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Forest Cover Changes Under Selective Logging in the Kabaung Reserved Forest, Bago Mountains, Myanmar

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This study examined the main factors affecting forest cover changes in Kabaung Reserved Forest, where selective logging has been carried out. Change detection was performed based on analysis of Landsat images taken in January 1989, November 2000, and January 2003. We used a combination of supervised classification and normalized difference vegetation index (NDVI) image-differencing methods to detect the selective logging area; a chi-square test confirmed the effectiveness of this method. Analysis of the spatial distribution pattern of forest cover changes pointed to selective logging, dam construction, shifting cultivation, and teak plantation operations as the factors influencing forest cover changes in the logging compartments. Illegal logging was a possible process of forest cover change in easily accessible nonlogging compartments. Regarding deforestation, intensive felling before dam construction was the main factor among the above-mentioned four. This study suggests the need for further development of regular assessment and monitoring of forest cover changes in the Kabaung Reserved Forest to examine and protect this natural teak-bearing area against forest reduction.

Keywords: *Selective logging; logging record; dam construction; shifting cultivation; Landsat images; NDVI; Myanmar.*

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Introduction

Selective logging is the practice of harvesting the most important timber species in natural forests while allowing the remaining forest to regenerate naturally over time (Bawa and Seidler 1998). This approach is implemented in a number of tropical countries and has been proposed as a successful method for the sustainable exploitation of complex natural communities (Lobo et al 2007). Although Myanmar has a long history of forest management, including scientifically based approaches, the country is currently facing problems of forest degradation and deforestation. The Food and Agriculture Organization (FAO) estimates that 466,000 ha of forested area in Myanmar were destroyed annually between 2000 and 2005 (FAO 2006). However, very few empirical studies have been carried out to ascertain the main cause of deforestation.

Ochoa-Gaona and González-Espinosa (2000) used Landsat satellite images to study deforestation rates and land use changes related to environmental factors in Chiapas, Mexico. Phong (2004) also used Landsat imagery but with different change-detection techniques to analyze forest cover dynamics and deforestation in a national park in Vietnam. Information on changes in land use and forest cover plays a key role in current strategies for managing natural forests and monitoring their environmental change. Understanding the processes and causes of forest cover change will help resource managers and policy-makers to decide where action should be taken and what kind of intervention is needed. Thus, this study sought to detect forest cover changes and their causes in natural teak-bearing forests under selective logging operations in the Bago Mountains from 1989 to 2003 by using a combination of field observations, interviews, logging records, and satellite image analysis to contribute to sustainable forest management of the area.

Site description

The Bago Mountains area is located in the southern part of the central basin of Myanmar. The area has a monsoon climate divided into well-marked seasons: a wet season from the end of May to November, with maximum rainfall in July and August, and a dry season divided into a cold period from December to the end of January and a hot period from February to May. The study area, Kabaung Reserved Forest (Figure 1), is one of the reserved forests in the Bago Mountains. Located at approximately 18°50′–19°09′N, 95°50′–96°12′E and situated in Taungoo and Oktwin townships of the Taungoo District, the forest covers approximately 78,046 ha consisting of 219 compartments. As teak which grows on the Bago Mountains area has the highest quality in Myanmar, the study area is one of the best teak forests.

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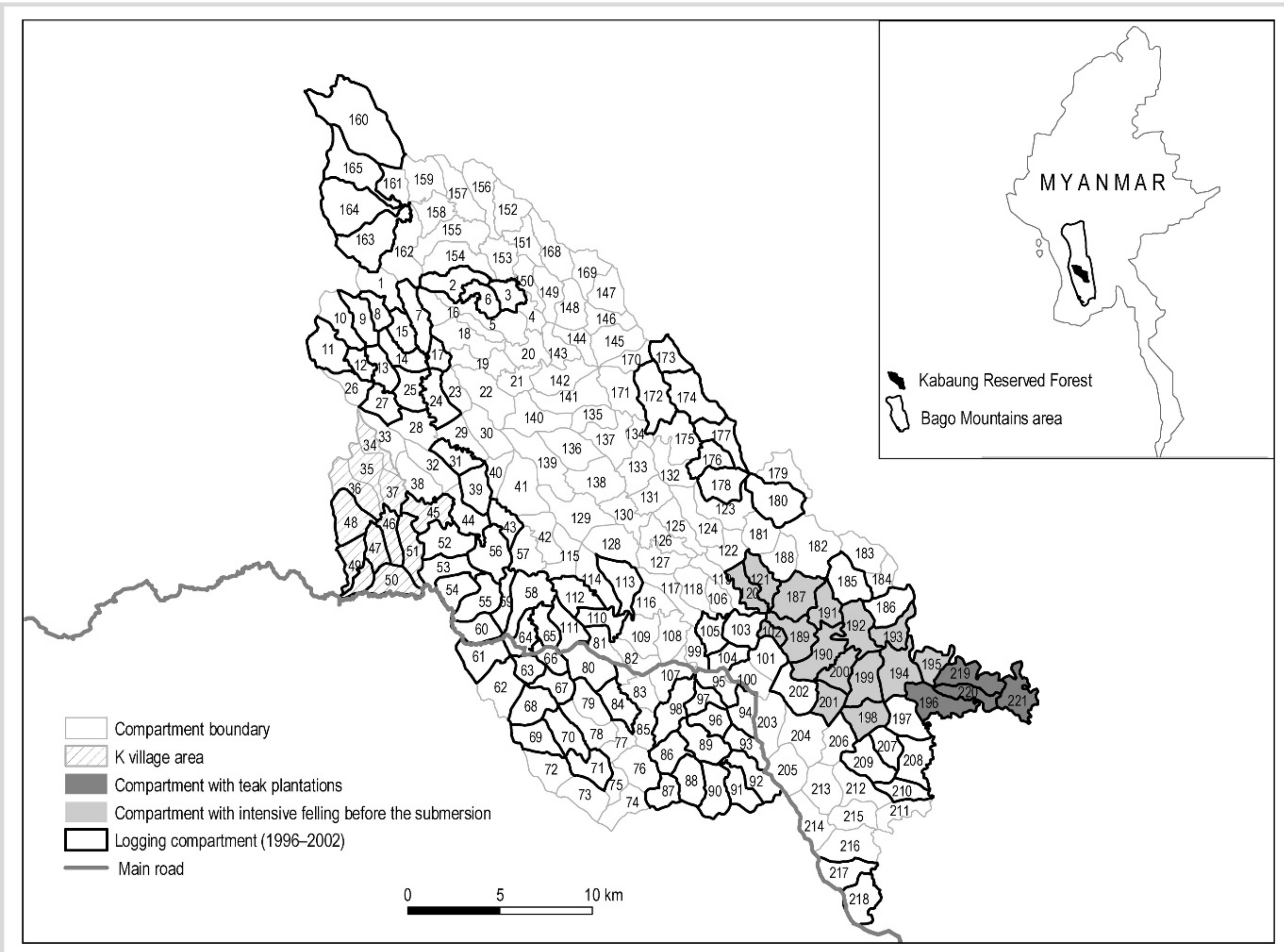
FIGURE 1 Location and compartments of Kabaung Reserved Forest.



Natural teak-bearing forests in the Bago Mountains have been managed under a selective logging system called the Myanmar Selection System (MSS) since 1856 (Ko Ko Gyi and Kyaw Tint 1995), and the MSS is still the main scheme used to manage natural teak-bearing forests. Under the MSS, the felling cycle is 30 years, and marketable trees meeting exploitable diameter at breast height (Dbh) limits (73 cm in moist teak forests and 63 cm in dry teak forests) are selected and cut. Compartments represent the basic units in managing natural teak-bearing forests in Myanmar, and a logging record for each compartment can be obtained from the Forest Department. The Dbh limit for other hardwoods varies according to species, and most timber extraction is carried out by elephants. In 2001–2002, the construction of Kabaung Dam commenced; some compartments of Kabaung Reserved Forest were submerged by 2006, and part of the natural teak-bearing forest was intensively felled before the submergence.

Shifting cultivation and agriculture are prohibited in Kabaung Reserved Forest, except that people in K village are allowed to practice shifting cultivation. The Karen people who live in this village depend mainly on this agricultural system for their livelihood, and they have practiced shifting cultivation since colonial times. To compensate for the loss of forest resources in Kabaung Reserved Forest, teak plantations have been established using the *taungya* method. *Taungya* teak planting entails growing teak seedlings together with agricultural crops. In this system, farmers who plant trees are granted the official right to cultivate intercrops for at least 2 or 3 years after planting teak.

Material and methods

Classification of the satellite images

Landsat Thematic Mapper and Enhanced Thematic Mapper Plus images for January 1989, November 2000, and January 2003 and logging records (including logging year, logging compartment, number of extracted trees, total volume of extracted trees, and species name) from 1996 to 2002 were used to assess forest cover changes. The spectral signature is not much different between the image from November (end of the wet season) and that from January (end of the cold period of the dry season). According to the field survey, a few leaves start shedding in January, but most trees retain their leaves in the study area. The three satellite images were geo-referenced to the Universal Transverse Mercator and World Geodetic System 1984 coordinate systems.

Training sites for forest cover in 1989, 2000, and 2003 were selected based on a field survey, interviews with villagers, and information from the Forest Department. In addition to field data, shifting cultivation plots were extracted from each corresponding satellite image using the normalized difference vegetation index (NDVI) (Ne Win 2008) and used for training sites.

To identify shifting cultivation plots, the area, shape, and chronological change in plant cover were taken into consideration. Plots much smaller or larger than the sizes of actual shifting cultivation plots obtained from the field survey were excluded. Areas having NDVI values lower than the threshold value for several consecutive years were determined as "other" areas (such as settlements, roads, permanent agriculture) and also excluded.

Image classification was made in ERDAS IMAGINE using the supervised classification technique with the maximum likelihood algorithm. In the supervised classification, the study area was divided into 4 forest cover classes: forest, degraded forest (bamboo), bare land and grassland, and water body.

NDVI image differencing

In addition to the 4 forest cover classes created by supervised classification, the area affected by selective logging should be considered in the forest cover change analysis. Numerous methods have been used to detect selective logging. According to Souza et al (2005), the first technique for detecting an area of selective logging was visual interpretation of Landsat images; however, this method is challenging when the logging intensity is low, and it can be susceptible to human bias. Landsat reflectance data and texture analysis have also been used to map selective logging (Asner et al 2002), but this method is prone to error caused by spectral ambiguity between selectively logged areas of various ages and extraction intensities (Souza et al 2005). Several approaches, such as maximum likelihood classification, subpixel classification, vegetation indices (eg the modified soil adjusted vegetation index [MSAVI], soil adjusted vegetation index, and NDVI), and forest canopy density mapping, have been tested to detect the selective logging area (Bhandari 2003). Only subpixel classification and MSAVI gave reasonable results.

In our study, most of the selective logging area could be classified as forest because the felling of selected trees meeting exploitable Dbh limits causes little change in canopy density. To overcome these problems, many studies have applied a combination of methods, for example, a combination of a decision tree classifier and fraction images (Souza et al 2003) or of a normalized difference fraction index and a contextual classification algorithm classifier (Souza et al 2005). However, an optimal method for detecting selective logging has not yet been developed. In this study, we applied a combination of supervised classification and NDVI image differencing to detect the selective logging areas because, in an area of selective logging, the NDVI value decreases even though the area can still be classified as forest.

For the NDVI image-differencing method, radiometric quality adjustment was performed to mitigate differences in spectral reflectance properties among the three images. The image from 2000 was selected as the reference image to adjust the 1989 and 2003 images. The control set for radiometric adjustment was selected from the protected forest, which had similar surface reflectance properties in the images from different dates. Radiation quality adjustment for band 3 and band 4 of the 1989 and 2003 images was conducted. The NDVI was then calculated for all three images as

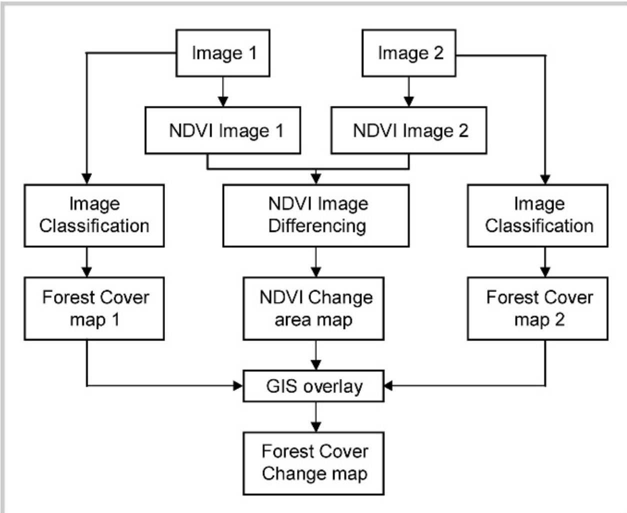
$$\mathrm{NDVI} = (\text{band } 4 - \text{band } 3)/(\text{band } 4 + \text{band } 3)$$

From two NDVI images, approximately 100 pixels were chosen from the protected forest area, and the NDVI change value for each pixel was calculated. The mean and standard deviation (SD) for the NDVI change value of 100 pixels were determined. Then, the NDVI change image (1989–2000 or 2000–2003) was classified into three categories: positive change (greater than mean $\pm$ SD of protected forest), no change (mean value $\pm$ SD of protected forest), and negative change (less than the mean value $\pm$ SD of protected forest). The extraction area (EA) is included in the negative change category because we defined an EA as the area in which the land class was classified as forest in two satellite images but the NDVI was lower in the later image. Most of the selective logging area was expected to be included in the EA.

Preparation of maps of forest cover change

The forest cover change maps were generated using a combination of NDVI change maps and classified images created by supervised classification (Figure 2). To assess the accuracy of the image classification, Kappa statistics were calculated. Global positioning system points for each forest cover identified in the field survey and in interviews with local community members and staff of the Forest Department were used in the accuracy assessment. First, an error matrix was created and the overall accuracy and Kappa were calculated.

FIGURE 2 Flow chart of the preparation of the forest cover change map.



Regrouping the forest cover changes

After preparing the forest cover change maps, we calculated the area changes from one forest cover class to another. Not all changes were taken into account; changes from water to other forest cover classes and from other forest cover classes to water were not considered, as the change in area was quite small. Seven changes that were analyzed for forest cover change assessment were regrouped into two categories, namely, forest loss and forest gain. Forest to extraction area (F to EA), forest to degraded forest (F to DF), forest to bare land and grassland (F to BG), and degraded forest to bare land and grassland (DF to BG) were regarded as forest loss. Degraded forest to forest (DF to F), bare land and grassland to forest (BG to F), and bare land and grassland to degraded forest (BG to DF) were defined as forest gain.

Forest cover change analysis

To determine suitable classes for each forest cover change, the deviation value was calculated by the following equation:

$$\text{Deviation value} = 10(a - \bar{a})/\text{SD} + 50$$

where a = forest cover percentage change of each compartment, $\bar{a}$ = mean forest cover percentage change of the total of all compartments, and SD = standard deviation.

The concept of the deviation value is identical to that of normalization. The mean value of 0 corresponds to that of 50, and the standard deviation of 1 is replaced with 10. In this study, the ranges of percentages of forest cover change differed considerably (ie the change percentages of DF to BG and of F to BG were much lower than were those of other changes). Here, we used the deviation value to adjust the forest cover change data and selected the most suitable class of deviation value that was uniform in two periods. Depending on the data in the two forest cover change maps, deviation value categories of <60, 60–70, and >70 are the best for clearly showing the forest cover changes (Figures 3–5).

To analyze the effect of logging on forest cover change, recent annual data for logging compartments (1996–2000 for the first period and 2001–2002 for the second period) were used. These recent annual data were used because visible signals of selective logging may be evident for only a limited time due to canopy recovery. Each type of forest cover change was divided using the deviation value, and the spatial distribution pattern of each change in forest cover for both periods was then analyzed.

Intensity analysis of forest loss and forest gain

To analyze forest loss and forest gain, five categories were developed: logging, others, shifting cultivation, dam construction, and teak plantations. In dividing the categories, if two factors were simultaneously found in one compartment, the data were checked and the compartment was placed in the more suitable category. For example, during the first period, logging operations and shifting cultivation occurred simultaneously in seven compartments of K village. However, according to the logging data and interviews with villagers, the effects of logging were very limited in these seven compartments. Therefore, these compartments were excluded from the logging category and put into the shifting cultivation category for analysis. The same method was used to choose categories for other compartments affected by two factors.

Results

Accuracy assessment

The overall accuracy of the forest cover change classification map for 1989–2000 was 78.7% (Kappa coefficient of 0.70), whereas for 2000–2003 the accuracy was 74.4% (Kappa coefficient of 0.64).

Spatial distribution patterns of forest cover change

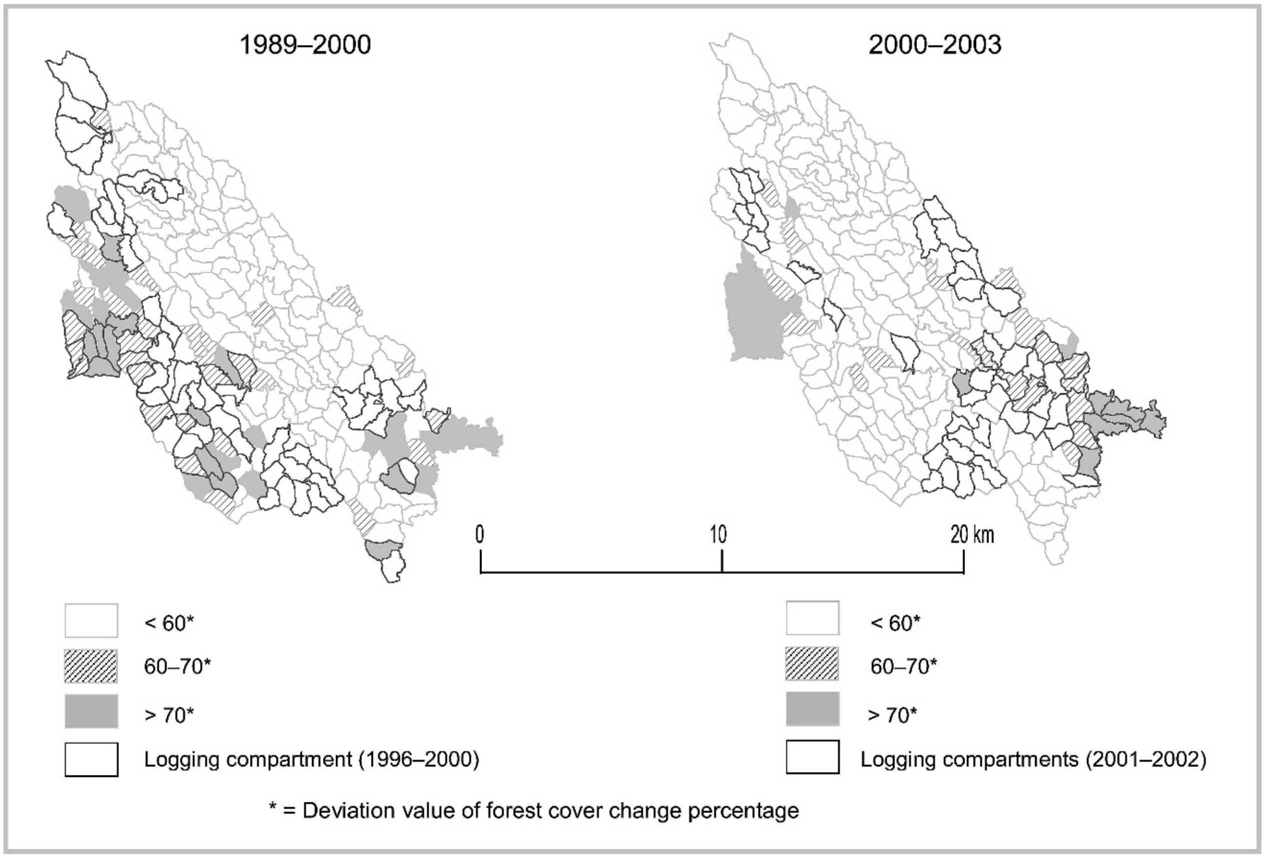
Forest loss

- **Forest to extraction area:** Forest loss from F to EA was observed in logging compartments as well as in nonlogging compartments located near logging compartments (Figures 3, 4).
- **Forest to degraded forest:** During 1989–2000, a high percentage of F to DF was found in K village, where shifting cultivation has been practiced since colonial times, and also in some nonlogging compartments (Figure 3). In 2000–2003, a high percentage of F to DF was observed in nonlogging compartments near the

FIGURE 3 Spatial distribution pattern of each type of forest cover change in 1989–2000.

FIGURE 4 Spatial distribution pattern of each type of forest cover change in 2000–2003.

FIGURE 5 Spatial distribution pattern of forest gain in 1989–2000 and 2000–2003.



main road and near the logging compartments (Figure 4).

- **Forest or degraded forest to bare land and grassland:** During 1989–2000, F to BG and DF to BG were observed in K village and in the teak plantations area where *taungya* teak plantations have been established by the Forest Department (Figure 3). In 2000–2003, F to BG was seen only in the dam construction area, where intensive logging was carried out in 2002. DF to BG was found in the dam and teak plantation areas and in K village (Figure 4).

The analysis of the spatial distribution pattern of forest cover changes revealed four main factors that may have contributed to these changes: logging, intensive felling due to dam construction, shifting cultivation, and *taungya* teak plantations.

Forest gain: Forest gain occurred in K village, teak plantations, and some logging and nonlogging compartments during 1989–2000. During 2000–2003, forest gain was observed in K village, teak plantations, and the dam construction area (Figure 5). However, forest gain was less than forest loss in both periods.

Analysis of the relationship between logging operations and the extraction area

Table 1 shows the relationship between logging operations and extraction area based on chi-square tests. For the chi-square test, EA was divided into two categories, >30 ha and <30 ha. The area of 30 ha was the estimated gap area in a logging compartment due to logging operations and was calculated using the following formula:

$$\begin{aligned}30\text{ ha} = &(\text{estimated crown area of a felled tree}\\ &\times \text{ no. of extracted trees})\\ &+ \text{estimated disturbed area during}\\ &\text{the logging operation}\end{aligned}$$

According to the field survey, the average crown area of a felled tree was 304 m^2. According to the logging data,

TABLE 1 Chi-square test of the relationship between logging operations and extraction area.

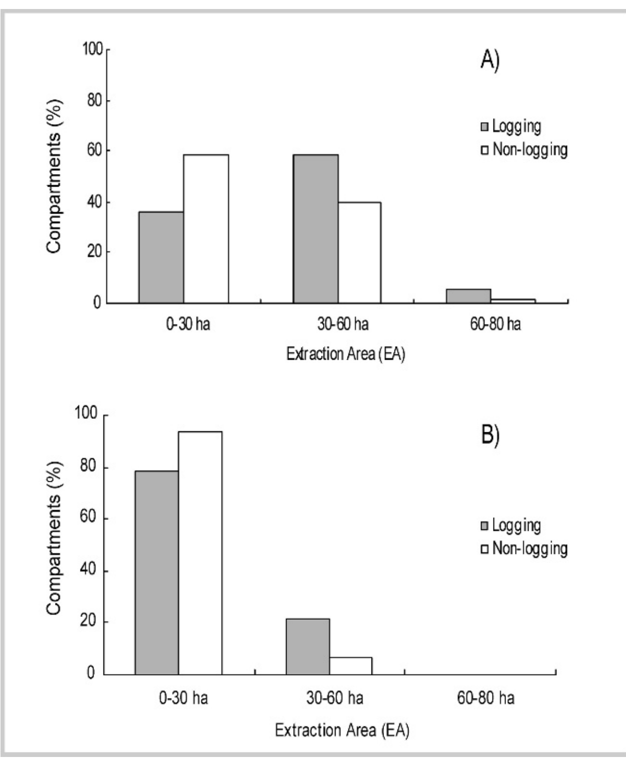
Factor[a)]	Extraction area		χ^2	df	*P* value
	<30 ha	>30 ha			
No. of logging compartments (1989–2000)	14 (36%)	25 (64%)			
No. of nonlogging compartments (1989–2000)	105 (58%)	75 (42%)	6.503	1	0.011
No. of logging compartments (2000–2003)	40 (78%)	11 (22%)			
No. of nonlogging compartments (2000–2003)	157 (93%)	11 (7%)	9.769	1	0.002

[a)] 1998–2000 and 2001–2002 logging compartments were used for the first period (1989–2000) and the second period (2000–2003), respectively.

the average logging intensity was three trees per ha. The average size of each compartment was about 300 ha, and the total number of extracted trees in each compartment was about 900 ha. Disturbance by logging (damage to the remaining trees, log landings, logging roads) was estimated to affect approximately 3 ha. Therefore, 30 ha = 0.0304 ha × 900 + 3 ha.

Figure 6 shows the size distribution of EA in logging and nonlogging compartments. Based on the chi-square test (Table 1), the ratio of compartments having an EA of more than 30 ha was higher in logging compartments than in nonlogging compartments.

FIGURE 6 Size distribution of extraction area (EA) in logging and nonlogging compartments in 1989–2000 (A) and 2000–2003 (B).



Intensity of forest loss and forest gain in each affected area

The percentage of forest loss or forest gain in each compartment was calculated using the following formula: (total area of forest loss [or] forest gain in each compartment × 100)/area of each compartment. From Tables 2 and 3, the high ratio of total logging compartments (85% in 1989–2000 and 79% in 2000–2003) led to 10–20% forest loss. However, 98% and 82% of the total compartments in the first and second periods, respectively, were reforested at less than 5%.

In nonlogging compartments, forest loss was higher than forest gain in both periods. In the shifting cultivation area, all compartments had >20% forest loss, and 64% of the total compartments had forest gain of 5–10% in 1989–2000. In 2000–2003, the forest loss was 10–20% and forest gain nearly equaled forest loss.

In the dam construction area, 43% of the total compartments in the first period had suffered >20% forest loss; in the second period, the ratio of all compartments having >20% forest loss increased to 86%. Forest gain in both periods was below 5%.

In teak plantation areas, all compartments had >20% forest loss in the first period, which decreased to 10–20% in the second period. Forest gain was higher in the second period than in the first period.

Discussion

Relationship between logging operations and forest cover change

The main cause of F to EA was the felling of selected trees. The effect of selective logging was determined in logging compartments by examining the higher ratio of logging compartments than of nonlogging compartments that had an EA >30 ha (Table 1; Figure 6A,B). From the results of this analysis, a combination of supervised classification and NDVI change detection methods was found to be suitable for detecting selective logging areas.

TABLE 2 Effect of each main factor on forest loss and forest gain in 1989–2000.

1989–2000						
Category of compartment[a)]	Total compartments	Forest loss area (%) in each compartment			
		<5	5–10	10–20	>20
Logging	52	0	3 (6%)	44 (85%)	5 (9%)
Others (nonlogging)	138	0	54 (39%)	72 (52%)	12 (9%)
Shifting cultivation (SC)	11	0	0	0	11 (100%)
Dam construction (DC)	14	0	0	8 (57%)	6 (43%)
Teak plantations (TP)	4	0	0	0	4 (100%)

TABLE 2 Extended.

1989–2000			
Forest gain area (%) in each compartment			
<5	5–10	10–20	>20
51 (98%)	1 (2%)	0	0
135 (98%)	3 (2%)	0	0
4 (36%)	7 (64%)	0	0
12 (86%)	2 (14%)	0	0
1 (25%)	3 (75%)	0	0

[a)] There were 66 logging compartments (1996–2000), but 7 SC compartments and 7 DC compartments were excluded and put in the corresponding category for analysis. Although logging operations were carried out, their impact could not be found in the shifting cultivation area (Ne Win 2008). There were 153 nonlogging compartments, but 4 SC compartments, 4 TP compartments, and 7 DC compartments were subtracted and put in the corresponding category for analysis.

Assessment of the main causes of forest cover change, forest loss, and forest gain in logging and nonlogging compartments

Effect of logging on forest cover change, forest loss, and forest gain: Selective logging operations are the main cause of F to EA changes. The impact of selective logging on deforestation can be seen by comparing forest loss to forest gain (Tables 2, 3). Change from F to DF was observed in some nonlogging compartments located near the main road and near logging compartments. Zaitunah (2004) found that roads are the main factor affecting illegal logging, and the closer an area is to the road, the higher is the level of illegal logging. Logging roads make the study area easily accessible, and deforestation in nonlogging compartments was detected (Tables 2, 3). Illegal cutting may be the main process of the forest cover change and deforestation in nonlogging compartments.

Effect of intensive felling due to dam construction on forest cover change, forest loss, and forest gain: In 2001, the construction of Kabaung Dam began. Because the dam would submerge some compartments, intensive logging operations were undertaken around the dam construction area prior to submersion, from 2002. Clear-cutting of forest and degraded forest areas during this operation may have caused F to BG and DF to BG changes in the dam construction area during 2000–2003. The construction of Kabaung Dam was one of the main causes of forest cover change.

In the dam construction area, the ratio of total compartments with >20% forest loss doubled in the second period compared to the first period (86% versus 43%; Tables 2, 3) due to intensive felling before the submersion in the second period. Table 3 shows that the forest loss in the second period was significantly higher in the intensive felling area than in other areas. In the dam construction area, forest gain occurred before 2006 as some compartments gradually became submerged; however, the reforested area will be completely lost as the dam fills.

Effect of shifting cultivation on forest cover change, forest loss, and forest gain: The Karen people living in K village are allowed to practice shifting cultivation, which they

TABLE 3 Effect of each main factor on forest loss and forest gain in 2000–2003.

2000–2003										
Category of compartment[a)]	Total compartments	Forest loss area (%) in each compartment				Forest gain area (%) in each compartment			
		<5	5–10	10–20	>20	<5	5–10	10–20	>20
Logging	33	0	3 (9%)	26 (79%)	4 (12%)	27 (82%)	5 (15%)	0	1 (3%)
Others (nonlogging)	157	2 (1%)	61 (39%)	79 (50%)	15 (10%)	148 (94%)	9 (6%)	0	0
Shifting cultivation (SC)	11	0	0	11 (100%)	0	0	1 (9%)	10 (91%)	0
Dam construction (DC)	14	0	0	2 (14%)	12 (86%)	11 (79%)	3 (21%)	0	0
Teak plantations (TP)	4	0	0	4 (100%)	0	0	0	4 (100%)	0

TABLE 3 Extended.

[a)] There were 51 logging compartments, but 14 DC compartments and 4 TP compartments were excluded and put in the corresponding category for analysis. Although logging operations were carried out, their intensity was very low in the teak plantation area (logging record, Forest Department). There were 168 nonlogging compartments, but 11 SC compartments were subtracted and put in the corresponding category for analysis.

have practiced since colonial times. They open a shifting cultivation area for 1 year in one place and then move to another plot the following year. The recovery process of fallow vegetation in this village is from BG to DF and then to F. On 1- and 2-year fallow lands, grasses and herbs are dominant. On 5-year fallow lands, the grasses and herbs are suppressed and bamboo becomes the dominant species. On 10-year and older lands, trees overtop the bamboo and gradually become dominant (Fukushima et al 2007). In this study, we could not unify the analytical range of time for the first and second periods due to a lack of available satellite images. The former period (1989–2000) was 11 years, and the latter period (2000–2003) was 3 years. According to the vegetation recovery process in K village, BG will recover to DF after 5 years, and F to DF was observed over the longer period (1989–2000).

From interviews with villagers, it was learned that shifting cultivators appear to prefer DF for practicing shifting cultivation because it is easy to open such areas. According to the analysis, 435 ha of DF existed in 1989, and this increased to 1048 ha in 2000 (Ne Win 2008). In 1989, not enough DF was available for shifting cultivation, and the cultivators used both F and DF. Therefore, F to BG and DF to BG were seen in the period 1989–2000 (Figure 3). In 2000, DF had increased to 1048 ha, and hence, it was used for shifting cultivation; DF to BG was only seen during 2000–2003 (Figure 4).

Forest gain in the shifting cultivation area was <10% in the first period; however, most compartments except one had 10–20% in the second period (Tables 2, 3). Shifting cultivation without a proper fallow period can contribute to forest degradation (Thet and Winn 1995). In K village, the population is quite low and stable (about 50–60 households), the available forest area is about 3639 ha, and the average fallow period is 14 years (interviews, 2006). If the population density is low and the area of forest relatively large, shifting cultivation may be environmentally benign. Due to the inability of fallow lands to reach the original vegetation stage during 11 years (1989–2000), spatial pattern changes were observed. However, low levels of deforestation in the shifting cultivation area occurred due to rapid forest regrowth on abandoned fallow lands.

We cannot discuss the population in other parts of the study area due to the difficulties of obtaining population data, although further information on population would undoubtedly improve our understanding of forest cover changes.

Effect of taungya *teak plantations on forest cover change, forest loss, and forest gain:* The Forest Department established *taungya* teak plantations to compensate for the logged trees. As an area was clear-cut for teak plantation establishment, F to BG and DF to BG were observed in the teak plantation areas.

In *taungya* teak plantation compartments, the forest area recovered by 5–10% in 1989–2000 and 10–20% in 2000–2003. In *taungya* teak plantations, the aboveground biomass increases with increasing stand age (Suzuki 2004). Forest loss is seen during the clear-cutting period before plantation establishment, followed by continuous forest gain through incremental increase in aboveground biomass after plantation establishment. The comparison between forest loss and forest gain showed the low impact of teak plantations on deforestation.

Conclusions

A combination of supervised classification and NDVI image differencing proved to be useful for detecting selective logging areas and facilitated a more detailed assessment of deforestation. Four main factors affected forest cover changes: logging, intensive felling due to dam construction, shifting cultivation, and teak plantation establishment. This study showed that selective logging under the Myanmar Selection System did not have a severe effect on forest cover change and forest loss. However, further work is necessary to examine the species composition, diversity, and structure of secondary forests following selective logging. Among the four possible factors, intensive felling before reservoir submersion was the main factor in deforestation. The impact of the construction of Kabaung Dam on forest cover change may be useful information when considering the construction of other dams in the Bago Mountains. Due to the difficulties of data collection in Myanmar, we could not touch upon the underlying reason. However, the results of this study can be used to increase awareness of threats to the environment and perhaps lead to timely decisions in forest conservation efforts.

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