twelve classes as an initial trial, and then refined into seven classes and labeled corresponding to the forest distribution used in Fig. 3, by applying expert knowledge of the phenological patterns of trees and crops in this area. The classification results in 2000 and 2009 were then compared and changes between the two images were detected.

3.3 Precipitation data

To analyze the effect of rainfall on changes in land cover, we used a daily gridded precipitation dataset created by collecting dense network rain-gauge observation data across Asia through the activities of APHRODITE project (Yatagai *et al.*, 2009). The dataset we used contains reanalyzed data of daily rainfall in the

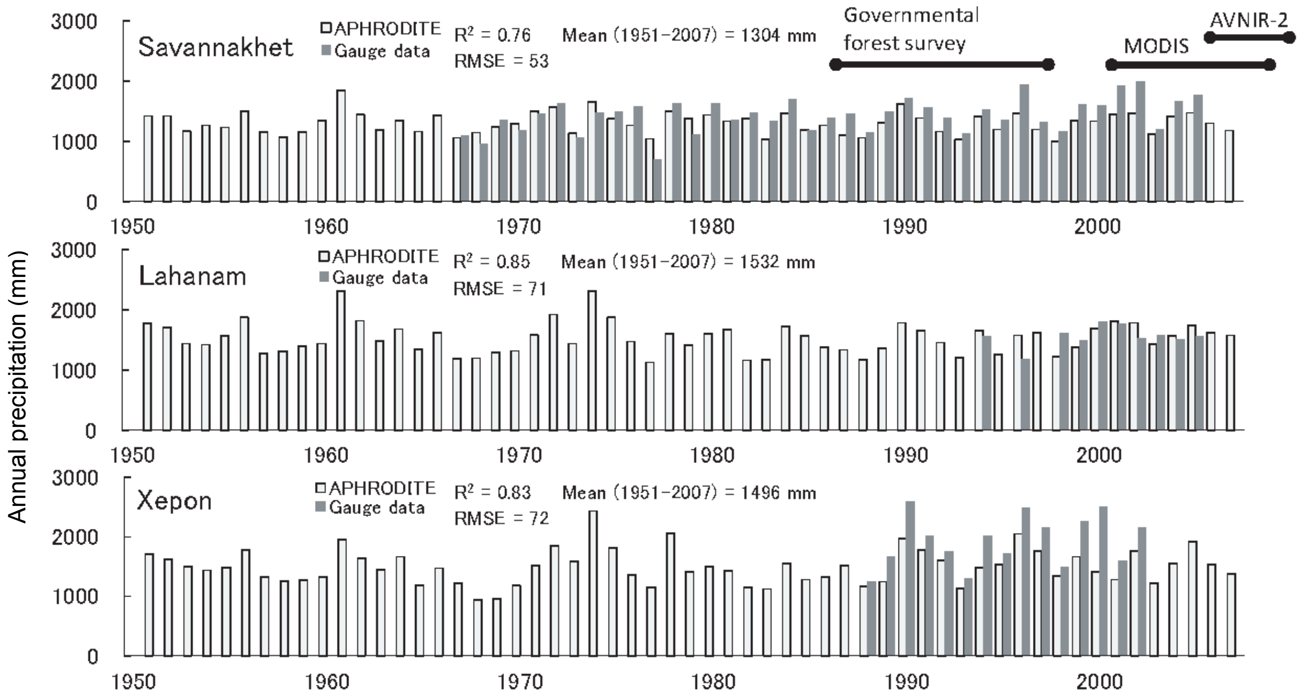

Fig. 4 Comparison of rain gauge data with the data of the nearest grid from APHRODITE for three locations, Savannakhet, Lahanam and Xepon in Savannakhet Province, Lao PDR..
RMSE: root mean square error between APHRODITE and the rain gauge data.
The crossbars indicate the period of the forest cover survey from which forest cover statistics were derived in this study.
Source: Rain gauge stations at Savannakhet (16.55°N, 104.75°E, 1967-2005), Lahanam (16.27°N, 105.27°E, 1994-2005) and Xepon (16.69°N, 106.22°E, 1988-2002), and APHRODITE grid data (1951-2007) at Savannakhet (17.00°N, 104.75°E), Lahanam (16.25°N, 105.25°E) and Xepon (16.75°N, 106.25°E).

period between 1951 and 2007 in the monsoon Asia area by daily 0.25 degree grids (APHRO_MA_025deg_V1003R1_1951-2007), from which we extracted the data of Savannakhet (16.00-17.00°N, 104.75-107.00°E). To verify the accuracy of the dataset, we generated monthly rainfall values from the dataset and compared them to rain gauge data observed at three stations in Savannakhet, Lahanam, and Xepon (shown in Fig. 1) published by the Department of Agriculture and Forestry, Meteorology and Hydrology Section, Savannakhet Province. APHRODITE's grid precipitation dataset tended to be larger than observed values (Fig. 4) and the root-mean- square error (RMSE) between the dataset and observed values were 53 mm, 71 mm and 72 mm for Savannakhet, Lahanam, and Xepon, respectively. Because APHRODITE's grid precipitation was generated with correction of orographic effects, the grid data containing mountains on the leeward side could be higher than the rain gauge data, particularly for gauges placed in the plains area (Xie *et al.,* 2007).

Using APHRODITE's annual precipitation data, we examined long-term (1951-2007) and medium-term rainfall changes between periods when government statistics were formulated (1989-1998) and when AVNIR-2 and MODIS images were captured (1998-2007). For the trend analysis we used the linear regression method, investigating the statistical significance of the differences by the t-test.

Monthly precipitation data were compared with the seasonal vegetation dynamics in the case study area where forest cover changes were detected by remote-sensing analysis. Since the precipitation data after year 2007 have not yet been published, comparison with vegetation data was possible only between the years of 2000 and 2007.

4. Results and Discussion

4.1 Forest cover distribution

Table 1 shows the area of each type of forest in Savannakhet Province, calculated by GIS. We used NGDD map data for 1987-1998 in the upper section. For 2006-2010 in the lower section, we calculated the size of the wooded area extracted from AVNIR-2 images intersected with the NGDD map (Fig. 3).

The total forest area in 2006-2010 was 1,494,361 ha, equivalent to 70.0% of the total area of Savannakhet Province. The difference between this estimate and the forest area by the government's statistics (1987-1998) was 312,009 ha (14.6% of the total area of the province). For most of the forest types the differences remained less than a few percent of the province's area but the difference of DDF alone was very large: 275,770 ha or 13% of the total area .

The difference in calculated area does not directly reflect the extent of deforestation between 1987 and 2010. In particular, the large decrease in DDF may be attributed to a difference in the spatial resolution of classification. DDF is scattered in the plains and these forests create complex mosaics with agricultural land and other land coverage. It is probable that the NGDD map and forest statistics by the Ministry of Agriculture and Forestry do not sufficiently reflect the area of land coverage by small agricultural lands and other land coverage that exist within the area defined as DDF.

In Table 1, 108,328 ha is classified as "others." This "others" refers to the area classified as wooded areas according to the satellite image analysis, yet classified as non-forests by the NGDD map. Because of this unconformity, they were excluded from the calculation of the total forest area. "Others" also includes wooded areas within cities, villages and agricultural fields, so not all of them are necessarily forests. However its extent, 108,328 ha, is equivalent to more than three times the area of the DEF of the whole province, and almost equivalent to the areas of shifting cultivation and savannas. Therefore the amount of wooded area that should have been counted as forests (primarily in DDF) is not negligible. This analysis alone did not clarify the extent of deforestation between the two periods but rather revealed the poorness of spatial resolution of the forest statistics in the past.

Table 1 Summary of area by forest type, calculated from GIS base map data for the Mekong River Basin and classification results of ALOS/AVNIR-2 satellite images for Savannakhet Province, Lao PDR.

Year	a. Dry Evergreen (DEF)	b. Mixed Deciduous (MDF)	c. Dry Dipterocarp (DDF)	d. Bamboo, Unstocked Forest	e. Ray, Savannah, Scrub, Grassland	f. Swamp	g. Others	Total
A.	31,223 ha	394,962 ha	639,761ha	612,885 ha	117,114 ha	10,425 ha	--- ha	1,806,370 ha
(1987-1998)	1.5%	18.5%	30.0%	28.7%	5.5%	0.5%	---%	84.5%
B.	31,023 ha	369,244 ha	363,991 ha	526,546 ha	90,265 ha	4,964 ha	108,328 ha	1,494,361 ha
(2006-2010)	1.5%	17.3%	17.0%	24.7%	4.2%	0.2%	5.1%	70.0%
B-A	- 210 ha	- 25, 718 ha	-275,770 ha	- 86,339 ha	- 26,849 ha	- 5,461 ha	+108,328 ha	- 312,009 ha
	- 0.0%	- 1.2%	- 13.0%	- 4.0%	- 1.3%	- 0.3%	+ 5.1%	- 14.6%

A. GIS base map data for the Mekong River Basin（Land use data from NOFIP (FIPC) 1987-1998）(Fig 1B).
B. Classification results of AVNIR-2 satellite images (2006-2010) (Fig 3).

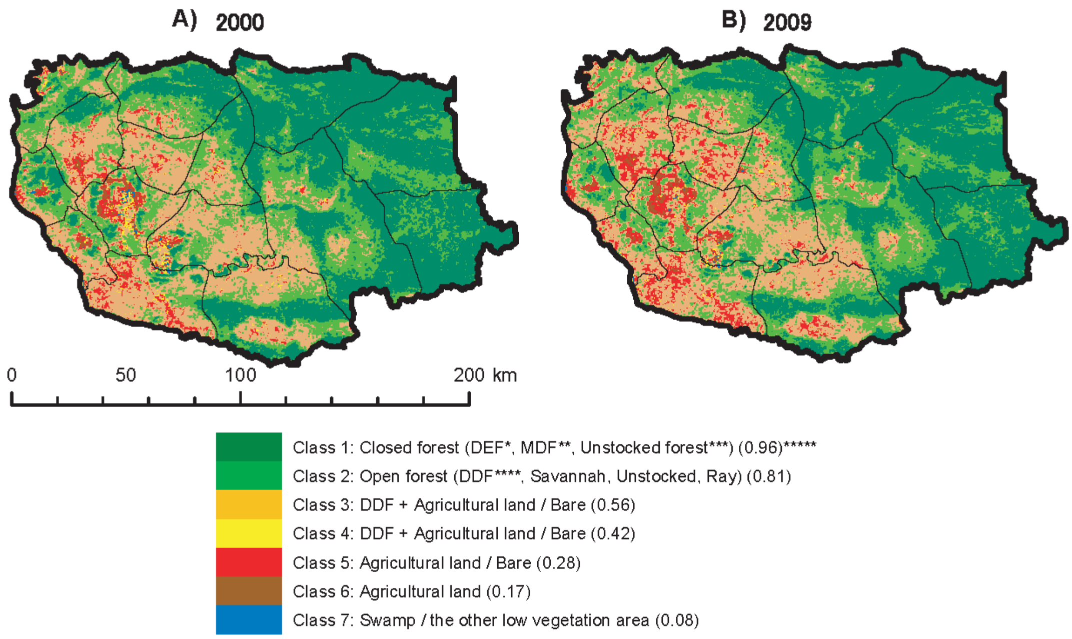

Fig. 5 Seven Land cover classes of Savannakhet Province, Lao PDR, in (A) 2000 and (B) 2009 generated from unsupervised classification of MODIS time-series data. This classification was based on annual phenology patterns from Apr. 2000 to Mar. 2001 (2000) and from Apr. 2009 to Mar. 2010 (2009).

* Dry evergreen forest.
** Mixed deciduous forest.
*** Unstocked forest is not closed forest because its tree cover is less than 20% in the definition of statistics, but actually, there are many areas of Unstocked forest in which vegetation has recovered to the level of Class 1.
**** Dry Dipterocarp Forest.
*****Values in parentheses are the average ratio of the wooded area in the whole province.

4.2 Detection of deforestation by time-series imagery

Figs. 5A and B show the distribution of seven classes of land cover derived from unsupervised classification of MODIS data. Fig. 6A shows the average phenological patterns of the seven classes. Each class is a mixture of multiple land cover types since the spatial resolution of each pixel is coarse (250 m). To clarify the composition of each class and to quantify the degree of deforestation, the images in Fig. 3 and Fig. 5 were intersected on the GIS and the ratio of wooded areas in each class was obtained (Fig. 6 B).

In Figs. 6A and B, classes 1 and 2 exhibit a relatively high NDVI throughout the year and the ratio of wooded areas is high in each class (0.96 and 0.81). Class 1 consists of closed DEF and MDF forests, with relatively low human intervention, while class 2 has a higher proportion of MDF with high human intervention (unstocked forest) and ray, or poor vegetation like open forest (mainly DDF situated in the plains). Contrarily, classes 5 and 6 have relatively low and varying NDVI and their ratios of wooded areas are 0.28 and 0.17, respectively. They can be considered as mainly agricultural (paddy) areas. Classes 3 and 4 can be considered areas where patches of wooded areas and agricultural areas are mixed. The ratio of wooded areas in classes 3 and 4 are 0.56 and 0.42, respectively. The wooded areas in these classes are mainly DDF. Classes 3 and 4 seem to represent the transitional states where large DDFs are being replaced by newly cultivated areas.

Table 2 is a matrix table summarizing the transition of each class from 2000 to 2009. From this table the total loss of forests throughout Savannakhet Province was estimated to be 41,578 ha. It is a very small number compared to the estimated forest loss in Table 1 (-312,009 ha). Large deforestations of -32,686 ha occurred in DEF and MDF (class 1) showing similarity to the value in Table 1 (-25,928 ha). The degree of deforestation in DDF (classes 3 to 5 and partly class 2), in the plains of the province, was calculated to be -10,875 ha. The calculated value for DDF in Table 1 (-275,770 ha) was much larger than this value and it is likely to be an overestimation arising from the poorness of spatial resolution of past statistics.

4.3 Effects of rainfall on land cover changes

In Savannakhet Province, no long-term trend was found in annual rainfall in the past 57 years between 1951 and 2007 ($P > 0.05$). Annual rainfall fluctuated from year to year, with coefficients of variation (CV) in around Savannakhet (16.75° N, 104.75°E), Lahanam (16.50° N, 105.25°E) and Xepon (16.75° N, 106.00°E) being 13.5, 16.7 and 19.5%, respectively.

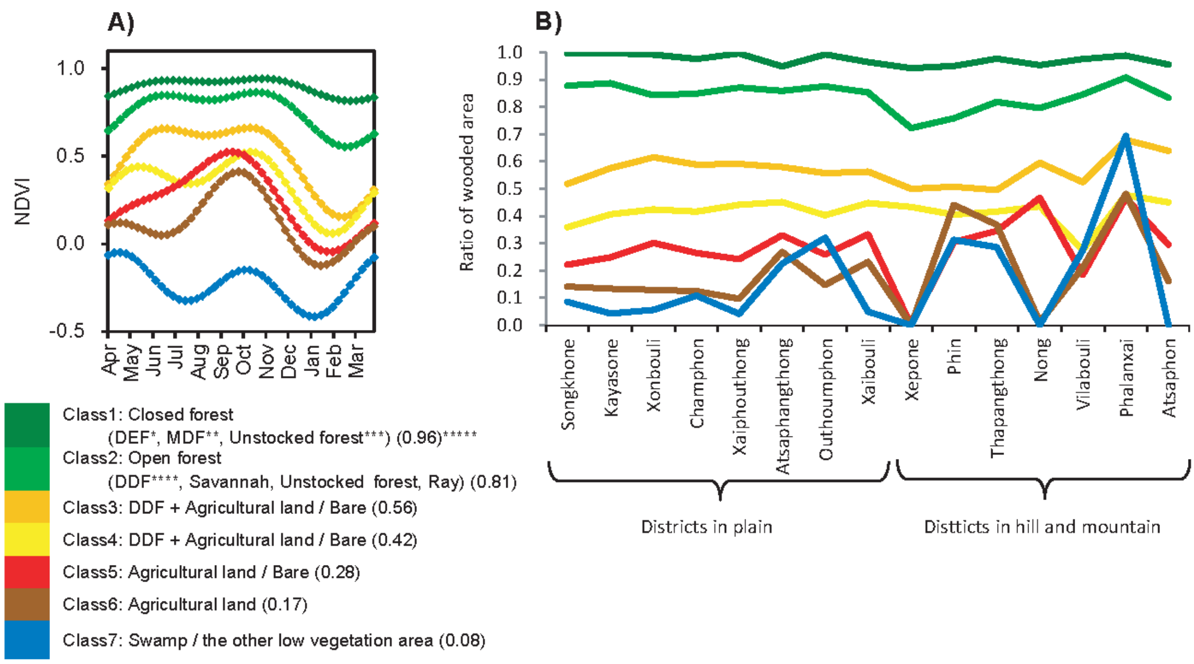

Fig. 6 Characteristics of vegetation classified to seven classes in Savannakhet Province.
A) Average pattern of seasonal NDVI change in seven classes.
B) Ratio of wooded areas in seven classes in 15 districts of Savannvakhet Province .

The ratio of wooded areas is derived from the wooded areas shown in Fig. 3 corresponding with each classified area shown in Fig. 5.

* Dry evergreen forest.
** Mixed deciduous forest.
*** Unstocked forest is not closed forest because its tree cover is less than 20% in the definition of statistics, but actually, there are many areas of Unstocked forest in which vegetation has recovered to the level of Class 1.
**** Dry dipterocarp forest.
*****Values in parentheses are the average ratio of the wooded area in the whole province.

Table 2 Transition of land cover classes between 2000 and 2009 in Savannakhet Province, Lao PDR, as a result of analysis of MODIS time-series NDVI data.

		2000								
		Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class area 2009 (ha)**	***Wooded area 2009 (ha)**
2009	**Class 1**	496,807	91,836	820	0	0	0	0	589,462 **(27.6%)	565,884 (26.5%)
	Class 2	119,681	466,334	40,078	407	6	0	6	626,511 (29.3%)	507,474 (23.7%)
	Class 3	4,870	79,480	420,416	45,494	6,125	1,032	647	558,064 (26.1%)	312,516 (14.6%)
	Class 4	876	3,397	80,629	44,345	9,538	3,146	1,724	143,655 (6.7%)	60,335 (2.8%)
	Class 5	569	1,534	43,765	39,230	37,160	15,066	1,422	138,746 (6.5%)	38,849 (1.8%)
	Class 6	379	502	6,755	7,759	14,860	29,435	4,680	64,370 (3.0%)	10,943 (0.5%)
	Class 7	329	257	552	441	279	1,729	14,865	18,524 (0.9%)	1,476 (0.1%)
	Class area in 2000	623,510 (29.1%)	643,339 (30.1%)	593,015 (27.7%)	137,675 (6.4%)	67,967 (3.2%)	50,408 (2.4%)	23,344 (1.4%)	2,139,259 (100.0%)	1,497,476 (70.0%)
	Wooded area in 2000 (ha)	598,570 (28.0%)	521,105 (24.4%)	332,089 (15.5%)	57,824 (2.7%)	19,031 (0.9%)	8,569 (0.4%)	1,868 (0.1%)	1,539,055 (71.9%)	
	Wooded area change in 2000-2009 (ha)	-32,686 (-1.5%)	-13,631 (-0.6%)	-19,573 (-0.9%)	+2,511 (+0.1%)	+19,818 (+0.9%)	+2,373 (+0.1%)	-391 (-0.0%)	-41,578 (-1.9%)	

Values indicate the area (ha) in each class in 2000 classified into the image in 2009. For example, 119,681 ha of class 1 area in 2000 changed to class 2 in 2009. Values with under bars indicate areas with no class change between 2000 and 2009.

* Wooded areas in each class are derived from the class area with the ratio of the wooded area shown in Fig. 4 (Class 1: 0.96, Class 2: 0.81, Class 3: 0.56, Class 4:0.42, Class 5: 0.28, Class 6, 0.08, Class 7: 0.08).

** Values in parentheses are the percentage ratio of the area to the province area.

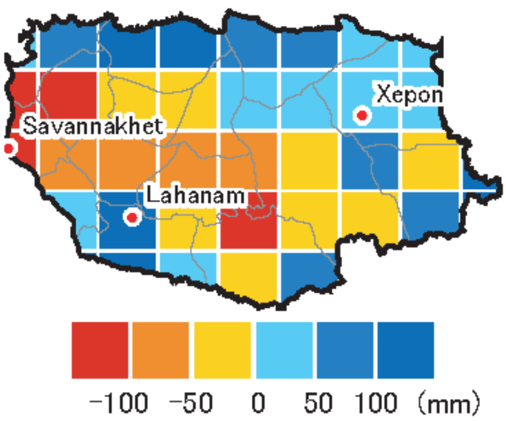

Fig. 7 Comparison of the mean annual rainfall of 1998-2007 to that of 1989-1998 in Savannakhet Province, Lao PDR, using the APHRODITE dataset.

The areal average rainfall in the province between the 1990s when the government statistics were formulated, and the 2000s when AVNIR-2 and MODIS images were captured, also showed no significant change ($P > 0.05$). The spatial distribution of rainfall in this period, however, shows a decline in the central and western areas (Fig. 7). This spatial distribution seems to coincide with the distribution of DDF, which was converted to cultivated land as explained in the previous section. Recently, the role of landscape change in altering convective rainfall has been well studied (*e.g.*, Kanae *et al.,* 2001; Pielke *et al.,* 2007). Kanae (2001) reported that significant decreases in rainfall occurred as a result of deforestation on the Indochina Peninsula, particularly in Thailand, which is situated next to Laos. In the case of Savannakhet Province, a similar phenomena may be going on and the establishment of a denser rainfall observation network would be necessary to verify it.

4.4 Forest cover changes due to human activity

Human intervention in natural vegetation, such as reclamation of agricultural land and commercial logging, have been reported as the primary reason for deforestation (Pheng, 1995; Chanthirath, 1998; Vajpeyi, 2001; MAF, 2005a). In this section, examples of such cases are shown by analysis of MODIS time-series vegetation data over the ten years between 2000 and 2009.

The change from Fig. 8A to Fig. 8B illustrates a typical case where a closed forest was cut down and became agricultural land (from class 1 to class 5). The annual average of NDVI remained high until 2005 but rapidly declined after 2006 (Fig. 8C). The annual rainfall of 2006 was less than that of 2005, but given the relationship between NDVI and rainfall up to 2006, it is difficult to conclude that the rainfall of 2006 caused the change in vegetation growth (Fig. 8C). From an analysis of seasonal changes in NDVI in Fig. 8D, logging of the forest seems to have started in December 2006. In 2007, NDVI remained low, similar to that of bare ground and it seems there was no active land use. The patterns of NDVI in 2008 and 2009 show signs of cultivation in this area.

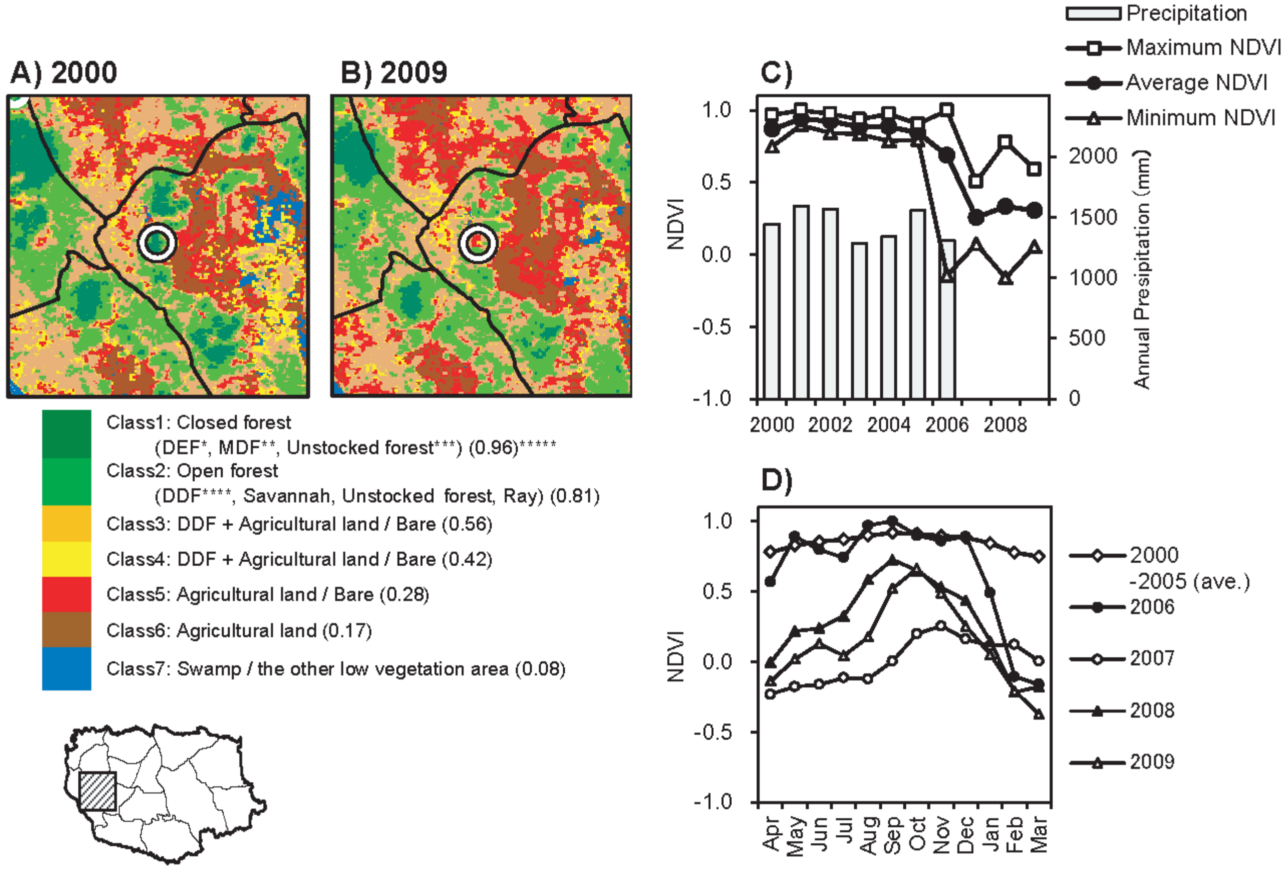

Fig. 8 Examples of cases of conversion of forest to agricultural land.
A) Land cover status around the tracking point indicated by center circle (105.064°E, 16.521°N) in 2000.
B) Land cover status around the tracking point indicated by center circle (106.374°E, 16.617°N) in 2009.
C) Annual change in NDVI and precipitation. Annual rain data were acquired from AHRODITE (105.0°E, 16.5°N).
D) Seasonal change in NDVI.
* Dry evergreen forest.
** Mixed deciduous forest.
*** Unstocked forest is not closed forest because its tree cover is less than 20% in the definition of statistics, but actually, there are many areas of unstocked forest in which vegetation has recovered to the level of Class 1.
**** Dry Dipterocarp Forest.
*****Values in parentheses are the average ratio of the wooded areas in the whole province.

The change from Fig. 9A to Fig. 9B is a case of slash-and-burn farming, which was confirmed by our field survey, too. In this site the slash-and-burn farming was conducted in 2005 and thus the NDVI in 2005 shows a distinctive pattern (Fig. 9 D). In 2006 and onward the patterns are similar to those before slashing.

Judging from Figs. 9C and D, the vegetation of slash-and-burn farming fields recovers on average to class 2 forest within two to four years of lying fallow, and it seems that a decade is enough to regenerate a once cultivated area into secondary forest again. In Table 2, there are 91,836 ha of class 2 area which have transformed to class 1. This number implies that at most about 15% of class 1 areas (estimated at 589,462 ha in 2009) in this province are under a cycle of slash-and-burn farming with a ten-year fallow period.

5. Conclusion

The analysis using MODIS time-series data showed that in Savannakhet Province, in the ten years between 2000 and 2009, forest coverage including DEF, MDF, DDF and unstocked forest declined nearly as much as 40,000 ha. From the comparison of spatial distribution between the years 2000 and 2009 (Fig. 5), it became apparent that most of this deforestation occurred as the result of expansion of agricultural areas in the western part of the province in both DDF and isolated masses of MDF. By combining AVNIR-2 and MODIS satellite image classification results we estimated that MDF and DDF coverage decreased by 30,000 ha and 10,000 ha, respectively. There was no long-term trend found in rainfall in the province though in recent years a slight decline in rainfall in the western part of the province was

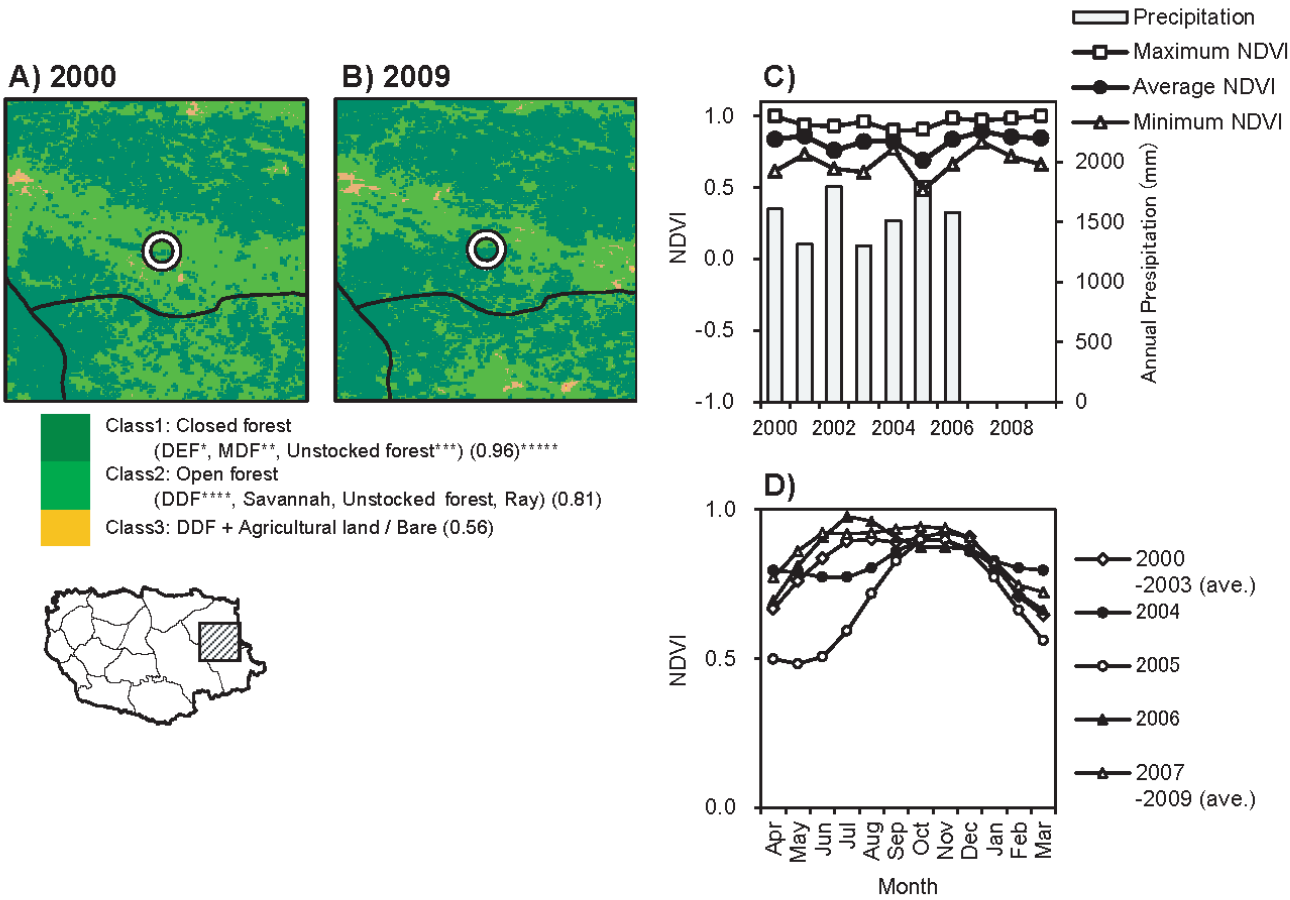

Fig. 9 Traces of slash-and-burn cultivation in a closed forest.
A) Land cover status around the tracking point indicated by center circle (106.374° E, 16.617° N) in 2000.
B) Land cover status around the tracking point indicated by center circle (106.374° E, 16.617° N) in 2009.
C) Annual change in NDVI and precipitation. Annual rain data were acquired from AHRODITE (106.25° E, 16.5° N).
D) Seasonal change in NDVI.
* Dry evergreen forest.
** Mixed deciduous forest.
*** Unstocked forest is not closed forest because its tree cover is less than 20% in the definition of statistics, but actually, there are many areas of Unstocked forest in which vegetation has recovered to the level of Class 1.
**** Dry dipterocarp Forest.
*****Values in parentheses are the average ratio of the wooded areas in the whole province.

observed. The amount of the decline was not likely to influence changes in forest coverage and land use over such a short time period.

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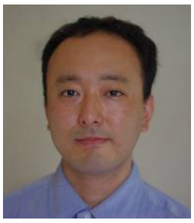


Bumpei TOJO

Bumpei TOJO is a project researcher at the Research Institute for Humanity and Nature (RIHN). In this project, he is engaged in interdisciplinary study concerning environmental change and infectious diseases in tropical Asia, mainly in the Lao PDR and Bangladesh. He received his Doctorate in Area Studies from the Graduate School of Area Studies, Kyoto University. His doctoral thesis was entitled "Conflict between Forest Conservation Policies and the Rights of Local Residents in Madhupur National Park, Bangladesh." He has been focusing on deforestation and forest use of local residents in Southeast Asia using R/S, GPS, GIS monitoring and field interviews.

Akihiko KOTERA

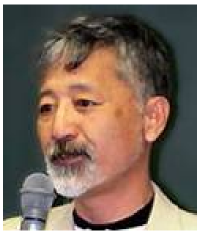
Akihiko KOTERA is a post-doctoral fellow of the CREST project at the Graduate School of Agricultural Science, Kobe University (http://www.edu.kobe-u.ac.jp/ans-rpww/index-j.htm). He has a Doctorate in Agriculture from the Department of Environmental Science and Technology, Graduate School of Agriculture, Kyoto University. He is interested in studies of sustainable water use in agricultural production at both local and global scales. He is also currently engaged in developing a World Atlas of Irrigation Agriculture.

Koji NAKAI

Koji NAKAI is a graduate student at the Graduate School of Agricultural Science, Kobe University (http://www.edu.kobe-u.ac.jp/ans-rpww/index-j.htm). He is a project member of "Environmental Change and Infectious Diseases in Tropical Asia" at the Research Institute for Humanity and Nature. He is currently engaged in developing a hair analysis method to monitor mineral balance and heavy metal exposure in humans.

Takanori NAGANO

Takanori NAGANO has been an Associate Professor at the Graduate School of Agricultural Science, Kobe University since 2008. He received his Doctorate in Agriculture from the Graduate School of Kyoto University in 2002. He worked as a post-doctoral fellow at the Research Institute for Humanity and Nature (2001-2004), as a postdoctoral fellow at JSPS (2004-2007) and as a technical assistant staff member (2007-2008). His research fields are soil hydrology, irrigation and drainage and rural planning. His current research focus is on sustainability analyses of large irrigation schemes.



Shigeo KOBAYASHI

Shigeo KOBAYASHI has been a Professor at the Graduate School of Asian and African Area Studies, Kyoto University since 2004. He worked at the Soil Division of the Forestry & Forest Products Research Institute until 1987. In 1988 he moved to the Forestry and Forest Products Research Institute, where he served as Head of Laboratory at the Department of Forest Site Environment.

Kazuhiko MOJI

Kazuhiko MOJI has worked for RIHN since 2007. He received his MA (1978) and Ph.D. (1987) in Health Sciences at the University of Tokyo. He was a Research Associate at the Department of Human Ecology at the University of Tokyo (1983-1987). In 1987 he moved to Nagasaki University, where he served as Associate Professor in the Department of Public Health (1987-1999) and Professor at the School of Allied Medical Sciences (1999-2001), Faculty of Health Sciences (2001-2002), and the Research Centre for Tropical Infectious Diseases at the Institute of Tropical Medicine (2002-2007).

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