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Spatial and Temporal Characteristics of Shifting Cultivation Patches in Kotopanjang Dam Watershed

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Abstract

Shifting cultivation patches distributed in the Kotopanjang dam watershed in central Sumatra were detected by the analysis of 4 datasets of Landsat imagery acquired in 1985, 1989, 1992 and 1994. Detection of shifting cultivation areas was performed based on sifting using patch size and the normalized difference vegetation index (NDVI) from bare lands obtained by unsupervised clustering and maximum likelihood classification. Area, name of sub-watershed, location of center, average elevation, average slope gradient and the NDVI values were computed for each detected patch and registered in a database. Overlaying of results revealed an increase of shifting cultivation patches in this area year by year. Furthermore, it appeared that the increase of the number of patches occurred in specific areas such as surroundings of villages and newly developed areas after dam construction. Sub-watersheds in which much attention should be paid to land degradation were identified by assessing and temporal characteristics of shifting cultivation patches.

Discipline: Agricultural environment
Additional key words: Landsat, land degradation, NDVI, remote sensing

Introduction

In the report on "Tropical forest resources"[1], FAO/UNEP estimated that 45% of total deforestation in the world was derived from subsistence shifting agriculture. Shifting cultivation, in its original sense, refers to the recurrent land use by alternation of a long fallow period with a short period of intensive cultivation. However, especially in tropical Asia and Africa, rapid growth of population leads to the shortening of the fallow period.

Most of the concern about shifting cultivation has focused on the destruction of forest resources or reduction of land productivity. The negative effects of shifting cultivation, however, involve not only the loss of forest resources but also degradation of land and water conservation capacity of water source areas. Reservoir sedimentation is one of the typical problems which is considered to be accelerated by soil erosion from shifting cultivation areas.

It is generally recognized that the construction of dams in the developing countries often involves the intrusion of forest pioneers with resulting land degradation. In several studies on reservoir sedimentation in the tropical countries it was pointed out that such land degradation resulted in rapid reservoir sedimentation compared with the designed value and shortening of the designed dam life[5,7]. In order to prevent land degradation of a dam watershed, an appropriate water and land conservation plan should be drafted based on accurate information of land use transition. In this paper, a monitoring approach for assessing spatial and temporal characteristics of shifting cultivation patches using satellite imagery is described.

Study area

1) Physical conditions[3,4]

The study area consisted of the watershed of the Kotopanjang dam located upstream of the Kampar river in central Sumatra. It was located between longitudes 100°8′23″ and 100°54′22″ east and between latitudes 0°30′50″ north and 0°4′29″ south. It covered 333,087 ha and consisted of 3 sub-watersheds:

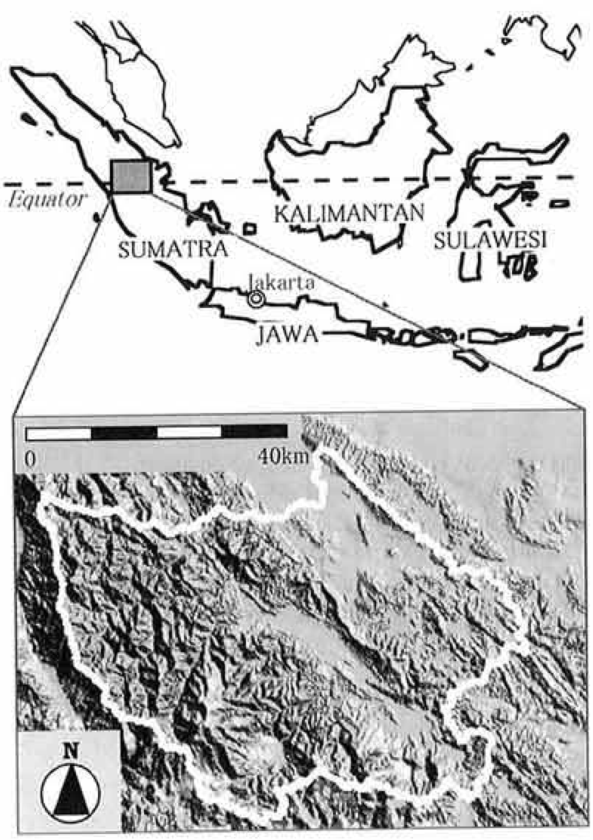

Fig. 1. Location of study area and shaded relief map

Mahat (115,284 ha), Kampar Kanan (145,754 ha) and Kapur (72,085 ha).

The study area was characterized by a hilly and mountainous terrain. Altitude ranged from 55 m ASL at Batang Gulamo (a village near the dam site) to over 1,000 m in the southern and western mountainous area. Location and geomorphological conditions of the study area are illustrated in Fig. 1.

2) Sub-watersheds

In order to analyze the relationship between the distribution of shifting cultivation patches and geomorphological conditions, land use conditions and accessibility from village, the authors divided the whole study area into 23 small sub-watersheds and categorized them into 9 medium-sized sub-watersheds and 3 large sub-watersheds (Fig. 2 and Table 1).

3) Land use characteristics

Most of the sub-watersheds were dominated by secondary forest and shrubs. In the upper zone of the Mahat sub-watershed (I-C-1, 2 and 3) and the middle zone of the Kapur sub-watershed (III-A-2 and III-C-1), a large number of settlement quarters with home gardens and/or paddy fields were distributed. Typical shifting cultivation fields in this area could be seen on hillsides and upland areas surrounding the villages.

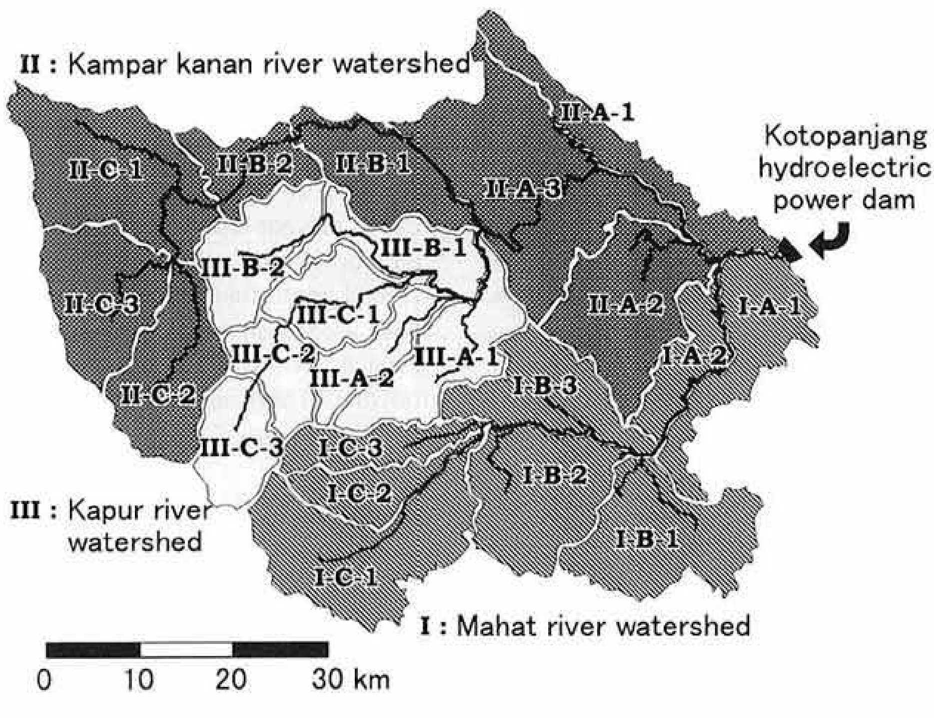

Fig. 2. River pattern and sub-watersheds

Table 1. Properties of sub-watersheds

Large unit	Middle unit	Small unit	Area (ha)	Average gradient (°)	Average elevation (m)
I Mahat river watershed	A	1	15,514	11	186
		2	7,901	12	195
	B	1	20,064	12	396
		2	18,820	13	565
		3	14,081	9	217
	C	1	23,924	16	813
		2	7,277	20	701
		3	7,668	22	813
II Kampar Kanan river watershed	A	1	13,067	7	139
		2	20,190	9	182
		3	33,895	3	131
	B	1	13,424	15	335
		2	8,318	14	389
	C	1	24,625	20	778
		2	16,073	27	1,078
		3	16,161	24	1,144
III Kapur river watershed	A	1	14,415	14	288
		2	7,478	16	392
	B	1	10,464	13	276
		2	11,950	18	490
	C	1	10,574	12	310
		2	7,550	21	790
		3	9,654	26	1,260
Total			333,087	14	501

Large-scale rubber plantations predominated in the flat and slightly undulating area such as the lower zone of the Kampar Kanan sub-watershed (II-A-1 and 3) and the middle zone of the Mahat sub-watershed (I-B-3). Shifting cultivation was also practiced in surrounding areas of these rubber plantations.

Data

1) Landsat data

The following 4 sets of satellite imagery were used for analysis: Landsat MSS, 28 June 1985, Landsat TM, 25 July 1989, Landsat TM, 15 June 1992, Landsat TM, 7 July 1994.

For 1989 and 1994, only quadrant images, which did not cover the southern part of the study area, were obtained. Therefore the Mahat sub-watershed was eliminated from the analysis of the target area in this study.

2) Digital elevation model

Digital elevation model (DEM) was constructed in order to obtain the slope gradient of the patches. Data sources of the DEM were 1 : 50,000 topographic maps.

Methods

1) Detection of shifting cultivation patches

(1) Geometric correction

The Landsat datasets were registered in a standard map projection (Universal transverse mercator: UTM). The MSS data were resampled to 30 × 30 m pixels to overlay the TM images.

(2) Land cover classification

Unsupervised clustering was performed for each dataset and based on these statistics, every pixel on the images was classified into 100 classes with a

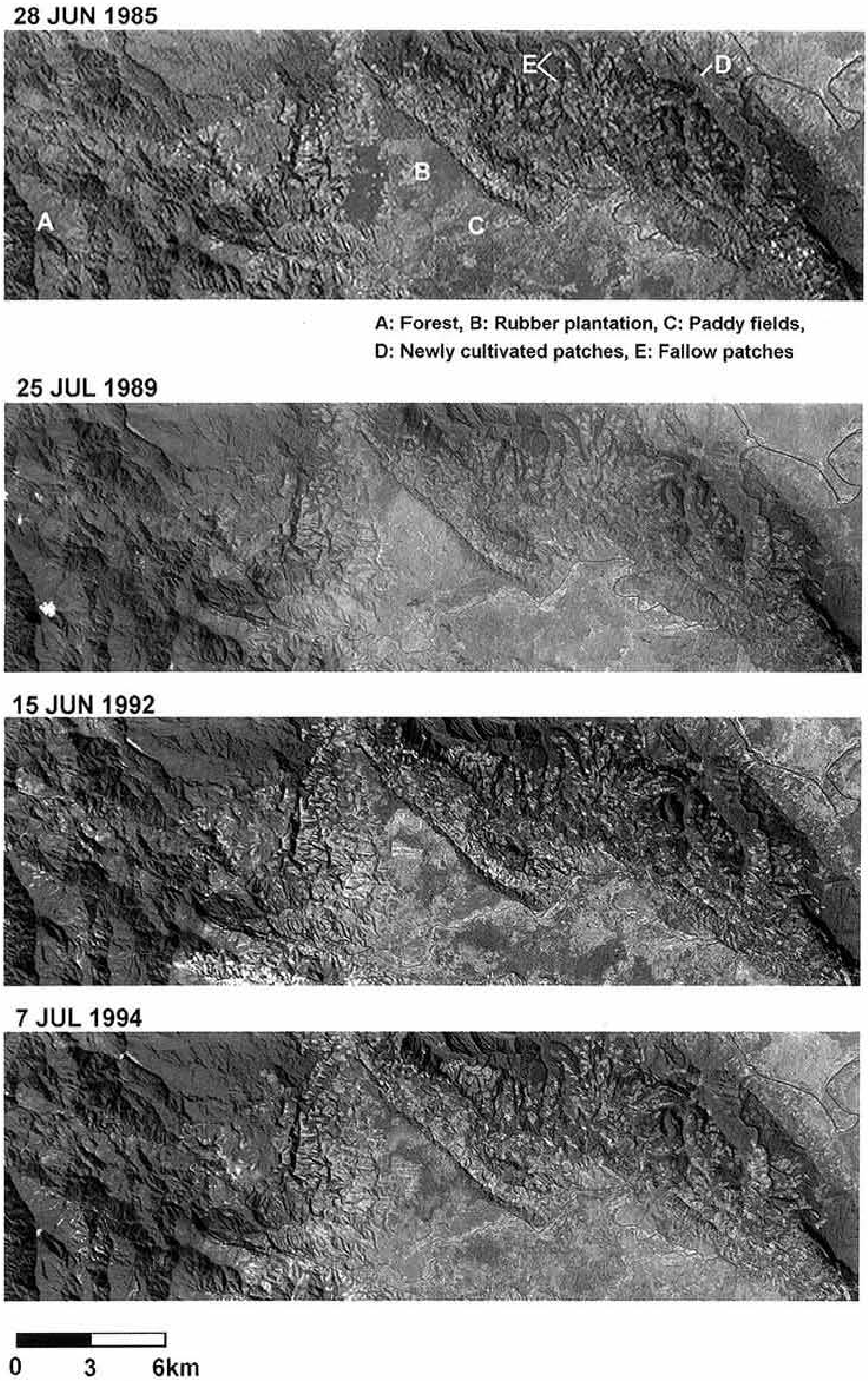

Plate 1. Typical distribution pattern of shifting cultivation patches

maximum likelihood classification algorithm. By comparing the images obtained with false color composite images, classes corresponding to new forest clearings were selected and potential areas for shifting cultivation were identified.

(3) Sifting using patch size

Large scale patches, such as newly developed rubber plantations and transmigration areas, were eliminated from the potential areas. Small patches consisting of a few pixels were also eliminated, since they tended to involve misclassified pixels. Threshold of patch size for sifting was determined by interpretation of false color composite images.

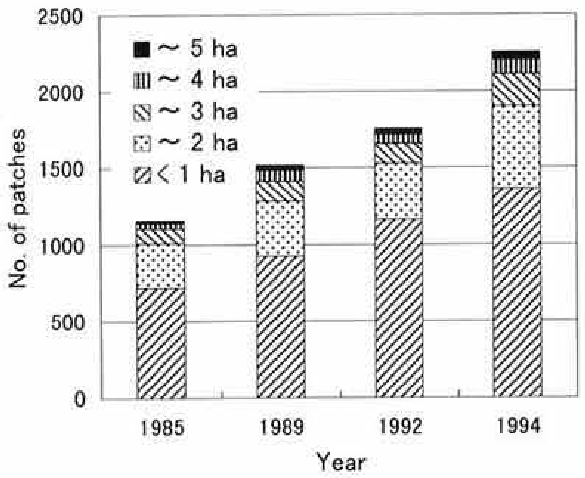

Fig. 3. Temporal change in the number of patches

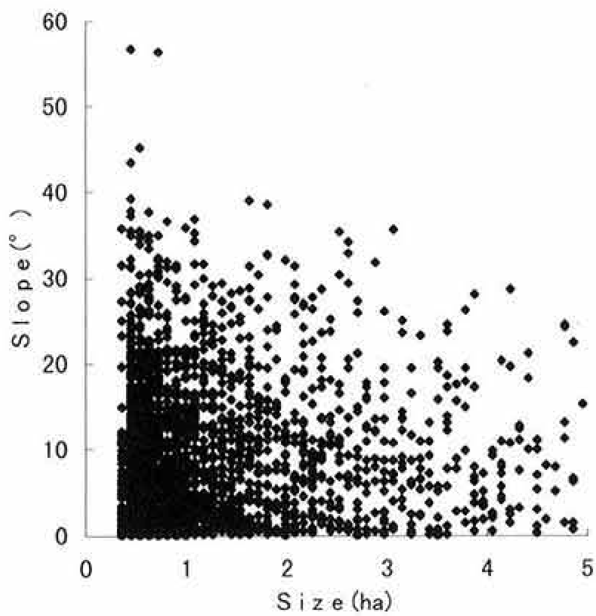

Fig. 4. Relationship between patch size and slope gradient

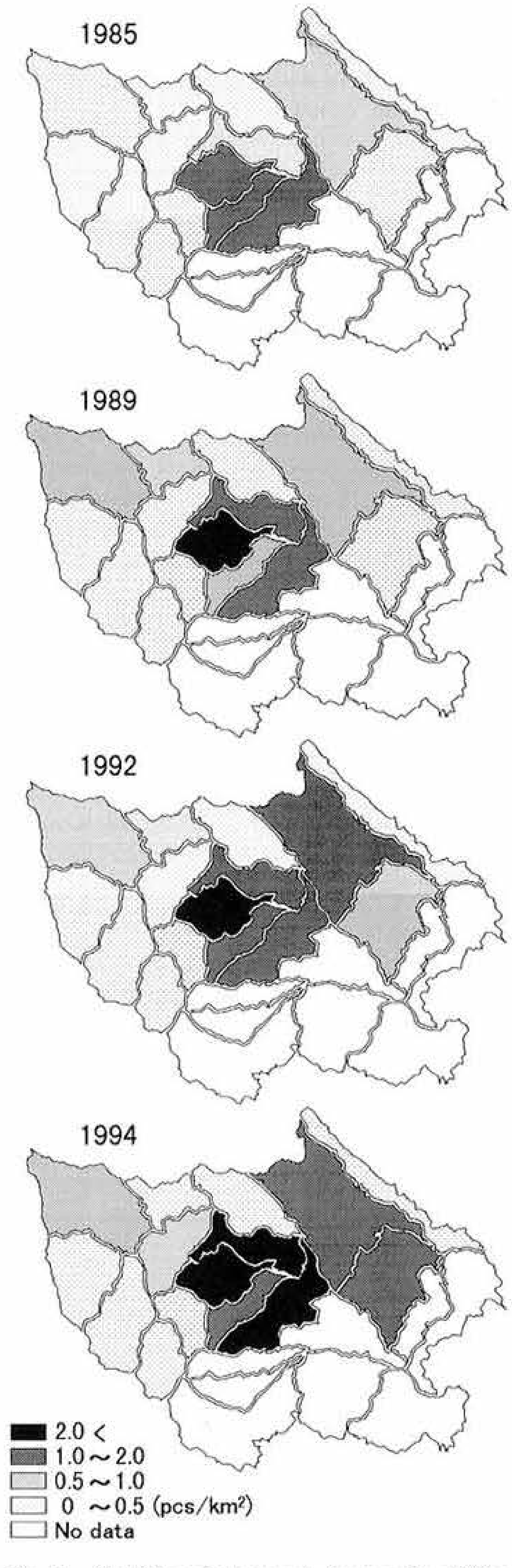

Fig. 5. Spatial and temporal changes in shifting cultivation patches

(4) Sifting using NDVI

The normalized difference vegetation index (NDVI) has been used to evaluate the changes in biomass in forest degradation areas[2,6]. The NDVI is given by the equation:

$$\mathrm{NDVI} = \frac{\mathrm{B2} - \mathrm{N1}}{\mathrm{N2} + \mathrm{N1}}$$

where N1 and N2 denote the image density of red band and near-infrared band, respectively (in the case of TM data, N1 = band 3 and N2 = band 4). The average value of the NDVI was computed for each patch in order to discriminate between shifting cultivation patches and permanent bare land including continuously cultivated fields; namely, the patches, with a low NDVI value throughout 4 datasets from 1985 to 1994, were considered to correspond to permanent bare land and were removed from the potential areas.

2) Assessment of spatial and temporal characteristics of shifting cultivation patches

Spatial and temporal characteristics were computed for each detected shifting cultivation patch, and registered in a database. Registered characteristics were as follows: ID number, area, name of sub-watershed, location of center, average elevation, average slope gradient and the NDVI values (1985, 1989, 1992 and 1994).

Results and discussion

1) General characteristics

Plate 1 shows the typical distribution pattern of the shifting cultivation patches on hillsides in the III-C-1 sub-watershed.

Threshold of shifting cultivation patch size was determined based on 5 ha maximum to 0.36 ha (= 4 pixels) minimum by in-depth interpretation of false color composite images. In the Kampar Kanan and the Kapur sub-watersheds, more than 1,000 patches were detected for every dataset. Approximately 60% of the patches were smaller than 1 ha (Fig. 3). The average slope gradient of the patches was approximately 9°. The relationship between the patch size and slope gradient is displayed in a scatter diagram (Fig. 4).

2) Spatial distribution

The density of the patches for each sub-watershed is illustrated in Fig. 5. The sub-watersheds with a high patch density, such as III-A-1, III-B-1 and III-C-1, consisted of a flat plane, on which many settlement quarters were distributed, and surrounding hillsides. These were potential areas for shifting cultivation indicating that the accessibility from villages plays a significant role in the distribution of shifting cultivation patches.

Table 2. Spatial and temporal distribution of detected shifting cultivation patches

Sub-watershed	1985		1989		1992		1994		Increase ratio (1994/1985)
	No. of patches	Patch density (pcs/km²)	No. of patches	Patch density (pcs/km²)	No. of patches	Patch density (pcs/km²)	No. of patches	Patch density (pcs/km²)	
II-A-1	63	0.48	28	0.21	55	0.42	45	0.34	0.71
II-A-2	21	0.10	48	0.24	179	0.89	215	1.06	10.24
II-A-3	308	0.91	307	0.91	416	1.23	478	1.41	1.55
II-B-1	21	0.16	42	0.31	32	0.24	45	0.34	2.14
II-B-2	31	0.37	44	0.53	45	0.54	41	0.49	1.32
II-C-1	44	0.18	159	0.65	145	0.59	143	0.58	3.25
II-C-2	9	0.06	21	0.13	9	0.06	13	0.08	1.44
II-C-3	63	0.39	52	0.32	45	0.28	25	0.15	0.40
III-A-1	200	1.39	262	1.82	238	1.65	424	2.94	2.12
III-A-2	101	1.35	70	0.94	120	1.60	98	1.31	0.97
III-B-1	65	0.62	183	1.75	127	1.21	386	3.69	5.94
III-B-2	18	0.15	46	0.38	38	0.32	65	0.54	3.61
III-C-1	205	1.94	222	2.10	276	2.61	270	2.55	1.32
III-C-2	7	0.09	32	0.42	16	0.21	2	0.03	0.29
III-C-3	4	0.04	1	0.01	13	0.13	5	0.05	1.25
II + III	1.160	0.53	1,517	0.70	1,754	0.81	2,255	1.04	1.94

Table 3. Number of patches categorized by cultivation pattern

Type	Cultivation pattern				No. of patches
	1985	1989	1992	1994	
A	○	○	○	○	–
B	–	○	○	○	102
C	○	–	○	○	13
D	–	–	○	○	235
E	○	○	–	○	3
F	–	○	–	○	94
G	○	–	–	○	78
H	–	–	–	○	1,903

○ : Cultivated, – : Fallow.

3) Temporal tendency

The number of patches increased rapidly during this decade (Fig. 3). In the II-A-2 sub-watershed, the number of patches in 1994 was more than 10 times of the number in 1985 (Table 2). These findings suggest that the construction of roads and settlements for the people living in the designed dam reservoir area attracted forest pioneers resulting in the overrun of the shifting cultivation patches.

Cultivation and fallow patterns of the patches detected from the 1994 dataset were categorized and are listed in Table 3. Although the average fallow period could not be easily identified since the observation period was too short, a few conclusions were drawn from the Table. It was noteworthy that almost 20% of the patches had been cultivated during the preceding 9-year period. In addition, further observations revealed that the patches with continuous cultivation pattern, such as types B and D, were concentrated in the II-A-3 and III-C-1 sub-watersheds, suggesting that an efficient land conservation plan could be drafted by focusing on these areas.

Conclusion

Shifting cultivation patches distributed in the Kotopanjang dam watershed in central Sumatra were detected by the analysis of 4 datasets of Landsat imagery acquired in 1985, 1989, 1992 and 1994. Overlaying of 4 datasets revealed an increase of the number of shifting cultivation patches in this area year by year. Furthermore, it appeared that the increase of the number of patches occurred in specific areas such as surroundings of villages and newly developed areas after dam construction. Sub-watersheds in which much attention should be paid to land degradation were identified by evaluating the spatial and temporal characteristics of the shifting cultivation patches.

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