Modern Land-use Changes in the Upland and the Lowland Terrains of Sabah, Malaysia, and their Causal Interpretation

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Introduction

The conversion of tropical rain forests has been wide-spread and rapid in Southeast Asia (Sodhi and Brook 2006). Presently, this region demonstrates the highest rate of the loss of tropical rain forests (Laurance 1999). Approximately, 1.5 million ha of tropical forests were converted annually from the major four islands of Indonesia (Sumatra, Borneo, Sulawesi and Irian Jaya) (Sodhi and Brook 2006). For the entire world, Laurance (1999) estimated that 15.4 million ha was destroyed annually between 1980 and 1990 based on the FAO data on forest cover; the same author also suggested that additionally 5.6 million ha was degraded. These numbers are based on broad categories of land cover types over large areas. Achard et al. (2002) argued that the rate of forest loss in the world tropics was much lower (5.8 million ha per year), using satellite data, than previously believed.

This kind of controversy may arise from several factors. We suggest that one of such factors is related to the resolution of analysis in terms of time and space. The rate of progressive, secondary succession such as the one in old fields or in selectively logged forests can be quite fast in the tropics. If one analyzes the land-use changes in which vegetation recovery is involved, over an extended period longer than the recovery process, the analysis will result in an underestimate of forest conversion. In addition, land conversion can often take place in a smaller spatial extent than 1ha (100 x 100m) on the ground, in which case the conversion cannot be adequately detected by a large-scale analysis that commonly uses a larger mesh size than several km. Mismatch of spatial resolution may under- or over-estimate the area of forest conversion.

The spatial scale of land-use changes is intimately related to their drivers. Land use for subsistence farming may be small in scale, while the land use caused by large-scale socio-economic drivers at regional to international levels can be quite extensive. The changes of any given landscape in Southeast Asian tropical rain forests are actually driven by several different drivers. Contemporary landscapes must demonstrate a complex pattern of small-scale land cover types intermixed with large-scale land cover types. Therefore, we analyzed the spatio-temporal patterns of land use in contemporary Sabah, Malaysia, with the use of Landsat data (resolution of 30x30 m), so that we can analyze the land-use patterns of subsistence farming as well as of large-scale developments.

Although the drivers of land use are the same, the type of land cover and the consequences (e.g. spatial patterns) can be quite different if physical environments are different. For instance, for the same driver (i.e.

the demand for cash and cash crop), farmers will choose the crop that yields the best return for an investment in each environmental setting. The sate of Sabah is mountainous and environmental setting is contrasting between upland and lowland. Therefore, we hypothesize that the same driver will result in different types of land cover and consequences in the upland versus the lowland. We compare the land-use type and patterns between the two climate zones.

Materials & Methods

Land-use and modern history of the study areas

The state of Sabah is located in the northernmost part of Borneo and presents mountainous upland to undulating low-lying terrains. The mountainous topography culminates on Mount Kinabalu and a typical undulating low-lying terrain is found in the Deramakot area.

Kinabalu: The summit of Mount Kinabalu (4,095m, 6N 116E) and its surrounding area was first gazetted as the Kinabalu National Park in 1964. Originally, the purpose of gazetting the area was to preserve the mountain as a permanent war memorial. Later, park boundaries were modified and it was re- gazetted as Kinabalu Park with a total area of 73,500 ha in 1984. In 2000, the entire park was designated as a World Natural Heritage site because the continuum of pristine vegetation from the lowland to the summit together with its high biological diversity was recognized as a common human heritage. The vegetation consists of mixed dipterocarp lowland tropical rain forests up to 1200 m, montane tropical rain forests up to 2700 m, subalpine forests up to 3400 m and alpine vegetation up to the summit. Park Headquarters are located at 1560 m asl and serve as the base for mountain climbers and tourists. Mean annual air temperature at the Park Headquarters is 18.3℃ with mean annual rainfall of 2380mm between 1996 and 1997 (Kitayama et al. 1999).

The majority of the area within the park is pristine with only 6.56% of the total area being substituted by man as of 1986 (Kitayama 1991). No permanent farming and little encroachment within the park are recognized as of 2007. However, the surrounding areas are heavily used by man. Particularly, the southeastern upland plateau (Mesilau Plateau) in the elevation range of 800 to 1600 m are now used for intensive agriculture (mostly temperate-vegetable growing), large-scale dairy farming, golf course, and etc. The southern to western slopes are mostly used for subsistence agriculture and shifting cultivation. Logging activities were once rigorous in the eastern and the northern areas, but now subsided. Noteworthy is the cupper mining which began in 1970 and was recently shut down. A total area of 2,555 ha was removed as the mining area from the national park in 1970 and it produced 15,000 tons of ore daily at its full operation.

The land conversion by modern agriculture around Mount Kinabalu began probably as early as 1958 when a jeep track connected the Park Headquarters with the capital city of Kota Kinabalu. By 1960, there were 8 ha of land under vegetable cultivation. The jeep track was not enough to support a fuller production of temperate vegetables and production rate did not increase drastically. In 1971, a total area of 162 ha was under "cabbage ladang" which means temperate vegetables cultivated in shifting cultivation system. The agricultural production drastically changed after 1982 when a sealed highway connected Mount Kinabalu with Kota Kinabalu. Fig. 1 depicts the change in the number of visitors to Kinabalu Park. The number drastically increased after the highway was completed. Better transportation changed attitude of farmers from “cabbage ladang” to permanent terrace farming, and triggered systematic land conversions.

Deramakot: Deramakot Forest Reserve (5N 117E) is part of Sabah’s 2,674,570-ha Class II Commercial Forest Reserves, which are meant to conserve forest for commercial timber production. Deramakot Forest Reserve consists of one forestry management unit of 55,149 ha and is situated at the upper Kinabatangan River. The climate is humid equatorial with a mean annual temperature of about 26℃ with a mean annual rainfall of approximately 3,500 mm. The elevation ranges from 100 to 300m and the entire area represents a lowland undulating terrain. The entire area is covered with mixed dipterocarp lowland tropical rain forests.

Commercial logging started in Deramakot in 1956 (Huth and Ditzer 2001). The initially adopted logging method was the Malayan Uniform System (MUS), which allowed harvesting all commercial timber trees over 45 cm in diameter at breast height (DBH). In 1971, the Sabah Uniform System (SUM) was newly introduced following the timber boom in the late 1960s. This method employed heavy machinery for harvesting, skidding and transportation without appropriate consideration for forest stand and site condition (Kleine and Heuvedlop 1993). The area was licensed for logging from 1955 to 1989. The minimum diameter for harvesting was 60 cm and the felling cycle was 60 years. The majority of the Deramakot area was probably affected mildly to heavily by this logging system. Variable cutting intensities of past management practices resulted in an extremely heterogeneous condition of the residual forests (Lagan et al. 2007). Only 20 % of the area was considered well stocked with harvesting trees and more than 30% was covered by very poor forest with virtually no mature growing stock left. The demise of timber resources in Deramakot might have followed the same track of economic downfall of Sabah (Fig. 2). The state annual revenue from forestry and forest-related industries peaked in 1988 with an approximate amount of 1,100 million ringgits, but sharply dropped since then. This triggered the reform of Sabah’s old forestry system into a new sustainable forestry system (Ong and Sinajin 2003).

For the period 1989–2000, the Sabah Forestry Department, in collaboration with the German Technical Agency implemented the Malaysian-German Sustainable Forest Management Project, and Deramakot Forest Reserve was chosen in 1989 as the project site. The project was made up of four phases (Lagan et al. in press): 1) a strong research emphasis with a component for management planning (1989–1992), 2) management planning, training and consolidation (1992–1994), 3) institution building, human resource and development, consolidation/ implementation and extension (1995–1998), and 4) consolidation, planning and human resource development (1999–2000). Deramakot Forest Reserve was certified as “well managed” by an international certification body, the Forest Stewardship Council (FSC), in 1997. It is the first natural forest reserve in Southeast Asia managed in accordance with sustainable forestry principles.

Deramakot Forest Reserve is now divided into 134 compartments, a smallest operational unit where annual timber production takes place. Sabah Forestry Department harvests timber at a rate of two compartments per year, with an intention of 67 years of recovery time before the next harvest takes place.

For the details of the guidelines currently adopted in the Deramakot Forest Reserve, see Sabah Forestry Department (2000).

Adjacent to the western border of Deramakot Forest Reserve lies Tangkulap Forest Reserve where until recently conventional intensive logging was continuously applied by a private sector. Therefore, compared with Deramakot training area, Tangkulap Forest Reserve represents more dynamic timber harvest and the rapid reduction in forested area. There are no statistical data available for the amount or the rate of past timber harvest in the Tangkulap area.

To the north of Deramakot and Tangkulap is located a vast area of oil palm fields. The development of oil palm plantation involves large-scale mechanical removal of above-ground vegetation and the establishment of the monoculture of single oil palm. However, land conversion in this area in recent years has been less dynamic, as fruits only are collected if once developed, although the development of oil palm fields still occurs in marginal areas. Replanting of juvenile oil palm trees also takes place in the senescent fields.

Methods

The following nine data of Landsat imagery of Multi-Spectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM^+) were acquired in time series for classifying land cover and use types from the archives of Tropical Rain Forest Information Center (TRFIC) (http://www.bsrsi.msu.edu/trfic/index.html) and from Earth Resource Observing System (EROS) data gateway of USGS (http://edc.usgs.gov/products/satellite.html):

Kinabalu	January 12^{th}, 1973, Landsat MSS; June 29^{th}, 1985, Landsat MSS; June 14^{th}, 1991, Landsat TM; Oct 22^{nd}, 1999, Landsat ETM^+; May 19^{th}, 2002, Landsat ETM^+
Deramakot	August 25^{th}, 1985, Landsat MSS; May 22^{nd} , 1991, Landsat TM Sept. 9^{th}, 1999, Landsat ETM^+; May 28^{th}, 2002, Landsat ETM^+

Radiometric and geometric correction were applied to these Landsat data before analyzing them in time series to eliminate some errors commonly produced during data acquisition (see Darmawan 2004 for the details). Land cover and use types were categorized based on supervised classification with maximum likelihood method. In the first stage, unsupervised classification was applied to each date of Landsat data with the fuzzy C mean and K mean method for selecting training area. By evaluating dendrogram and co-occurrence, about 50 classes of land cover types were analyzed and regrouped into a fewer number of classes. Land cover type was assigned to each of the classes based on ground truth and spectral patterns. Subsequently, the tasseled cap transformation was used to develop the temporal pattern of land cover and use types in each of the two areas (see Darmawan 2004 for the details).

We attempted to link the land-use change with the change of the taxonomic diversity of canopy trees based on the relationships between above-ground biomass and the taxonomic diversity of canopy trees. As the satellite data of the Kinabalu area are often noisy due to haze and clouds, we used the data of Deramakot only. Because there is an inherent problem that normalized indexes using spectral reflectance saturate at higher biomass (Nakazono et al. submitted), we employed the biomass values that were estimated with a special algorithm by Nakazono et al. (submitted) and Kitayama et al. (2006). First, we regressed the number of canopy-tree taxa per 0.2 ha at species, genus and family level with actually measured biomass values using the census data of Seino et al. (2006) (N=10). The number of families yielded the highest correlation coefficient (r^2=0.552; P=0.014). Therefore, we used the number of families per 0.2ha as dependent variable. We extrapolated this regression model to the entire Deramakot area using the biomass values estimated by Nakazono et al. (submitted) and Kitayama et al. (2006) for 1985 and 2002. We arbitrary assigned the value 1 to oil palm plantations. Subsequently, we calculated frequency distribution of canopy diversity classes.

Results

Land use types changed drastically in both areas through time (Figs. 3 and 4). In the Kinabalu area, the most drastic change was the rapid increase of agricultural and bare lands between 1973 and 1991. In 1991, patches of agricultural and bare lands occurred in the southeast and southwest slopes. In 1973, the most wide-spread cover type in the Kinabalu area was secondary forests, which decreased in area later (Fig. 5). After 1991, shrub land and rangeland increased drastically. The area of “pristine forests” temporary increased in 1991, probably due to the re-growth of secondary forests.

In the Deramakot area, land-use changes were also dynamic and rapid (Fig. 4). Most obvious change was the steady increase of oil palm plantations. The development of oil palm plantations is massive but not patchy unlike the agricultural development in the Kinabalu area. Oil palm plantation expanded in area steadily after 1985 (Fig. 6). On the other hand, the area of pristine forests decreased successively from 1985 to 2002 (Figs. 4 and 6). The reduction of pristine forests from 1991 to 2002 occurred as the disappearance of the remnant forests which were interspersed among selectively logged production forests. Some areas that were recognized as bare or sparse vegetation interspersed in the logged-over forests in 1991 recovered to secondary forests, probably reflecting the protection from severe logging. A new land cover category “other agriculture” appeared in 2002; however, we could not confirm the actual land use of this category on the ground.

The frequency distribution of species richness (indexed by the number of families per 0.2ha) changed considerably from 1985 to 2002 because the above-ground biomass of the vegetation changed between the two years (Fig. 7). The mode of the richness occurred at 27-28 families per 0.2 ha in 1985. It became 23-24 families per 0.2 ha in 2002. The frequency of the mono-culture with reduced canopy diversity increased in 2002.

Discussions

Both areas (Kinabalu and Deramakot) demonstrated rapid and dynamic changes in land use. However, land-use type and spatial pattern (patchiness and extension) differed much between the areas.

On Kinabalu, small patches of agricultural lands occurred in the southeast and southwest slopes and surrounded the park boundaries in 1991. Most of these patches corresponded with the intensive agriculture employing terracing and with sporadic shifting cultivations. This contrasts with the occurrence of sparse shrubby vegetation in 1973, the time when traditional shifting cultivation was more widespread. Although our time resolution is coarse (i.e. 1973, 1991 and 2002 only in time series), the increase of intensive agriculture fields is likely to correspond with the development of the sealed highway that connects the Kinabalu area with Kota Kinabalu in 1982. The development of the highway improved the transportation ability of harvested temperate vegetables to the coastal town and contributed to the cash yield of local farmers. This might have triggered the expansion of intensive-agricultural land to the interior.

Although intensive, farmers frequently lay land fallow in their terrace system. During fallow time, pioneer trees such as *Trema orientalis* form a shrub land in three years (Ohtsuka 1999). Such fallow system and fast secondary succession in this area form a dynamic land-cover system of retrogressive and progressive successions. Cool upland climate is a prerequisite for the formation of such a system because temperate vegetable is grown only in this upland area. Secondly, small-scale tenant farming is still the major faming method here and hence the patchy land-uses occur throughout the area.

The existence of the protected area (Kinabalu Park) must have indirectly influenced the land use of the surrounding non-protected area. As the passage of the highway was completed and the number of climbers rapidly increased, more local people were engaged as the park staff or in the tourism industry, bringing capital to the local village for further development. Thus, the mountainous topography, cool climate and the passage of the highway provided the basis for both protection and development forming a dynamic land-use system in the Kinabalu area. In contrast to the Indonesian state of Kalimantan, where the area of protected areas declined by more than 56% (Curran et al. 2004), we did not find any trace of encroachment into the park.

In the lowland Deramakot area, selective logging and the development of large-scale oil-palm plantations are the driving force of the land-use changes. The original vegetation of the entire area of Deramakot must have been mixed dipterocarp lowland tropical rain forests. The pristine forests that have consistently retained high stocks from 1985 to 2002 are recognized in the west mountainous area and the southwest area as of 2002 by dark green color in Fig. 4. More than one half area of this region had been heavily affected by selective logging by 1985 as indicated by light green color in Fig. 4. By 1991, many stands of the selectively logged forests had obviously recovered in stock by 1991 as patches of dark green color occurred. Therefore, the Deramakot area again represents a dynamic landscape with selective logging and fast secondary successions.

The area of oil palm plantations increased rapidly between 1985 and 1991; the timing of the rapid expansion appears to correspond with either or both the downfall of logging industry or/and the increased commodity price of palm oil products. Between 1991 and 2002, the area of oil palm plantations was extended into the south towards Deramakot Forest Reserve. It is an interesting subject as to how the capital for the oil palm development has been collected, but it is beyond the scope of our paper. Because the Class II Commercial Forest Reserves (Deramakot is one of them) are the designated areas by law with boundaries, the oil palm plantations will not proceed to the south anymore.

The frequency diagram of the family numbers of canopy trees demonstrated impoverished diversity in 2002. Although our assumption is based on a simple regression between above-ground biomass and family number, the depicted pattern reflects a generally impoverished trend of diversity due to harvest and land conversions. The expansion of oil palm plantations will further lead to the increase of monoculture stands. Our estimate depicts a crude spatiotemporal pattern only and it is not known what are the biological consequences of reduced diversity.

Overall, our analysis demonstrated dynamic land-use changes in two tropical rain forest areas. Both areas simultaneously demonstrated progressive and retrogressive successions in a range of patch scales. The simultaneous occurrence of progressive and retrogressive changes was detected because we employed satellite data of relatively-high resolution (30x30 m) in a time series. This type of dynamism would not have been elucidated if we employ coarse-scale data (e.g. 1x1 km) that are conventionally used for processes at global scales.

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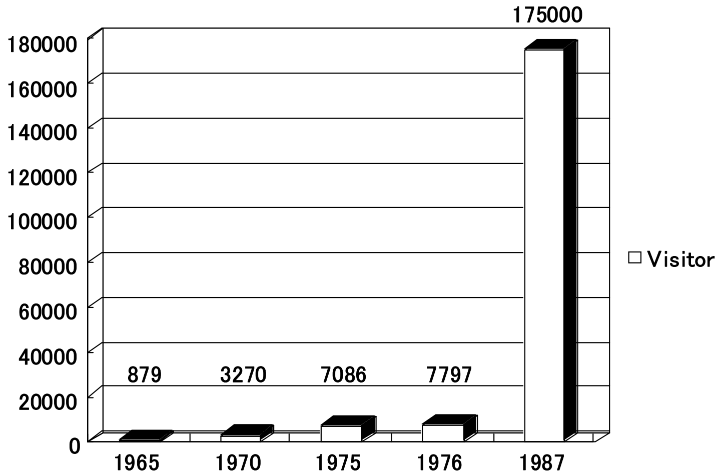

Fig. 1 The number of visitors to Kinabalu Park through time.
Data based on the unpublished statistical data of the Sabah Parks.

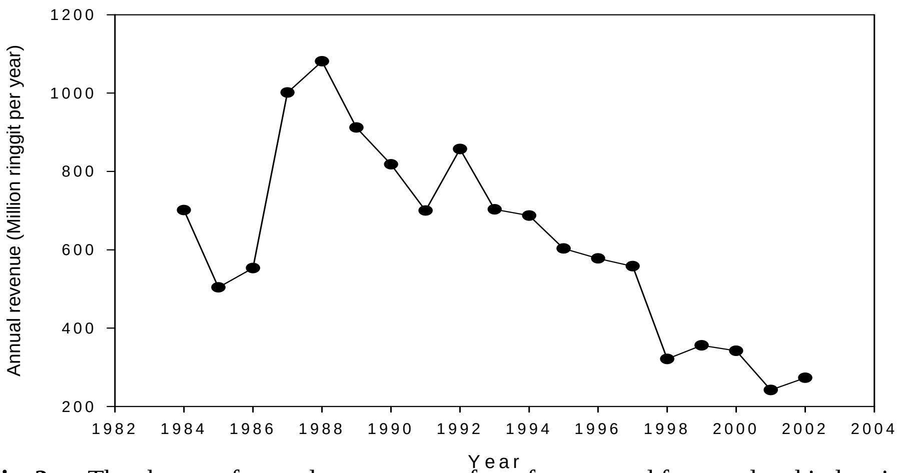

Fig. 2 The change of annual state revenue from forestry and forest-related industries in Sabah
Data after Sabah Forestry Department (2002).

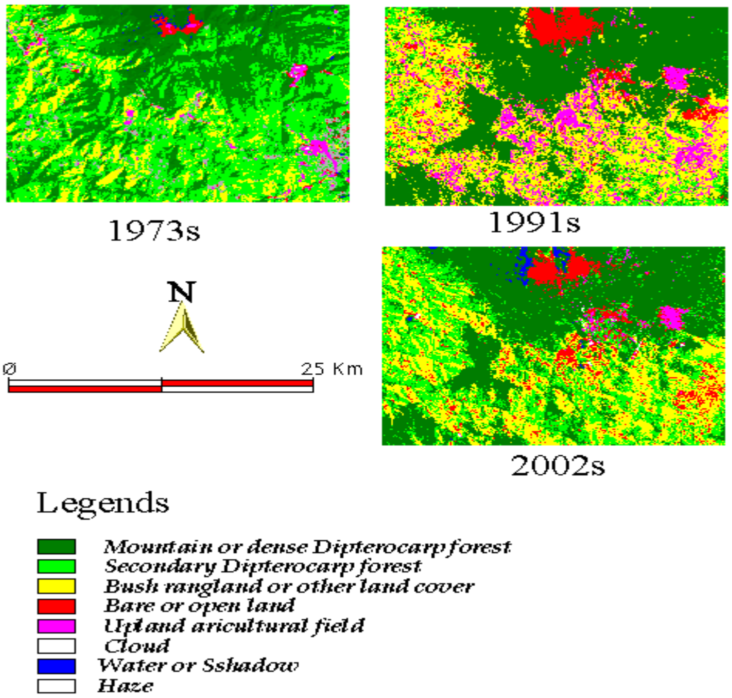

Fig. 3 Land cover changes in the Kinabalu area from 1973 to 2002.

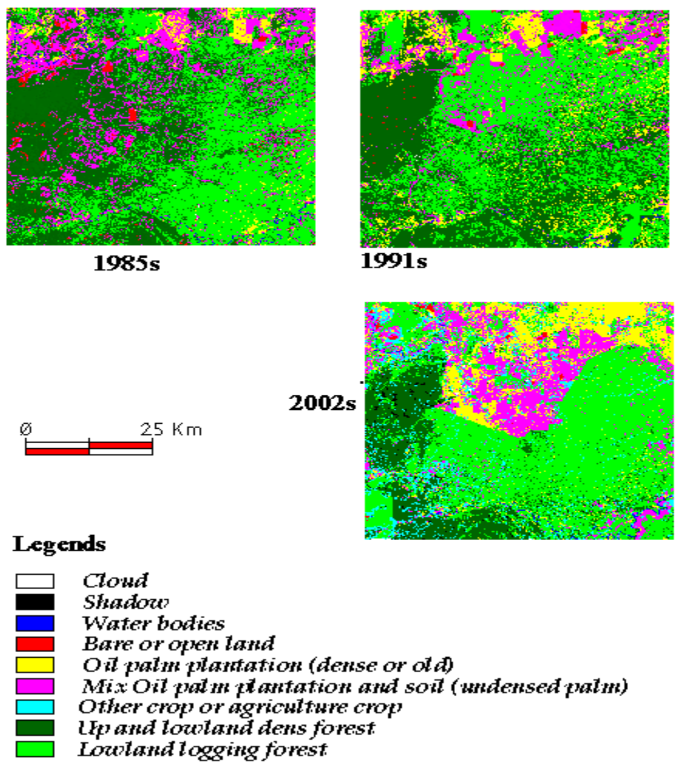

Fig. 4 Land cover change in the Deramakot area from 1985 to 2002.

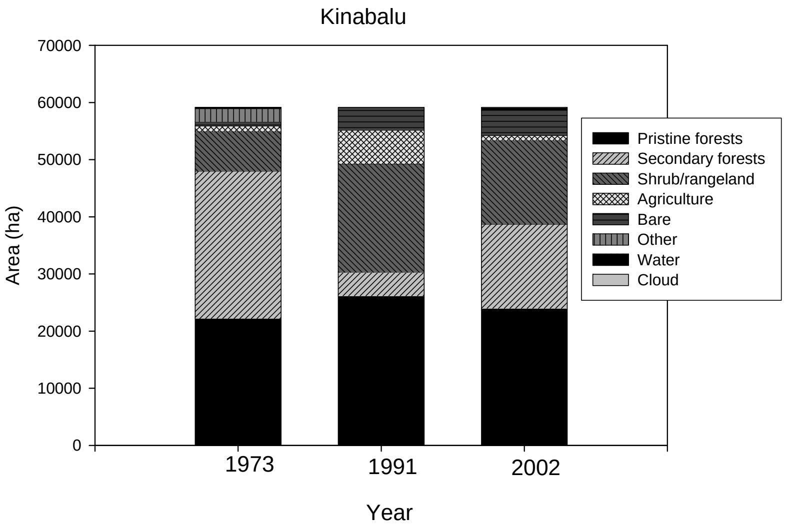

Fig. 5 The change in the relative area of land cover categories in the Kinabalu area from 1973 to 2002.

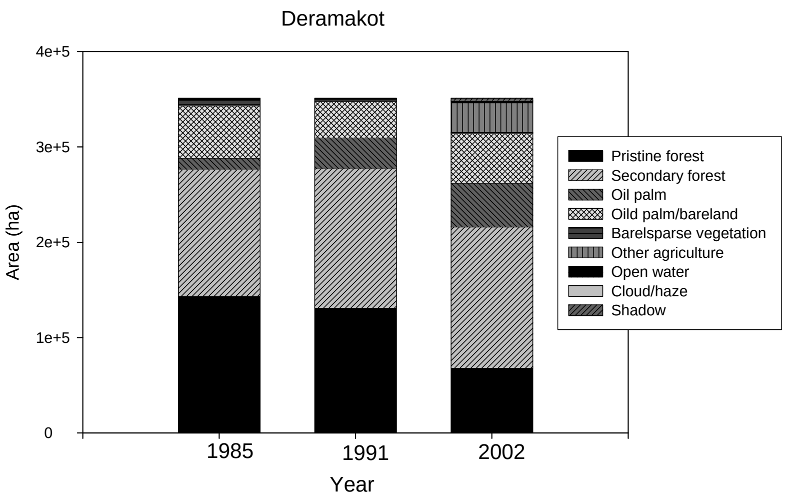

Fig. 6 The change in the relative area of land cover categories in the Deramakot area from 1985 to 2002.

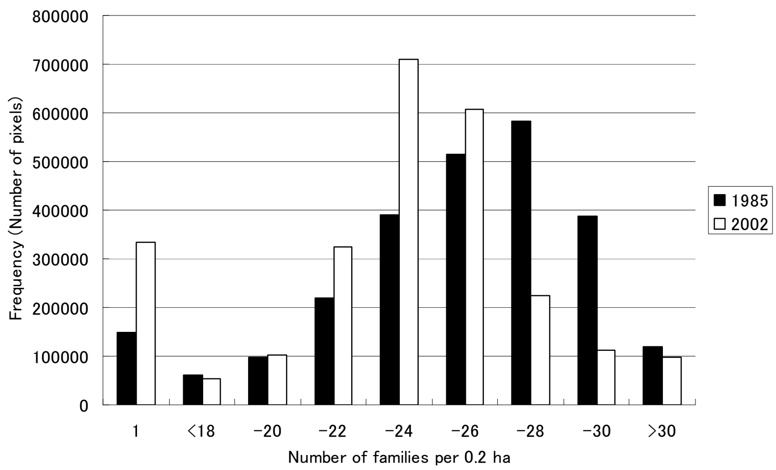

Fig. 7 The frequency distribution of the number of the families of canopy trees per 0.2 ha in year 1985 and 2002. Frequency indicates the number of pixels that fallen to each of diversity classes (the number of canopy trees per 0.2 ha).