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LAND USE AND FORESTED LANDSCAPE CHANGES AT SAKAERAT ENVIRONMENTAL RESEARCH STATION IN NAKHORN RATCHASIMA PROVINCE, THAILAND

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Abstract

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The Sakaerat Environmental Research Station (SERS) was established to promote long- term ecological research (LTER) and to demonstrate sustainable forest management and biodiversity conservation. In the past decade, the government puts a lot of efforts to rehabilitate degraded forest both inside and surrounding the SERS landscape in order to link fragmented forest patches. However, there is a lack of appropriate methods that allow the measurement of the effectiveness of reforestation. The objective of this paper is to quantify land use and landscape structure changes between 1990 and 2002. The study area encompasses the SERS and its buffer zone. Land use/land cover maps were visually interpreted into 9 classes using temporal Landsat-TM images. These classes include dry evergreen forest, mixed deciduous forest, dry dipterocarp forest, secondary growth, plantation, grassland, old clearing, agriculture & settlement, and water body. In addition, Geographic Information (GIS) and FRAGSTATS package were used to assess fragmentation indices. The results revealed that the annual increment rate of dry evergreen forest and dry dipterocarp forest were 0.51% and 0.97%, respectively. In addition, the surface area of forest plantation gained roughly three times or increased 193.23% during this period. On the other hand, agricultural and settlement area decreases 7.56% per year, most area was replaced by plantation and natural regeneration. The fragmentation indices indicated that the remaining dry evergreen forest was highly aggregated or low fragmentation. The number of patches decreased from 7 to 5 patches and mean patch size increased significantly. However, mixed deciduous forest and dry dipterocarp forest showed relative fragmentation. Mixed deciduous forest showed higher fragmentation. Mean patch size area was substantially decreased from 293 ha in 1990 to 123 ha in 2002 and the mean nearest neighbour distance increased approximately 400 m during this period.

Key words: land use, landscape structure, fragmentation, GIS, Sakaerat Biosphere Reserve

Introduction

Deforestation has been given much attention in land use and landscape changes because of the high rate of forest change and the ecological importance of forest ecosystem. Basically, the rate and spatial distribution of deforestation has been provided by the analysis of remote sensing images and Geographic Information Systems (GIS) (Tucker, Townshend, 2000; Brannstrom et al., 2008). The Royal Forest Department in Thailand has monitored forest cover using satellite images in the last four decades. The results revealed that in 1961 the forest cover was 27.36 million ha (53.3% of the country area) but approximately 12.97 million ha (25.2%) remained in 1998. The total loss of forest area during this 37 year period was 143.90 million ha and the average annual loss was approximately 400,000 ha or 2.0% (Trisurat, 2007). After year 2000, the Department of National Park, Wildlife and Plant Conservation (DNP) uses high resolution satellite images and new methods of measuring forest cover, the results indicates that approximately 33.1% and 32.3% of the country's total area remained under forest (inclusive of reforested area and secondary growth) in 2000 and 2003, respectively (DNP, 2003; 2006).

Deforestation causes a number of consequent effects on biological and physical environment such as habitat loss, habitat fragmentation, species extinction, deterioration of soil properties, drought, flooding, etc. Habitat fragmentation is the process of dissecting large and contiguous areas of similar native vegetation types into smaller unites separated by different vegetation types and/or areas of intensive human activity (Saunders et al., 1991). Fragmentation occurs in conjunction with loss of area and includes changes in composition, shape and configuration of resulting patches (Rutledge, 2003). A number of landscape indices have been developed to measure the effects of fragmentation. Increased fragmentation often results in the subdivision of the natural environment into isolated patches of different size and shapes (Turner, Corlett, 1996). The effects of fragmentation include decreased species richness, increased habitat edges, thus favoring species adapted to edge habitats but preventing species living in core areas (Yahner, 1988), diminished species distribution and gene flow (Raabova et al., 2007). Another consequence of habitat fragmentation is alteration of physical fluxes of radiation, wind and water across the landscape (Saunders et al., 1991). Sahunalu et al. (1993) investigated the effects of reforestation, abandoned area and natural forests on biological and physical environments in the SERS. The studies revealed that although reforestation was limited to a single tree species, so that it had lower species diversity than abandoned area and natural forests. However, relative humidity, air and soil temperature and relative light intensity were kept at comparable level with dry evergreen forest in wet and dry seasons. In addition, storage of organic matter increased with stand age of plantation and would be comparable to natural forests in the future.

In the past decade, the government and private sector put a lot of efforts to rehabilitate degraded forest to cope with the high rate of deforestation and enhance biodiversity conservation, especially in protected areas. For instance, the PPT Public Company Limited of Thailand (PPT) was extensively involved in the "*Reforestation Campaign*" in Commemoration of the Royal Golden Jubilee covering 8,000 km^2 in protected areas and head watersheds nationwide during 1994–2006 (RFD, 2005). However, there is a lack of appropriate methods to measure the effectiveness of forest plantation and previous conservation efforts implemented by the SERS. The objective of this paper is to estimate the rates of land use change and measure the levels of forest fragmentation that have occurred in the SERS and adjacent areas between 1990 and 2002.

Material and methods

Study sites

The study area covers the Sakaerat Environmental Research Station (SERS) and its surrounding landscape. The total area is approximately 420 km^2. The SERS is situated in Nakhon Ratchasima Province in northeast Thailand between latitude 14°25'–14°33' N and longitude 100°48'–100°56' E (Fig. 1). To the north of the SERS is reserve forest and to the south is Thaplan National Park. The SERS is one of five biosphere reserve in the Thailand and aims are to promote long term ecological research, in addition to demonstrate sustainable forest management and biodiversity conservation according to Man and Biosphere Reserve (MAB) concept. It is also listed as one of two international long-term ecological research (ILTER) sites in Thailand. The total area of the research station is approximately 81 km^2 (Trisurat, 2006). It was formerly administered by the National Research Council of Thailand, but now is under the Thailand Science Research Institute. According to Jamroenprucksa et al. (1999) more than 150 research topics related to forest ecology, watershed and environmental aspects had been conducted since the establishment of the SERS in 1967.

The SERS is located in the Korat plateau and its altitude ranges from 250–762 m above mean sea level. Approximately 35 percent of the research station is situated in altitude between 300–400 m (Sanguanpong, 1993). The SERS is surrounded by extensive agricultural area and human settlement. According to long-term monitoring, it was found that the natural forest had been diminished due to encroachment and illegal logging (Maninan, 1976; Tangkitjavisuth, 1979). There were 15 villages situated inside the SERS but all settlements were relocated to the land reform plot in 1983 (Khernark, 1991). In 1982, the Royal Forest Department started to rehabilitate degraded forest and abandoned settlements inside the SERS (Sahunalu et al., 1993), thus, forest cover gained more area since then. The assessment in 1985 indicated that the percentages of forest, agriculture, settlement, and water body in the SERS were 63.15%, 36.45%, 0.26% and 0.13% respectively (Ongsomwang, 1986). Dominant forest types in the SERS landscape are dry evergreen forest, dry dipterocarp forest and mixed deciduous forest. However, a lot of reforestation efforts have been implemented both inside and outside the SERS since 1994 under the Royal Golden Jubilee program (RFD, 2005). Man-made forest fire is common in dry dipterocarp forest and mixed deciduous forest in dry season.

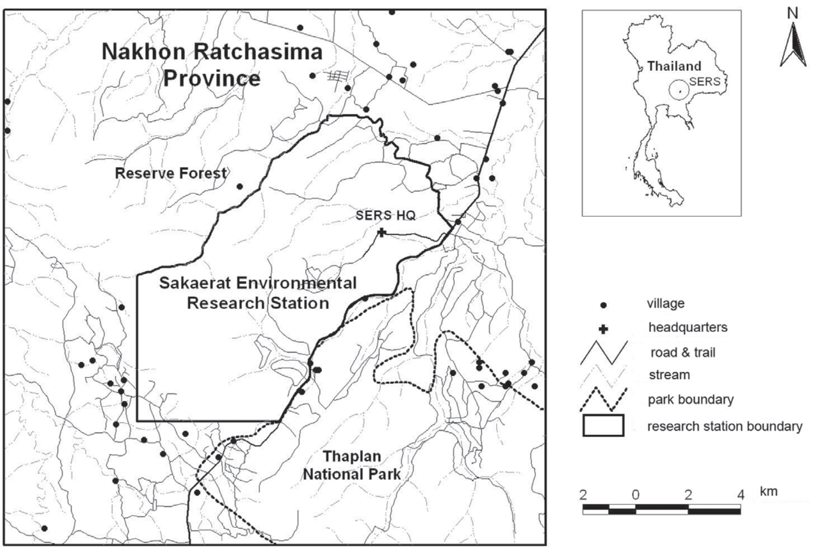

Fig. 1. Location of Sakerat Environmental Research Station.

Image interpretation

The cloud-free multi-temporal Landsat imageries corresponding to path 128 and row 50 dated January 8, 1990 (Landsat-5 TM) and February 18, 2002 (Landsat-7 ETM+) were acquired from the Geo-informatics and Space Technology Development Agency. Then a subscene of image covering the study area was extracted using ERDAS Imagine software. The multi-spectral bands used in this study were Band 4 (Red), Band 5 (Green) and Band 7 (blue) with a resolution of 25 m. The raw images were rectified to the Universal Transverse Mercator (UTM) coordinate system of WGS zone 47N corresponding to up-to-date topographic maps. The visual interpretation technique was adopted to classify false color composite images into 9 land-use/land-cover classes, including 1) dry evergreen forest, 2) mixed deciduous forest, 3) dry dipterocarp forest, 4) plantation, 5) secondary growth, 6) agriculture and settlement area, 7) grassland, 8) old clearing and 9) water body. In addition, key image features of vegetation types were developed to assist visual interpretation. A total of 80 sample points were selected using stratified random method to evaluate the classification accuracy. It is noted that the original thematic land use/land cover map in vector format was later converted to raster format of 100-m resolution for further analyses.

Analysis of land-use change

After deriving land-use/land-cover maps in years 1990 and 2002, both maps were overlaid and change detection over this 12 years period was determined. In addition, the rate of deforestation was calculated with the formula proposed by Watcharakitti (1987) as follows:

$$r = [1-(A_t/A_0)^{1/t}] * 100, \qquad \text{Ex. (1)}$$

where r = annual rate of deforestation
A_0 = land use coverage at beginning year
A_t = land use coverage at ending year
t = duration in years.

Calculation of fragmentation indices

The GIS rater files were exported to ASCII format which were used as the basis for the fragmentation. The FRAGSTATS 3.0 software was used to assess landscape structure and fragmentation indices (McGarigal, Marks, 1995). The following indices were calculated to imply forest fragmentation that may have a direct impact on biodiversity:

Area indices. These indices include (1) total area (TA): the total area that the land use class occupies in the study area. (2) number of patches (NP): the number of patches of a particular land use class. (3) mean patch size (MPZ): average area of a patch of a particular class. (4) largest patch index (LPI): the percentage of landscape area occupied by the largest patch of a particular land use class.

Edge indices. Only the total edge length index (TE) was chosen for calculation. The TE is defined as the total length of all edge segments involving the corresponding land use class. The edge represents an outer boundary that is environmentally and biologically different from the core area (Ochoa-Gaona, 2001).

Shape index. The mean shape index (MSI) attempts to quantify patch complexity, which can be important for different ecological processes (Forman, 1995). It is the ratio of perimeter to area adjusted by contrast to account for a particular patch shape (circular or square). The MSI is ≥ 1, without upper limit. The index of 1 represents a regular shape.

Core area indices. These indices include: (1) mean core area (MCA): the area within a fragment located beyond a specified edge distance (1 km for this study); (2) total core area (TCA): the sum of the total surface of all areas of a particular land use class (in hectares). A higher of core areas indicates less fragmentation.

Neighbour index. Only mean nearest neighbour distance index (MNN) was selected for calculation. The MNN is based on the nearest edge-to-edge distance between the nearest patch of a particular land use class. This index is used to measure patch isolation.

Results and discussion

Land use/land cover changes

The classification accuracy of land use/land cover 2002 map compared to field visit was 84%. The accuracy for water was 100% because this class was clearly delineated from other classes. The accuracy for mixed deciduous forest was the lowest (72%) among 9 classes. This problem may be resulted to the fact that mixed deciduous forest is a mosaic pattern and its spectral signature is in between dry evergreen forest and dry dipterocarp forest (Ongsomwang, 1986).

Land use/land cover maps in 1990 and 2002 were shown in Figs 2 and 3, respectively while their areas were presented in Table 1. The results revealed that dry evergreen forest, dry dipterocarp forest, plantation, secondary growth and water gained more areas during the 12-year period. The annual increment rates of these classes were 0.51%, 0.97%, 9.37%, 2.18%, and 0.63%, respectively. On the other hand, parts of mixed deciduous forest, agriculture and settlement area and old clearing classes were converted to other land use classes (Table 2).

Forest covers were found mainly in the SERS and in mountainous areas. Among three forest types, dry evergreen forest gained more areas and constituted the highest proportion and followed by dry dipterocarp forest for both periods. The total area of mixed deciduous forest diminished slightly. Fig. 3 showed that one large patch to the southwest of SERS was degraded but a few patches increased in the north. The increment rate of plantation in 12 years was highest (193.23%) due to continuing plantation since 1982 and especially huge reforestation programs under the Royal Golden Jubilee (RFD, 2005). Its total area increased from approximately 1,282 ha to 2,479 ha. Besides plantation for natural restoration by the SERS and PTT, small-scale commercial plantation, mainly eucalyptus, by local residents in marginal land of buffer zone to earn more income is also common. It is expected that more areas will be planted in the future due to high demand of raw material for pulp and paper.

Agriculture and settlement decreased from 40.59% in 1990 and to 37.52% in 2002. However, this land use class constituted the highest percentage of the SERS landscape in both periods. An area of 318 ha was reforested and the rests were left over for natural succession (Table 2). Old clearing lost approximately 2,790 ha (11.09% annually). Basically, it was substituted by plantation, and regenerated to dry dipterocap forest, dry evergreen forest and mixed deciduous forest. The areas of conversion were approximately 1,683 ha, 911 ha, 333 ha and 312 ha, respectively (Table 2). It is noted that the coverage of mixed deciduous forest, grassland and water body were almost stable and their change rates were less than 1% per year (Table 1).

Table 1. Land use/land cover classes inside and outside the SERS landscape and their coverage (ha).

Land use classes	1990		2002		Total change	Change rate (%)	
	ha	%	ha	%	(ha)	12 yrs	Yearly
Dry evergreen forest	11,574.03	27.68	12,305.03	29.43	731.00	6.32	0.51
Mixed deciduous forest	2,641.48	6.32	2,586.41	6.19	-55.06	-2.08	-0.18
Dry dipterocarp forest	3,668.83	8.77	4,118.58	9.85	449.75	12.26	0.97
Plantation	1,282.96	3.07	3,761.97	9.00	2,479.01	193.23	9.37
Secondary growth	1,535.64	3.67	1,989.83	4.76	454.18	29.58	2.18
Agriculture & settlement	16,972.65	40.59	15,689.01	37.52	-1,283.64	-7.56	-0.65
Grassland	88.28	0.21	74.78	0.18	-13.50	-15.29	-1.37
Old clearing	3,690.14	8.82	900.12	2.15	-2,790.02	-75.61	-11.09
Water	360.80	0.86	389.08	0.93	28.28	7.84	0.63
Total	41,814.80	100.00	41,814.80	100.00	0.00	-	-

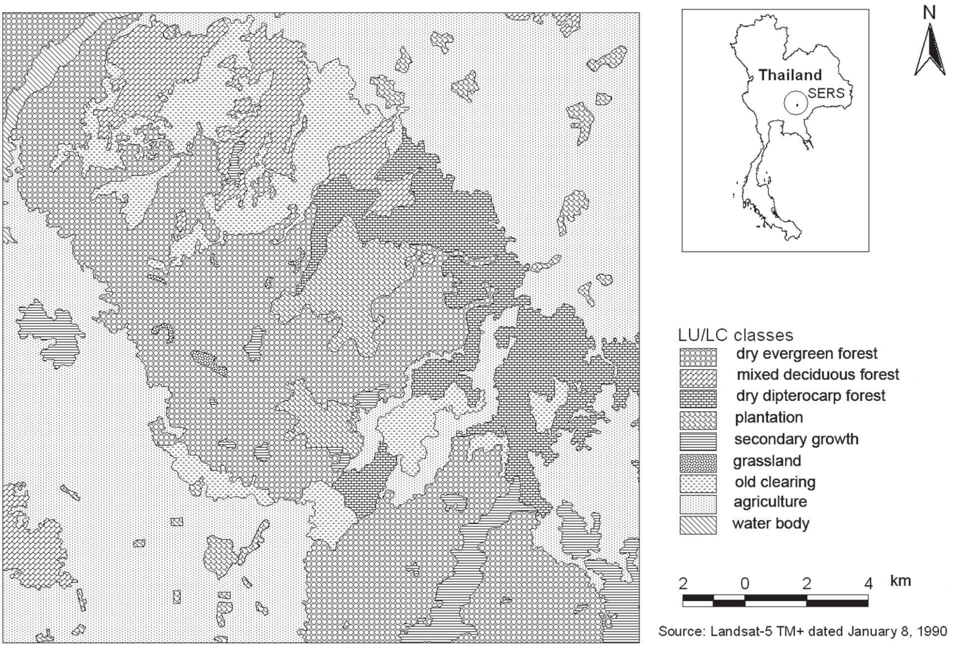

Fig. 2. Land use/land cover map of Sakaerat landscape in 1990.

Table 2. Land use/land cover transition matrix between years 1990–2002 (area in ha).

Year 1990	Year 2002									
	DEF	MDF	DDF	PLT	SEC	AGR	GRS	OLD	WAT	Total
DEF	11,252.07	66.93	0.00	230.84	17.10	0.00	5.44	1.65	0.00	11,574.03
MDF	190.72	1,999.45	7.83	3.70	439.77	0.00	0.00	0.00	0.00	2,641.48
DDF	51.80	111.94	3,191.08	266.40	44.04	0.00	0.00	3.56	0.00	3,668.83
PLT	102.66	19.06	0.00	1,149.07	3.89	0.00	0.00	8.28	0.00	1,282.96
SEC	319.33	0.00	0.00	105.13	1,053.45	16.65	41.08	0.00	0.00	1,535.64
AGR	0.00	76.20	7.80	318.31	278.77	15,651.27	0.00	612.03	28.28	16,972.65
GRS	54.95	0.00	0.00	5.07	0.00	0.00	28.25	0.00	0.00	88.28
OLD	333.50	312.84	911.86	1,683.45	152.81	21.10	0.00	274.59	0.00	3,690.14
WAT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	360.80	360.80
Total	12,305.03	2,586.41	4,118.58	3,761.97	1,989.83	15,689.01	74.78	900.12	389.08	41,814.80

Notes: DEF – dry evergreen forest; MDF – mixed deciduous forest; DDF – dry dipterocarp forest; PLT – plantation; SEC – secondary growth; AGR – agriculture and settlement; GRS – grassland; OLD – old clearing; WAT – water body

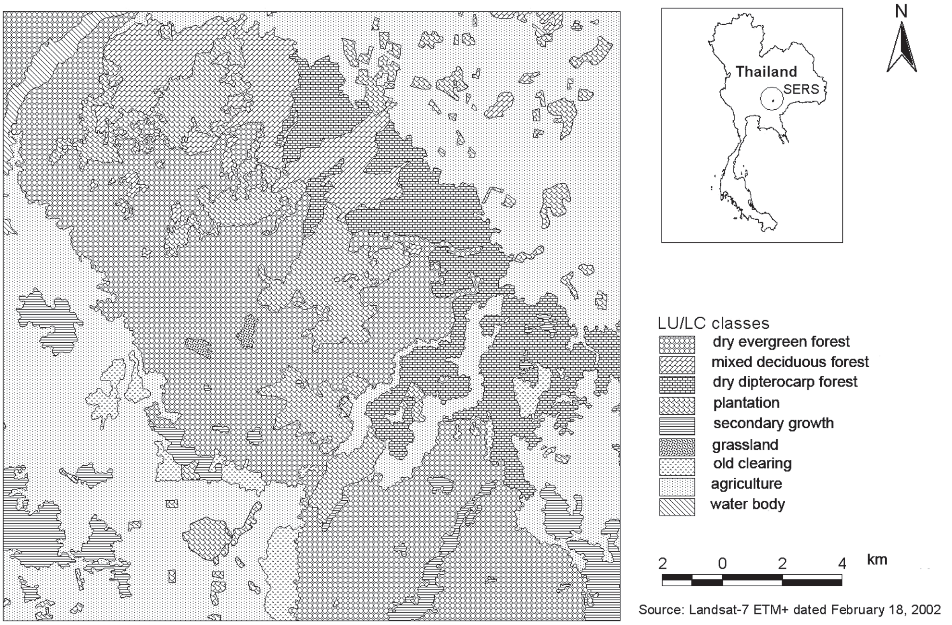

Fig. 3. Land use/land cover map of Sakaerat landscape in 2002.

Forest fragmentation

Number of patches and mean patch size

The total number of patches dry evergreen forest decreased from 7 patches to 5 patches (Table 3). On the other hand, mixed deciduous forest and dry dipterocarp forest gained more patches. It is noted that the number of mixed deciduous forest patches increased significantly from 9 to 21 patches during 12-year period. This index is relevant to mean patch size index which revealed that the mean patch size of dry evergreen forest and dry dipterocarp forest increased, while those of the mixed deciduous forest decreased from 239 ha in 1990 to 38 ha in 2002 or reduced approximately 6 times. In 1990, the largest patch of dry evergreen forest occupied 18.12% (11,574 ha) of this vegetation type and increased to 28.25% (12,305 ha) in 2002. Even though, the total area of mixed deciduous forest was relatively stable but this class was occupied by approximately 2 largest patches in 1990 and 5 largest patches in 2002. These area indices implied that dry evergreen forest and dry dipterocarp forest were more aggregated but mixed deciduous forest was severely fragmented. This is due to the fact that it is found in low altitude and fertilized soil, as well as contains economic trees. Thus, it becomes main target for encroachment and illegal logging (Maninan et al., 1976).

Edge and shape indices

The total edge length of dry evergreen forest and mixed deciduous forest slightly increased between 1990 and 2002. The edge length of dry dipterocarp forest gained approximately 36 km or 22.64%. Meanwhile, the mean shape index of dry evergreen forest and dry dipterocarp forest was relatively the same during 12-year period, indicating that patches of both forest types remained irregular shape (Forman, 1995; Rutledge, 2003). On the other hand, the mean shape index of mixed deciduous forest was changed substantially. This result represented a more regular shape (Table 3). This may be the fact that mixed deciduous had been disturbed by human activities such as encroachment, so that its shape was changing toward a man-made shape (McGarigal, Marks, 1995).

T a b l e 3. Landscape indices of land use/land cover in 1990 and 2002.

Landscape indices	1990			2002		
	DEF	MDF	DDF	DEF	MDF	DDF
Total area (TA) (ha)	11,574.03	2,641.48	3,668.83	12,305.03	2,586.41	4,118.58
Number of patches (NP)	7.00	9.00	7.00	5.00	21.00	9.00
Mean patch size (MNZ) (ha)	1,653.84	293.39	524.44	2,461.23	38.93	1,429.60
Largest patch index (LPI)	18.12	2.20	8.17	28.25	5.31	8.14
Total edge length (TE) (km)	302.34	136.26	159.96	326.37	147.81	195.90
Mean shape index (MSI)	2.58	2.27	2.06	2.93	1.74	2.11
Mean core area (MCA) (ha)	1,555.86	260.10	474.84	2,313.88	108.25	410.57
Total core area (TCA) (ha)	10,890.99	2,340.90	3,323.88	11,569.41	2,273.22	3,695.13
Mean nearest neighbour (MNN) (m)	295.57	1,680.00	532.45	159.14	2,105.44	723.24

Core area indices

The total core area of three forest types was not significantly different between 1990 and 2002. In 1990, the total core area of dry evergreen forest was 11,890 ha and increased to 11,569 ha in 2002, where the dry dipterocarp forest core area increased from 3,323 ha to 3,695 ha. On the other hand, the total core area diminished only 67 ha for mixed deciduous forest (Table 3). However, if the mean core area index was taken into account it showed better view how much area the fragments have without the influence of borders. Mean core area of dry evergreen forest showed significantly increased but that of mixed deciduous forest substantially decreased in 12 years. The mean core area of dry dipterocarp forest showed a slightly decrease (Table 3). These two indices implied that the interior species or understory species and/or shade tolerant species of dry evergreen forest (e.g. *Hopea ferra, H. odorata, Dipterocarpus alatus*) were more favorable (Kanzuki, Dhanmanonda, 1995) than those of mixed deciduous forest.

Neighbour index

The mean nearest neighbour distance between patches increased for mixed deciduous forest and dry dipterocarp forest, and decreased for dry evergreen forest (Table 3). This implies that the first two forest types were more isolated than dry evergreen forest (Rutledge, 2003). The average nearest distance between mixed deciduous forest patches was approximately 2.1 km, which increased around 400 m during 12-year period. This was due to the fact that most reforestations were done in degraded dry evergreen forest, so that the fragmented patches had been connected after 12 years. The increasing distance between forest patches was corresponding the increasing the number of patches and decreasing mean patch size as mentioned in previous section. This effect may diminish species distribution and gene flow inhabiting in this vegetation type (Raabova et al., 2007).

Conclusion

The results of this study indicated that the coverage of dry evergreen forest, dry dipterocarp forest, plantation and secondary growth in the SERS landscape increased during 1990–2002. They were resulted from concrete protection by the SERS staff, natural regeneration and enrichment plantation in disturbed forest. Plantation area increased significantly or 193.23% in 12-year period. Reforestation was mainly done in old clearing, degraded forest lands, and marginal agricultural area. It is expected that plantation will increase in farmland due to high demand of raw material, so that farmers will substitute upland crops with eucalyptus. In addition, parts of degraded forests were regenerated to natural forest and their image signature showed as forest areas.

This study also employed FRAGSTATS package to measure landscape indices to determine forest fragmentation between 1990 and 2002. The results of area indices showed that there were less patches of dry evergreen forest but the average mean patch size and the largest patch index increased indicating more aggregation. This is due to the fact that previous enrichment program was mainly conducted in degraded dry evergreen forest. On the other hand, the significant increase of mixed deciduous forest patches and decrease of mean patch size indicated severe fragmentation in the last decade. This phenomenon was resulted from encroachment and illegal logging of economic trees. Besides, the core area indices, total core area and mean core area, also supported previous conclusion. Mean core area of mixed deciduous forest decreased more than 2 folds and mean nearest neighbour distance increased approximately 400 m in 12-year period. The overall results implied that biological and physical environment features in mixed deciduous forest are significantly affected in the last decade. It is recommended that concrete efforts to prevent further encroachment and fragmentation in this vegetation type are essential. In addition, maintaining the ecological linkage between national reserve forest, SERS and Thaplan National Park is also important in order to facilitate species movement in this forest complex. These research findings show the benefits of remotely sensed data, GIS and FRAGSTATS for landscape analysis which significantly enhance to effective management of the SERS for sustainable forest management and biodiversity conservation. Further research should focus on the prediction of land use changes and consequent effects of forest fragmentation on key species distribution found in this area e.g. bear, serow and sambar.

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