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Report

Land cover changes in tropical seasonal forests at Mae Klong head watershed, Kanchanaburi province, Thailand

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Abstract: We investigated land-cover changes recorded at Mae Klong Watershed Research Station to clarify how forested areas have changed since they were abandoned between 1982-2012. Normalised vegetation indices were calculated based on satellite images (Landsat-5 TM) at 4-year intervals from 1992 to 2012. We found that areas of degraded forest and forest fluctuated during those years. During the first 4-year period, from 1992 to 1996, 61% of degraded forest areas rapidly recovered, although some areas changed from forest to degraded forest (4.2 ± 1.27 km^2), indicating that these areas were still being disturbed. However, since then, the forest area has completely recovered, indicating that natural succession has been proceeding well for about 20 years.

Keywords: land-cover change, tropical seasonal forests, Mae Klong Watershed Research Station, forest dynamics, long-term ecological research

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INTRODUCTION

Ecologists have long sought to understand the extent and mode of ecological responses to environmental changes [1-3]. To obtain a holistic picture of system dynamics, the study of ecological processes within communities should be accompanied by a consideration of the topology of interactions among the communities in the form of state transitions. Remote sensing techniques and long-term ecological research are fruitful tools for detecting state transitions and forest dynamics.

In Thailand deforestation and degraded forests have increased due to anthropological impacts and conflicts over land use. Vast expanses of original forest have been converted to pastures and agricultural croplands, often under shifting cultivation with subsequent abandonment [4-6]. The causes of degradation vary, ranging from poor harvesting methods to shifting agriculture following logging and forest fires. In abandoned areas, changes in vegetation start with newly recruited species, known as pioneer species, which prefer high light intensity [7, 8]. During seral succession, the establishment of pioneer communities facilitates a suitable environment for other species, particularly native species. Finally, stands of these species develop into mature, structured ecosystems [9]. However, there is little documentation on how interactions among species change over time during this process of succession. Furthermore, it remains unclear how human disturbance can modify this process. To this end, geographic information system (GIS) analyses can be used to clarify and resolve changes that occur in recovering forests, particularly by predicting land-cover changes over time [10].

Mae Klong Watershed Research Station (MKWRS) was established as a long-term ecological research centre in 1992 under a co-operative project between the National Research Council of Thailand and the Science and Technology Association of Japan. Several permanent plots were established in areas with different land uses, including a teak plantation, natural forest and abandoned areas [8]. However, no reports have presented integrated research using geo-informatics techniques to investigate forest change at MKWRS. Thus, in this study we aimed to clarify the recovery of degraded forests based on long-term GIS data.

STUDY SITE

The study was conducted in a tropical seasonal forest with bamboo undergrowth and without teak [11] at MKWRS, Thong Pha Phoom district (14°30′–14°45′N, 98°45′–99°E), Kanchanaburi province, Thailand (Figure 1). The watershed is about 109 km^2 in area and is located at a branch of Kwai Noi River. The climate is sub-tropical, with a long wet season alternating with a short, cool dry season and a subsequent hot dry season. The annual rainfall normally exceeds 1,650 mm and is concentrated from late April to October. The mean monthly temperature is 27.5°C, with a maximum of 39.1°C in April and a minimum of 14.6°C in December. Geologically, the area is underlain by the parent material of the Ratchaburi and Kanchanaburi series. The Ratchaburi series, composed of shale and limestone, is present in the middle area of the watershed. Some metamorphic rocks contain phyllite and quartzite. The reddish-brown lateritic soil, weathered from parent materials of alluvium, shows residuals of sandstone, limestone and quartzite [12].

The prevailing forest type is mixed deciduous forest, with some dry dipterocarp forest on the mountain ridges and dry evergreen forest along the creeks [11]. Bamboos are dominant in the understory and include *Bambusa tulda*, *Cephalostachyum pergracile*, *Gigantochloa albociliata* and *Gigantochloa hasskarliana*. In 1998 and 2001 two bamboo species (*Gigantochloa albociliata* and *Cephalostrachyum pergracile*) had gregariously flowered and died, and forest fires broke out in 2000, 2002 and 2004 [8, 13, 14]. The dead culms of bamboo were burnt by fire. Wild banana is mainly found at a mesic site along the valley, within the area where severe forest fires have repeatedly occurred [7, 15].

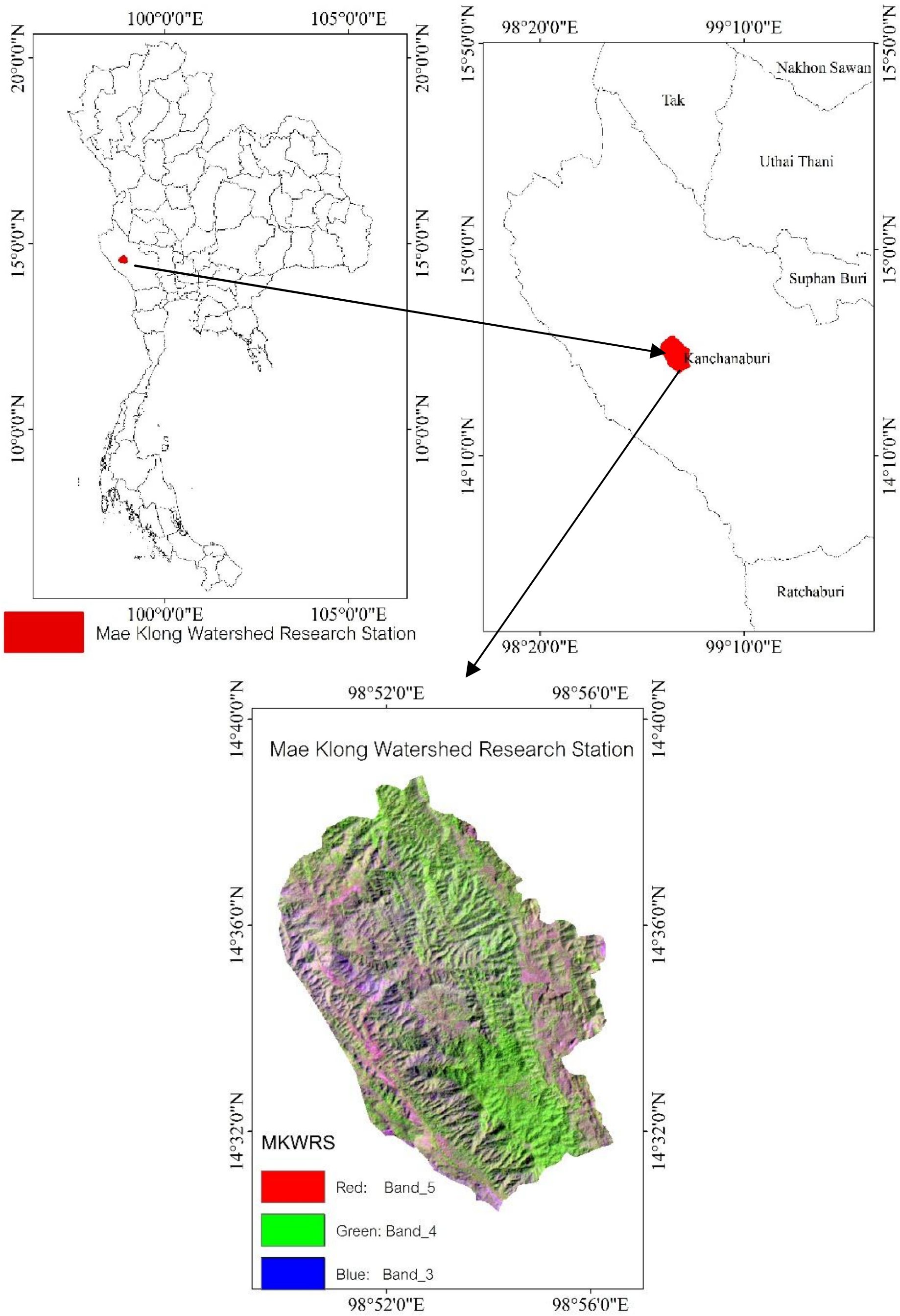

Figure1. Mae Klong Watershed Research Station (MKWRS), Kanchanaburi province: Landsat-5 TM bands 5, 4, 3 are represented with red, green and blue respectively. Green and pink in map indicate high vegetation and low vegetation respectively.

DATA COLLECTION

Land Use Classification

We used Landsat-5 TM satellite images [16] for the years 1992, 1996, 2000, 2004, 2008 and 2012 to classify land use into five types: agricultural area, degraded area, deciduous dipterocarp forest (DDF), mixed deciduous forest (MDF) and dry evergreen forest (DEF). We used a hybrid classification method to classify images [17]. The computer-automated interpretation approach used in this study was unsupervised classification by the iterative self-organising data analysis technique (ISODATA). A clustering algorithm [18] was used to generate clusters of differentiation that included all of the main land-use types designated in this study. Previous classifications were run using only numerical data and statistical analysis to classify data into groups. Each of the land-use and land-cover maps was compared to the reference data to assess the accuracy of this classification. Reference data were obtained by ground-truthing at 100 random sample points. During these field visits, a hand-held global positioning system (GPS) was used to identify exact positions, and land-use types were determined based on visual observation. Ground-truth data for 100 points were used to verify the classification accuracy.

Land Cover Change

To detect land-cover changes, Landsat-5 TM satellite images from 1992 to 2012, divided into 4-year intervals were used: 1992–1996, 1996–2000, 2000–2004, 2004–2008 and 2008–2012. A hybrid interpretation including visual and computer-assisted observations was employed to classify areas into two types (degraded forest and forest) using the normalised difference vegetation index (NDVI) as a remote sensing technique. NDVI is a measure of the balance between the energy received and the energy emitted by objects on earth. When applied to plant communities, its value indicates how green the area is, that is, the quantity of vegetation present in a given area and its state of health or vigour of growth. NDVI is a dimensionless index, so its value ranges from –1 to +1 [19, 20]. Values below 0.1 correspond to bodies of water and bare ground, and higher values indicate high photosynthetic activity linked to scrub land, temperate forest, rain forest and agricultural activity [21]. NDVI was calculated as follows: NDVI = (NIR – RED)/(NIR + RED), where NIR and RED are reflectance in the near-infrared and red bands respectively (bands 4 and 3 respectively in Landsat images). Then a region of interest was selected and a maximum-likelihood supervised classification algorithm was used to generate thematic maps of land cover for each period.

The classification results were evaluated by comparing them to ground-truth observations. One hundred sample plots (30 × 30 m each) were randomly chosen based on the Landsat pixel resolution. Assessment of the accuracy of the land-cover maps extracted from Landsat data based on 100 random reference points (truth points) for each land-cover map was used to estimate the error probability for each map. Two measurements, overall accuracy and the kappa coefficient, were tested.

Detection of Changes

To detect changes in land use, a threshold technique based on differences in image histograms was used. Using this method, significant changes were found in the tails of the histogram distribution while pixels showing no significant change tended to be clustered around the means [11]. First, a threshold was determined, where a value of zero indicates no change in land use and all other values indicate changes. Then NDVI values were calculated for all images, and images were compared between dates to identify differences in these values (DNDVI) [18]:

$$\text{DNDVI} = \text{NDVI}\ (\text{year}_{\text{after}}) - \text{NDVI}\ (\text{year}_{\text{before}})$$

The change-detection statistics routine is easy to use and identifies not only where changes occurred but also the land-use class into which the pixels changed. This routine was applied in this study to compile a detailed tabulation of changes between two classification images. This routine differs significantly from a simple differencing of the two images. While the statistics report does include a class-for-class image difference, the analysis focuses primarily on the changes in initial-state classification. Thus, for each initial-state class, the analysis identifies the classes into which

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individual pixels changed in the final-state image. Changes are reported as pixel counts, percentages and areas.

RESULTS AND DISCUSSION

Land Use Classification

We found that deciduous forests (DDF and MDF) occupied more land area than did other types of coverage (62.26% of the total area). DEF was found near valleys. Degraded forest peaked in 1992, decreasing thereafter (Table 1 and Figure 2). Overall, the classification accuracy using GIS data was 85.86%, 85.59%, 89.56%, 89.24% and 82.98% for 1992, 1996, 2000, 2004, 2008 and 2012 respectively.

Table 1. Patterns of land-use change and their areas from 1992 to 2012 at MKWRS

	1992		1996		2000		2004		2008		2012		
Land use	Area km^2	%	Area km^2	%	Area km^2	%	Area km^2	%	Area km^2	%	Area km^2	%	Average area (mean±S.D.)
Agricultural	7.95	7.19	7.58	6.86	3.77	3.41	4.42	3.99	2.45	2.22	4.16	3.76	5.06 ± 2.02
Degraded	23.46	21.21	16.60	15.00	12.71	11.49	13.80	12.47	10.50	9.49	11.28	10.20	14.73 ± 4.37
DDF	31.69	28.65	26.82	24.25	24.80	22.42	25.54	23.09	24.93	22.54	21.83	19.74	25.94 ± 2.98
MDF	29.87	27.00	32.52	29.40	38.57	34.87	38.18	34.52	40.31	36.45	38.48	34.78	36.32 ± 3.77
DEF	17.65	15.95	27.09	24.49	30.76	27.81	28.68	25.92	32.42	29.31	34.86	31.52	28.58 ± 5.49

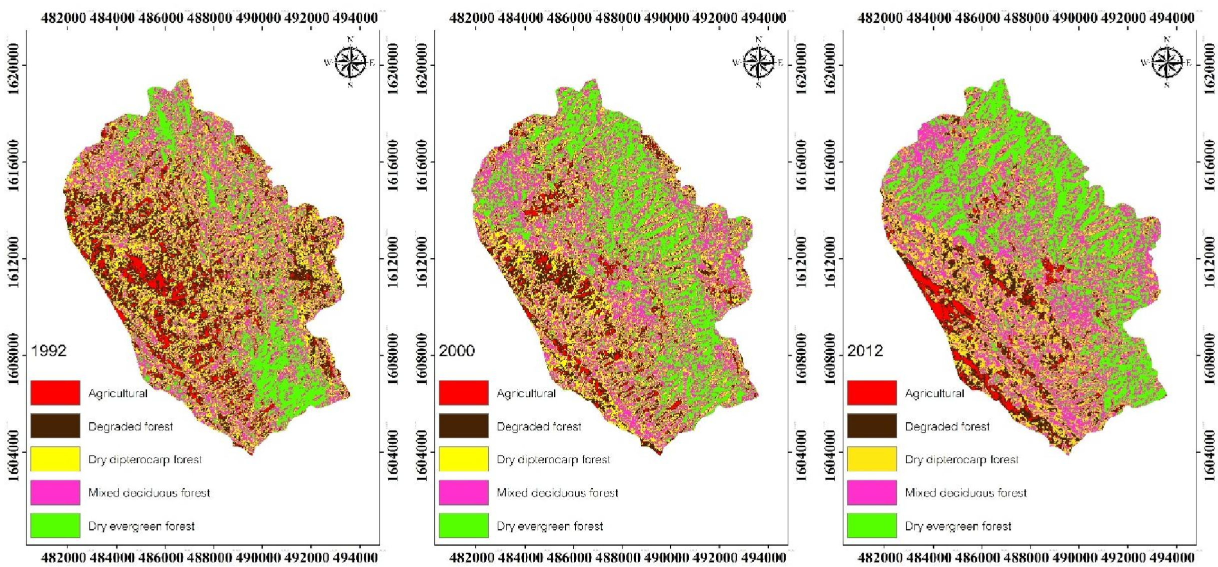

Figure 2. Land-use maps of MKWRS in 1992, 2000 and 2012

Land Cover Change

In 1992 the watershed had 22.28 km^2 of degraded forest and 88.30 km^2 of forest. Since then, natural succession has rapidly progressed, although the rate has varied significantly among years ($P < 0.001$) (Figure 3). The analysis of NDVI showed that the average change from degraded forest into forest was 3.81 ± 5.62 km^2 $4year^{-1}$ through the study period. The greatest increase in newly recovered forest occurred during the first phase of recovery (1992 to 1996), during which time an

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area of 13.66 km^2 transitioned back into forest. Since then, the average area of recovery, 8.14 ± 6.84 km^2 4year^{-1}, gradually declined (Figure 4). The early change was initiated by colonisation by pioneer species, particularly herbaceous and shrubby trees such as *Musa acuminata*, *Sacharum spontaneum*, *Trema orientalis* and *Croton oblongifoulius* [5]. This helped to create suitable environmental conditions for other native species to supersede them [13], although this was a slow process, with large heterogeneity in time and space [22] because the rapid growth and high fecundity of the pioneer species allowed them to colonise canopy openings quickly, with consequent damage to poorly defended leaves and wood [23, 24] and high mortality rate. By 2012, the forest had substantially recovered (85.42% of the total area). Forest recovery at MKWRS is very important for increasing the ecosystem services of this watershed [25]; for example, recovered forests reduce the rate of stream flow and thus the chances of flooding [26], and increase the diversity of flora and fauna [11, 27]. In this way, using GIS and other remote sensing technologies to assess changes in land cover can be useful for assessing and guiding biodiversity conservation initiatives [28].

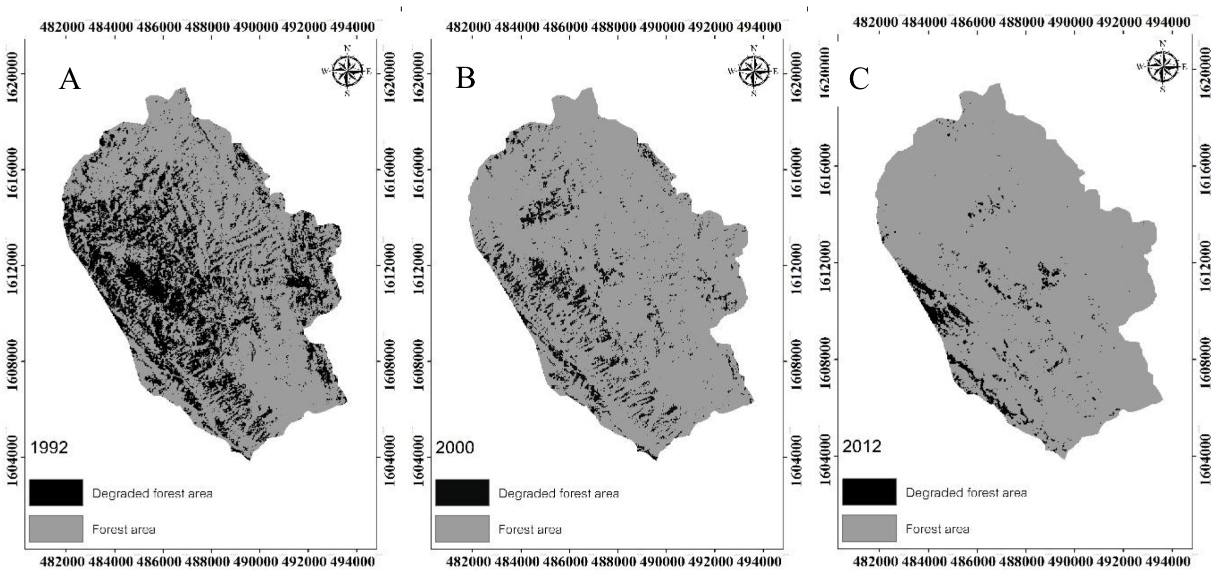

Figure 3. Degraded forest (black) and forest (grey) at MKWRS in 1992 (A), 2000 (B) and 2012 (C)

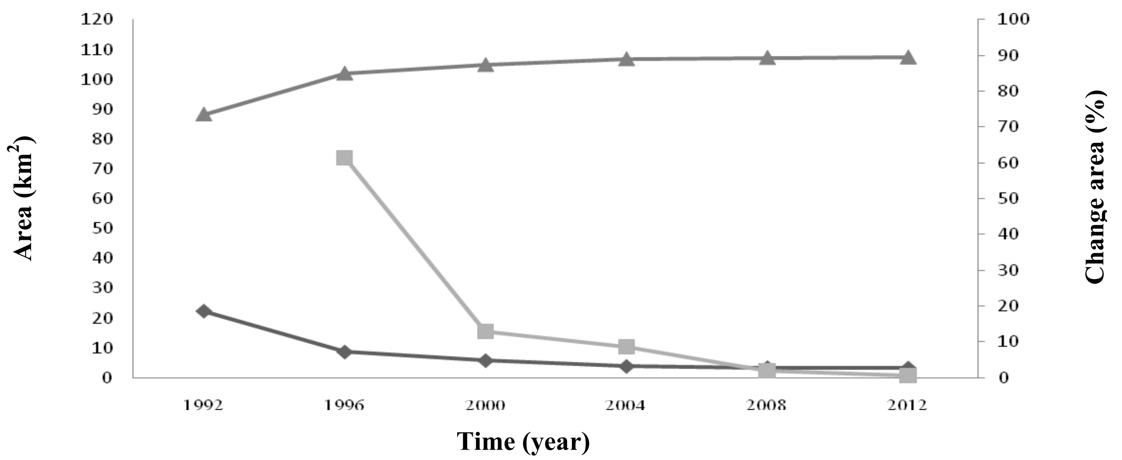

Figure 4. Changes in forest and degraded forest at MKWRS from 1992 to 2012. Lines represent degraded forest (—◆—), forest (—▲—) and rate of change from degraded forest to forest (—■—)

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Our DNDVI results (Table 2) indicated a high rate of change from degraded forest to forest, but some areas also changed from forest into degraded forest indicating continued disturbance. This may have been due to shifting cultivation of rice and rubber plantations [29]. However, as mentioned above, the forest had mostly recovered by 2012, indicating that natural succession progressed well during the 20 years after 1992.

Thus, our DNDVI results were useful for assessing land-use changes in our study area. This method also offers the benefit of allowing the creation and updating of GIS databases because it identifies land-use classes/categories, and quantitative values for each class can be determined [30].

Table 2. Detection of changed area from 1992 and 2012

Change type	Area change (km^2)					
	1992-1996	1996-2000	2000-2004	2004-2008	2008-2012	Average
Forest into degraded forest	5.79	5.36	3.52	3.31	3.02	4.2±1.27
No change*	84.89	97.30	101.28	103.38	104.48	98.26±7.96
Degraded forest into forest	19.93	7.95	5.81	3.92	3.12	8.14±6.84

* Indicates pixel was stable.

CONCLUSIONS

The present study demonstrates how satellite-based detection of changes in land cover can be used to accurately assess natural ecosystems and their dynamics. At our study site, natural recovery of forest occurred, with some disturbance, back to 1992; thereafter, succession progressed further, and the area became mostly forested. The recovered forest may promote ecosystem services such as regulation of the water cycle.

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