INTEGRATION OF REMOTELY SENSED DATA AND FOREST LANDSCAPE PATTERN ANALYSIS IN SAKAERAT BIOSPHERE RESERVE

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Abstract

This research aims to investigate forest landscape pattern changes in the Sakaerat Biosphere Reserve (SBR), and to classify and assess changes of multi-temporal forest landscape types, and analyze patterns using landscape metrics from 1980-2010. Landscape classification and assessment of 6 landscape types showed the natural forest landscape was the major landscape type and occupied an area of 46.23% to 44.40%. Landscape changes had occurred mostly in disturbed forest, decreasing from 10.22% to 3.99%, while forest plantations and urban and built-up landscapes increased from 1.61% to 3.71% and 1.36% to 2.98%, respectively. More importantly, the number of patches, mean proximity, and interspersion juxtaposition indices assisted in determining the forest landscape pattern changes. The trends of change in the indices' values of forest landscape types were subsequently used in relation to gains and losses in the context of forest landscape ecology to set up the priority levels of recommendations on a forest restoration and management plan. Therefore, this evaluation showed the priority levels of all forest landscape types in each of the management zones. As a result, recommendations in the core zones of natural forest, disturbed forest, and forest plantation landscapes were strictly limited to minimum restoration and management, but not limited to natural regeneration and succession; while in the buffer and transition zones, forest rehabilitation and reforestation, including regular patrolling and forest fire control were recommended. In conclusion the integration of remotely sensed data and landscape metrics can beapplied to quantify landscape pattern characteristics that directly relate to forest landscape ecology and to obtain important ecological landscape information for a forest resources restoration and management plan.

Keywords: **Sakaerat Biosphere Reserve, landscape metrics, landscape ecology, forest ecology, forest restoration and management plan**

Introduction

Forest habitat is prominent in some regions of Thailand, from the highland mountainous region of the north to the south. Changes in forest areas are apparently due to natural and human disturbances that alter the arrangement of forest patterns across the landscape and

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this, in turn, influences many species and ecosystem processes. The relationship between the ecological process and landscape pattern analysis is a major focus of landscape ecology. Landscape ecology is a new area of study which aims to understand the patterns of interactions and connections of biological and cultural communities with the effects of both natural and human disturbances across the landscape (Turner *et al*., 2001; Turner, 2010).

In recent years, international political momentum has led to an increased dedication to the conservation of biodiversity and sustainable forest development (Lindenmayar, 2009; Gesellschaft für Internationale Zusammenarbeit GmbH, 2012). Thus, forest management requires the collection of new kinds of forest landscape information to complement traditional forest databases and field observations. Remote sensingand geographical information systems (GIS) have emerged as key geospatial tools to satisfy the increasing information needs of resource managers (Franklin, 2001; Wulder *et al.,* 2004; Horning *et al.* 2010). Concurrently, landscape pattern analysis approaches are also widely used to obtainvaluable information in the same fields of study (Farina, 1998; Turner *et al*., 2001; Burel and Baudry, 2003; Peano *et. al*, 2011).

Spatial patterns in forest landscapes have long been of interest to ecologists, foresters, and managers because they are important for detecting and monitoring forest landscape patterns and changes and also for introducing several aspects that are important for planning (Mladenoff and Baker, 1999). Additionally, the technological and conceptual advances in remote sensing have shaped the way landscape ecologists conduct research. It is likely that the discipline of remote sensing will continue to use this important influence (Wulder and Franklin, 2007). The relationship between remote sensing and pattern analysis using landscape metrics is emphasized in an attempt not only to provide the context for how pattern analysis is currently conducted but also to explore the ways in which pattern analysis might develop in the future. Quantitative methods that link spatial patterns and ecological processes at broad spatial and temporal scales are needed both in basic ecological research and in applied environmental problems (Waring and Running, 1998; Horning *et al.* 2010).

Mapping and quantifying the forest landscape in the Sakaerat Biosphere Reserve (SBR) has relied on a variety of methods, primarily based on sample plots by researchers and ecologists. Many research projects for various forest and ecological aspects have been conducted in this area (Sutthivanich, 1989; Dhanmanonda, 1992; Sahunalu *et al.* 1993). However, few researchers have applied the technique of remotely sensed data and landscape pattern analysis. Basically, forest classification, monitoring, change detection, and other land use and land cover (LULC) studies focused on their extents (Ongsomwang, 1986). Nevertheless, Trisurat (2010), and Trisurat and Duengkae (2011) implemented those integration methods successfully in a part of the SBR. To date, new developments in the integration of GIS, advances in the high resolution of remote sensing, and spatial pattern analysis have been comprehended to be effective approaches for forest landscape mapping, updating spatial databases, the delineation of protection zones and habitat corridors, and forest landscape management planning worldwide (Mladenoff and Host, 1994; Mladenoff *et al*., 1994; Mladenoff and Baker, 1999; Wulder and Franklin, 2007).

Forest landscape restoration and management are increasingly recognized worldwide as components of a sustainable forest management plan. As discussed by Hobbs and Norton (1996), restoration is fundamentally conducted to improve or sustain an ecosystem's goods and services, which may include aesthetic and societal preferences. Noss (1999) provided more specific recommendations for managing habitat patterns and connectivity in forestry activities. Management means taking care of, improving, and enhancing natural communities already on that site; besides, management can also be considered as a form of restoration. Meanwhile, restoration represents a more intensive effort and is a process of returning a degraded natural community to its original structure and species composition (Kenk and Guehne, 2001; Nyland, 2003; Spiecker *et al*., 2004).

More recently, research has suggested that landscape pattern indices are effective evaluation tools for landscape planning and design. Botequilha Leitao and Ahern (2002) suggested recommendations for the use of landscape pattern indices in sustainable landscape planning. Similarly, Corry and Nassauer (2005) also showed that landscape patterns have potentially attractive attributes for landscape planners and designers. Forest restoration concepts and frameworks have also been exhaustively discussed by Stanturf *et al*. (2001); Van Diggelen *et al*. (2001), Stanturf and Madsen (2002), and Nagendra and Southworth (2010).

Research Objectives

This research aims to investigate and discuss the changes observed in the SBR forest landscape over time by integrating landscape pattern indices in the analysis. The specific objectives are: (1) to monitor temporal landscape changes during the period 1980-2010, and (2) to assess and evaluate forest landscape pattern changes using landscape pattern metrics (indices) with a gain and loss basis for the implementation of the forest restoration and management plan recommendations.

Materials and Methods

Study Area

The Sakaerat Environmental Research Station was established by the Thai government on September 19, 1967 as a facility for ecological and environmental research and was extended into the SBR in 1977with the support of the United Nations Educational, Scientific, and Cultural Organization's (UNESCO) Man and the Biosphere programme. The SBR is the first leading biodiversity hotspot in Thailand and covers an area of 1632.48 Sq.km. It is one of 4 biosphere reserve areas which have been created and established to sustain a balance between the goals of conserving biological diversity, promoting economic development, and maintaining cultural values (Thailand Institute of Scientific and Technological Research, 2009). It lies in Wang Nam Khieo and Pak Thong Chai districts, Nakhon Ratchasima province, Thailand (Figure 1).

The SBR has 3 management zones, including core, buffer, and transition zone sapproved by the UNESCO's Man and Biosphere Programme. Descriptions of each management zone are as follows:

(1) Core zone. The area comprises securely protected sites for conserving biological diversity, monitoring minimally disturbed ecosystems, and undertaking non-destructive research and other low-impact uses.

(2) Buffer zone. The area serves as a shield to protect the core zone and is used for environmental education, recreation, ecotourism, and research.

(3) Transition zone. The area that contains human settlements and activities and where local communities, cultural groups, economic interests, management agencies, scientists, and non-governmental organizations work together to manage and sustainably develop the area's resources.

The zone concept is designed to be flexible and may be implemented in a variety of ways in order to address local needs and conditions (Natural Resources Defense Council, 2010).

Dataset and Equipment

Remotely sensed and GIS datasets were collected for this study while basic equipment such as hardware and software were employed for data collection and data analysis (Table 1).

Research Methods

The research methods consist of 4 components: (1) visual interpretation of

LULC and landscape types classification; (2) analysis and assessment of forest landscape patterns using landscape metrics; (3) evaluation ona priority level setting for a forest landscape restoration and management plan; and (4) development of recommendations for a forest landscape restoration and management plan (Figure 2). Details of each component are described in the following sections.

Visual Interpretation of LULC and Landscape Types Classification

Based on multi-temporal remotely sensed datasets in 1980, 2002, and 2010, LULC types,which included (1) paddy field, (2) field crop, (3) orchard/perennial tree, (4) natural forest, (5) disturbed forest, (6) forest plantation, (7) urban/ and built up area, (8) water body, and (9) miscellaneous area, were firstly visually interpreted and digitized on screen at the scale of 1:10000. An accuracy assessment for LULC of the 2010 data had been conducted in April 2012 using 298 sample points based on the stratified random sampling scheme (Congalton, 1991; Congalton and Green, 2009). The overall accuracy was 87.92% and the kappa (with a hat) coefficient of agreement was 0.84. The kappa (with a hat) represents a strong agreement suggested by Landis and Koch (1977). The interpreted LULC types were further reclassified and

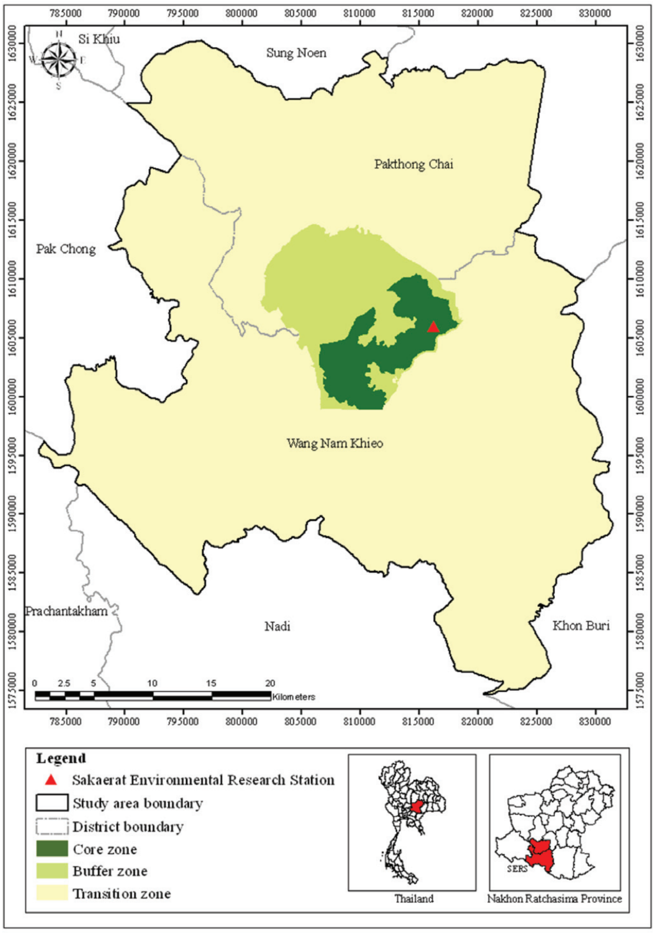


Figure 1. Study area location and boundary

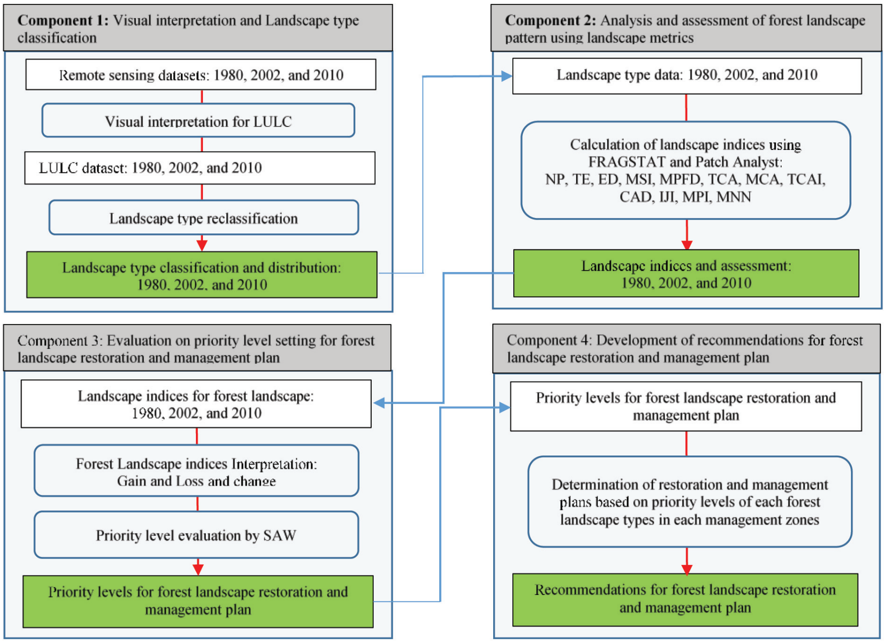


Figure 2. Framework of research methodology

Table 1. Dataset and equipment

Dataset and equipment	Date	Resolution/Scale	Source
1. Remote sensing datasets			
1.1 B&W aerial photographs	1980	1:40000	RTSD
1.2 Digital color orthophoto data	2002	1:4000	MOAC
1.3 THEOS pansharpened data	2010	2 × 2 m	GISTDA
2. GIS datasets			
2.1 Topographic map	1999	1:50000	RTSD
2.2 Land use data	2007	1:25000	LDD
3. Equipment			
3.1 Software			
3.1.1 ERDAS Imagine Version 8.7			
3.1.2 ESRI ArcGIS Version 9.0			Remote sensing Lab, SUT
3.1.3 Patch Analyst Version 5.0			
3.1.4 FRAGSTAT Version 3.3			
3.2 Hardware			
3.2.1 GPS			Remote sensing Lab, SUT and Personal
3.2.2 Computer and Notebook			

Note: RTSD = Royal Thai Survey Department, MOAC = Ministry of Agriculture and Cooperatives, GISTDA = Geo-Informatics and Space Technology Development Agency(Public Organization),LDD = Land Development Department, SUT =Suranaree University of Technology grouped into 6 landscape types including (1) agricultural landscape, (2) natural forest landscape, (3) disturbedforest landscape, (4) forest plantation landscape, (5) urban and built-up landscape, and (6) miscellaneous landscape including water body. The distribution of the SBR landscape types was identified.

Analysis and Assessment of Forest Landscape Patterns Using Landscape Metrics

Forest landscapes patterns were analyzed using 12 indices from 4 aspects of landscape pattern measurement which are normally used as follows:

(1) Area/Density/Edgemetrics: Number of Patches (NP), Total Edge (TE), Edge Density (ED),

(2) Shapemetrics: Mean Shape Index (MSI), Mean Patch Fractal Dimension (MPFD),

(3) Core areametrics: Total Core Area (TCA), Mean Core Area (MCA), Total Core Area Index (TCAI), Core Area Density (CAD), and

(4) Interspersion/Isolation metrics: Interspersion Juxtaposition Index (IJI),

Mean Proximity Index (MPI), and Mean Nearest Neighbor (MNN).

The definitions and equations of all those indices were described in detail by McGarigal and Mark 1995; McGarigal *et al.*, 2002; Rempel and Carr, 2012. The calculation of the landscape indices and analysis of the forest landscape patterns used the developed software FRAGSTAT and Patch Analyst package. For FRAGSTAT analysis with the raster format, 20 m pixel resolution and 4 neighborhood searching were applied in the study.

Evaluation on Priority Level Setting for Forest Landscape Restoration and Management Plan

In this study, the trends of change on an increase (gain) or decrease (loss) of the landscape indices of each forest landscape type in the SBR management zones (core, buffer, and transition zones) in 2 periods (1980-2002 and 2002-2010) were further evaluated to set up the priority level for a forest landscape restoration and management plan in terms of the forest ecology context with the following conditions:

Condition of Landscape indices	Interpretation First period (1980-2002)	Interpretation Second period (2002-2010)	Priority	Score
1	+	+	Low	1
2	-	+	Moderate	3
3	+	-	High	5
4	-	-	Urgent	7

Note: + = gain; - = loss

These priority levels of 12 indices were assigned to have a score value as follows: 1 for low priority, 3 for moderate priority, 5 for high priority, and 7 for urgent priority. After that, the simple additive weighting (SAW) method with equal weights was applied to justify the final priority level for the restoration and management plan in each of the forest landscape types. Finally, the overall score (12 to 84) from the SAW operation wasthen equally divided into 4 priority levels as follows:

12.0-30.0: Low priority;
30.0-48.0: Moderate priority;
48.0-66.0: High priority;
66.0-84.0: Urgent priority.

Thus, the final priority levels for the forest landscape restoration and management plan of each forest landscape typein the SBR management zones were derived. After that, recommendations for the forest landscape restoration and management plan were developed in association with the purposes and regulations of the biosphere reserve's establishment.

Results and Discussion

Landscape Type Distribution and Forest Landscape Assessment in the SBR

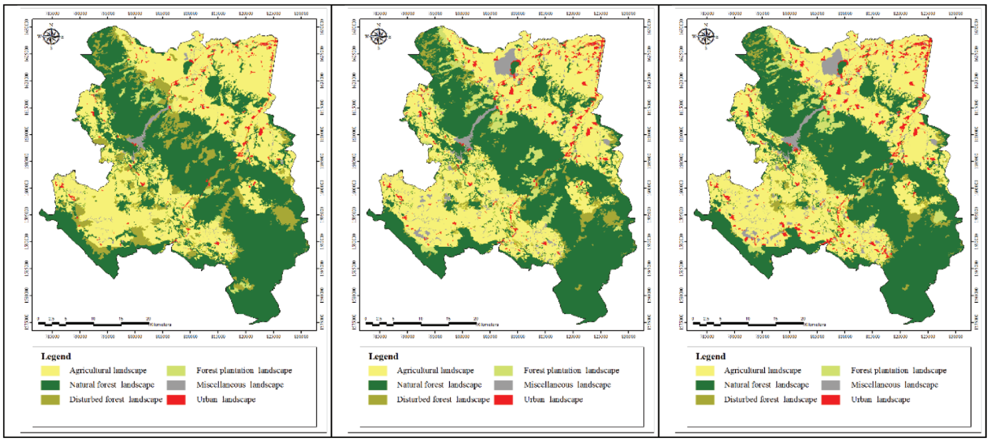
The areas and percentages of the SBR

landscape type distribution from 1980 to 2010 are reported in Table 2 and Figure 3. As a result, the classification and distribution showed that the most dominant landscape type of the SBR was natural forest landscape which occupied an area of 46.23% in 1980 and then slightly decreased to 44.38% and 44.40% in 2002 and 2010, respectively. Meanwhile, the moderate dominant landscape type was agricultural landscape. The least dominant landscape type was miscellaneous landscape which covered an area of 1.29% in 1980 but slightly increased to 3.4% and 3.64% in 2002 and 2010, respectively.

The distribution of forest landscape types in each of the SBR management zones indicated that the most dominant component of the forest landscapes was the natural forest, followed by the disturbed forest and forest plantation landscapes. As a result, it was found that the natural forest landscape in 3 different years was rather stable and dominated the other forest landscape types. Meanwhile, the disturbed forest landscape had dramatically decreased; conversely, the forest plantation landscape had sharply increased from 1980 to 2010. The distribution of the forest landscapes are presented in Figure 4,

Table 2. Area and percentage of the SBR landscape types in 1980, 2002, and 2010

Landscape Type	1980		2002		2010	
	Area (sq. km)	%	Area (sq. km)	%	Area (sq. km)	%
Agriculture	641.47	39.29	670.34	41.06	674.01	41.28
Natural forest	754.63	46.23	724.53	44.38	724.78	44.4
Disturbed forest	166.82	10.22	76.34	4.68	65.1	3.99
Forest plantation	26.23	1.61	67.62	4.14	60.59	3.71
Urban/Built-up land	22.16	1.36	38.14	2.34	48.58	2.98
Miscellaneous	21.17	1.29	55.51	3.4	59.42	3.64
Total	**1632.48**	**100**	**1632.48**	**100**	**1632.48**	**100**



(a) 1980 (b) 2002 (c) 2010

Figure 3. Landscape type distribution in SBR in (a) 1980, (b) 2002, and (c) 2010

whereas the areas and percentages are reported in Table 3.

In addition, the 3 SBR management zones, the core, buffer, and transition zones, were dominated by natural forest landscape with an increasing trend from 93.52% to 97.20% in the core zone, 72.73% to 80.31% in the buffer zone, and 79.55% to 84.97 % in the transition zone, respectively. Similarly, the forest plantation landscape exhibited an increasing trend in the buffer and transition zones from 2.62% to 17.43%, and 2.88% to 6.01%, respectively. On the other hand, the disturbed forest landscape showed a reversing trend as it had decreased in all management zones, particularly in the buffer and transition zones which showed a sharp decrease from 24.65% to 2.26% and 17.57% to 9.02%, respectively.

Forest Landscape Pattern Analysis in the SBR Management Zones

Landscape pattern analysis focused on forest landscapes which were natural forest, disturbed forest, and forest plantation landscapes. Each type of forest landscape was analyzed by the 12 selected landscape indices of the 4 landscape pattern measurements. The interpretation of the landscape indices are summarized in Table 4 and separately explained for each forest landscape as follows:

Natural Forest Landscape Metric Analysis

In the core zone, the area/density/edge metrics (NP, TE, and ED) were slightly changed and revealed less fragmentation, where as the shape metrics (MPFD and MSI)

Table 3. Area and percentage of forest landscape types in the SBR management zones in 1980, 2002, and 2010

1980	**Core zone**		**Buffer zone**		**Transition zone**	
	Area (km²)	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**
Natural forest landscape	53.52	93.52	77.41	72.73	623.70	79.55
Disturbed forest landscape	2.83	4.94	26.24	24.65	137.75	17.57
Forest plantation landscape	0.88	1.54	2.79	2.62	22.56	2.88
Total area	**57.23**	**100.00**	**106.44**	**100.00**	**784.01**	**100.00**
2002	**Core zone**		**Buffer zone**		**Transition zone**	
	Area (km²)	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**
Natural forest landscape	55.15	96.37	81.71	78.32	587.72	83.13
Disturbed forest landscape	0.44	0.77	3.18	3.05	72.72	10.29
Forest plantation landscape	1.64	2.87	19.43	18.63	46.55	6.58
Total area	**57.23**	**100.00**	**104.32**	**100.00**	**706.99**	**100.00**
2010	**Core zone**		**Buffer zone**		**Transition zone**	
	Area (km²)	**%**	**Area (km²)**	**%**	**Area (km²)**	**%**
Natural forest landscape	55.63	97.20	83.41	80.31	585.79	84.97
Disturbed forest landscape	0.54	0.95	2.35	2.26	62.22	9.02
Forest plantation landscape	1.06	1.86	18.10	17.43	41.43	6.01
Total area	**57.23**	**100.00**	**103.86**	**100.00**	**689.44**	**100.00**

implied that the shape complexity was rather stable. Similarly, the core area metrics (TCA, MCA, TCAI, and CAD) were very slightly changed which indicated that the core areas were somewhat stable. Meanwhile, the interspersion/isolation metrics (IJI, MPI, and MNN) showed a trend of being aggregated to each other.

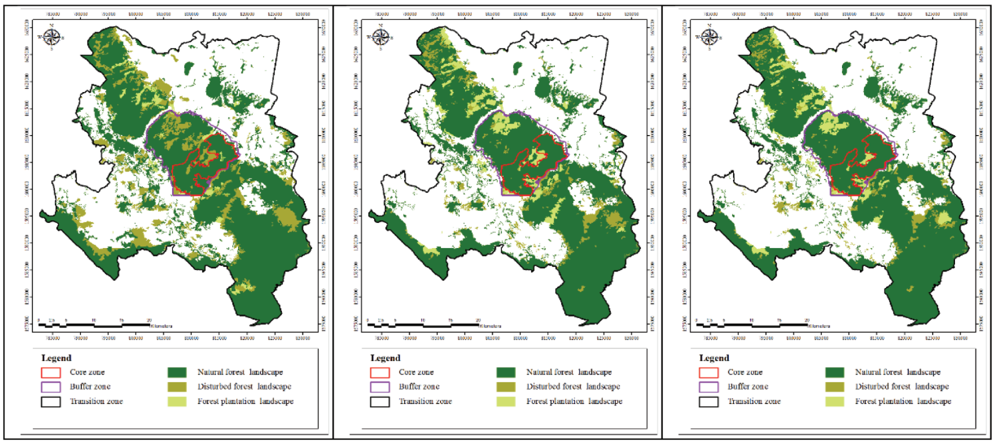
In the buffer zone, the area/density/edge metrics were moderately increasing. This implied that some fragmentation occurred in the buffer zone. At the same time, the shape and core area metrics showed the same trends of slight change and revealed rather stable stages. In contrast, the interspersion/isolation metrics showed some dispersal of patches from each other.

In the transition zone, the area/density/edge metrics fluctuated during the periods, which indicated some occurrences of fragmentation and compactness due to human activities (i.e., forest disturbance or forest encroachment). Concurrently, the shape and core area metrics slightly changed revealing rather stable stages. Mean while, the interspersion/isolation metrics showed trends of dispersion as the MPI index showed decreasing values but the IJI index indicated a relatively even distribution of patches.

Disturbed Forest Landscape Metrics Analysis

In the core zone, the area/density/edge metrics showed a highly decreasing change which implied compactness and less fragmentation; for example, the number of patchesin 1980, 2002, and 2010 varied from 19 to 6 and 7, respectively. The shape metrics revealed a stable complexity stage. Meanwhile, the core area metric sdecreased implying that the core area of disturbed forest was dramatically lowered. Similarly, the interspersion/isolation metrics had high fluctuation implying the dynamics of dispersion. For example, the MPI index values indicated change variationsin these periods from 10.42 to 3.81 and 14.58, respectively while the MNN index fluctuated from 463.48 to 720.79 and 379.25, respectively.

In the buffer zone, the area/density/edge metrics decreased indicating less fragmentation occurring in the disturbed forest landscape. At the same time, the shape metrics revealed a rather stable complexity



(a) 1980 **(b) 2002** **(c) 2010**

Figure 4. Forest landscape type distribution in SBR in (a) 1980, (b) 2002, and (c) 2010

Table 4. Landscape indices assessment in eachof the SBR management zones for each forest landscape type

Management Zone	Landscape Metrics (unit)	Metrics value of NF/DF/FP landscape in 1980	Metrics value of NF/DF/FP landscape in 2002	Metrics value of NF/DF/FP landscape in 2010	Change of metrics value of NF/DF/FP during 1980-2002	Change of metrics value of NF/DF/FP during 2002-2010
Core	NP	2/19/4	6/6/14	4/7/11	4/-13/10	-2/1/-3
	TE (km)	111/40.92/18.36	97.89/9.78/29.88	97.92/12.03/20.82	-13.11/-31.14/11.52	30/2.25/-9.06
	ED(m/m²)	19.40/7.15/3.21	17.12/1.71/5.23	17.13/2.10/3.64	-2.28/-5.44/2.02	0.01/0.39/-1.59
	MSI	2.47/1.64/2.42	1.70/1.67/1.71	1.78/1.68/1.59	-0.77/0.03/-0.71	0.08/0.01/-0.12
	MPFD	1.10/1.09/1.14	1.10/1.10/1.09	1.09/1.09/1.08	0.00/0.01/-0.05	-0.01/-0.01/-0.01
	TCA (ha.)	5,231.36/239.56/68.87	5,404.97/33.77/131.87	5,452.29/41.40/84.47	173.61/-205.79/63.00	47.32/7.63/-47.40
	MCA (ha)	1,743.79/12.61/11.48	1,801.66/4.22/8.24	1,817.43/4.60/6.50	57.87/-8.39/-3.24	15.77/0.38/-1.74
	TCAI	97.76/84.85/77.95	98.09/76.90/80.59	98.11/76.54/79.48	0.33/-7.95/2.64	0.02/-0.36/-1.11
	CAD (ha)	0.05/0.33/0.10	0.05/0.14/0.28	0.05/0.16/0.23	0/-0.19/0.18	0/0.02/-0.05
	IJI	93.17/12.62/20.47	86.87/73.49/45.65	95.92/63.65/48.72	-6.30/60.87/25.18	9.05/-9.84/3.07
	MPI	59.45/10.42/0.58	72.46/3.81/6.70	93.47/14.58/3.12	13.00/-6.61/6.12	21.00/10.77/-3.58
	MNN (m)	21.21/463.48/172.45	26.28/720.79/202.98	31.92/379.25/450.65	5.07/257.31/30.53	5.64/-341.54/247.67
Buffer	NP	29/35/16	43/31/14	41/29/10	14/-4/-2	-2/-2/-4
	TE (km)	365.34/22.27/33.90	311.94/66.63/124.92	291.33/54.15/110.88	-53.40/156.06/91.02	-20.61/12.48/14.04
	ED(m/m²)	34.33/20.92/3.19	29.90/6.39/11.97	28.05/5.21/10.68	-4.43/-14.53/8.78	-1.85/-1.18/-1.29
	MSI	2.27/1.92/1.71	2.00/1.77/1.97	1.99/1.73/2.13	-0.27/-0.15/0.26	-0.01/-0.04/0.16
	MPFD	1.11/1.10/1.10	1.11/1.10/1.09	1.1/1.10/1.10	0.00/0.00/-0.01	0.00/0.00/0.01
	TCA (ha)	7,356.53/2,389.73/243.63	7,845.35/247.90/1,810.30	8,035.11/178.24/1,691.1	488.82/2,141.83/1,566.7	189.76/-69.66/-119.29
	MCA (ha)	113.18/66.38/20.30	92.30/6.36/120.69	111.60/5.40/130.08	-20.88/60.02/100.39	19.30/-0.96/9.39
	TCAI	95.03/91.09/87.36	96.01/78.0/93.14	96.34/76.07/93.41	0.98/-13.01/5.78	0.33/-2.01/0.27
	CAD (ha)	0.61/0.34/0.11	0.81/0.37/0.14	0.69/0.32/0.13	0.20/0.03/0.03	-0.12/-0.05/-0.01
	IJI	42.68/28.17/93.42	92.38/67.91/47.17	88.16/54.60/32.02	49.70/39.74/-46.25	-4.22/-13.31/-15.15
	MPI	7,500.67/704.85/13.42	7,956.58/34.24/1,455.46	15,197.95/31.54/91.72	455.91/-670.61/1,442.04	7,241.37/2.70/1,363.74
	MNN (m)	197.52/339.25/405.21	115.63/703.09/131.51	117.49/755.98/383.05	-81.89/363.84/-273.70	1.86/52.89/251.54
Transition	NP	425/430/100	484/389/85	463/380/85	59/-41/-15	-21/-9/0
	TE (km)	3,499.8/1,590.06/279.840	3,375.84/1,255.08/461.12	2,970.84/1,131.56/393.16	-123.96/334.98/181.28	-405/123.52/-67.96
	ED(m/m²)	44.64/20.28/3.57	47.75/17.75/6.52	43.09/16.41/5.70	3.11/-2.53/2.95	-4.66/-1.34/-0.82
	MSI	2.37/1.97/1.72	2.34/2.04/1.94	2.28/2.02/1.83	-0.03/0.07/0.22	-0.06/-0.02/-0.11
	MPFD	1.13/1.11/1.09	1.12/1.11/1.10	1.12/1.11/1.09	-0.01/0.00/0.01	0.00/0.00/-0.01
	TCA (ha)	58,722.23/12,118.48/1,955.84	54,234.8/5,586.2/4,008.28	54,584.16/4,711.28/3,592.96	-4,487.43/6,532.28/2,052.44	349.36/-874.92/-415.32
	MCA (ha)	31.22/17.61/18.28	29.27/7.82/32.59	34.27/6.85/33.27	-1.95/-9.79/14.31	5.00/-0.97/0.68
	TCAI	94.16/87.96/86.79	92.28/76.79/86.11	93.18/75.68/86.71	-1.88/-11.17/-0.68	0.90/-1.11/0.60
	CAD (ha)	2.40/0.88/0.14	2.62/1.01/0.17	2.31/1.00/0.16	0.22/0.13/0.03	-0.31/-0.01/-0.01
	IJI	65.11/32.59/79.52	86.37/41.77/69.52	83.76/40.40/70.88	21.26/9.18/-10.00	-2.61/-1.37/1.36
	MPI	57,592.04/587.72/658.68	32,075.95/295.78/279.79	29,819.80/317.61/323.67	-25,516.09/291.94/378.89	-2,256.15/21.83/43.88
	MNN (m)	143.13/214.33/608.09	120.45/282.50/654.78	123.30/294.54/627.40	-22.68/68.17/46.69	2.85/12.04/-27.38

Note NF is Natural forest landscape, DF is Disturbed forest landscape, and FP is Forest plantation landscape stage. Meanwhile, the core area metrics had a high decrease which implied that there was a loss in the core area of disturbed forest landscape. In contrast, the interspersion/ isolation metrics showed a dispersion of disturbed the forest patches from each other.

In the transition zone, the area/density/ edge metrics decreased which implied less fragmentation and compactness. At the same time, the shape metrics revealed a rather stable complexity stage. On the other hand, the core area indices decreased implying a decrease in the core area of disturbed forest landscape. Meanwhile, the interspersion/ isolation metrics showed trends in dispersion and isolation.

Forest Plantation Landscape Metrics Analysis

In the core zone, the area/density/edge metrics increased indicating that the forest plantation landscape gained in area. Meanwhile, the shape metrics revealed fewer complexities but the core area metricsvery slightly changed which implied that the core areas of forest plantation were rather stable. In addition, the interspersion/isolation metrics indicated an aggregation of patches; for example,the IJI and MPI indices showed increases in their values from 1980 to 2002 and 2010 from 20.47 to 45.65 and 48.72 and from 0.58 to 6.70 and 3.12, respectively.

In the buffer zone,the area/density/edge metrics showed a decreaseim plying that forest plantation became more aggregated. Likewise, the shape metrics revealed a rather stable complexity which indicated man management in the forest plantation. Meanwhile, the core area metrics slightly changed which implied thatthe core areas were in a relatively stable stage. In contrast, the interspersion/isolation metrics showed some degree of dispersion.

In the transition zone, the area/density/ edge metrics decreased and this implied that less fragmentation and compactness had occurred in the forest plantation landscape. The shape metrics revealed a rather stable complexity. Similarly, the core area metrics slightly changed implying that the core areas werer elatively stable. Meanwhile, the interspersion /isolation metrics showed a trend of even distribution and isolation for the forest plantation patches.

Evaluation on Priority Level Setting for the Forest Landscape Restoration and Management Plan

In accordance with thelandscape change on an increase (+) or decease (-) of the landscape indicesof each of the forest landscape types in the SBR management zones which occurredin 2 periods (1980-2002 and 2002-2010) (Table 4), the gains and losses in terms of the forest ecology aspect were evaluated for a priority level setting (score value,) as shown in detail in Table 5.

The final derived priority levels for the restoration and management plan in each of the forest landscape types of each of the SBR management zones using the SAW method with equal weight operation are reported in Table 6. These results dictated the priority level for the forest restoration and management plan in each of the management zones of each of the forest landscapes in the SBR.

Recommendations for the Forest Restoration and Management Plan of the SBR

Basically, the SBR contains 3 different management zones,the core, buffer, and transition zones, in which activities are limited for the purposes of the established biosphere reserve. In addition, the typical forest restoration and management plan concepts that were suggested by many researchers including Hobbs and Norton (1996), Noss (1999), Stanturf *et al*. (2001), Van Diggelen *et al*. (2001), Botequilha Leitao and Ahern (2002), Stanturf and Madsen (2002), and Nagendra and Southworth (2010) were considered and appropriately modified for use in the study. Particularly, Sahunalu e*t al*. (1993) studied the effects of reforestation, abandoned areas, and natural forests in Sakaerat and reported that reforestation with a single species *(Acacia mangium)* resulted in no species diversity but produced a large

Table 5. Evaluation on gain and loss for priority level set upbased on each of the landscape metrics in each management zone of the SBR

Landscape metrics	Natural forest landscape		Priority	Disturbed forest landscape		Priority	Forest plantation landscape		Priority
	1980-2002	2002-2010		1980-2002	2002-2010		1980-2002	2002-2010	
Core zone									
NP	L	G	Moderate	G	L	High	L	G	Moderate
TE	G	L	High	G	L	High	L	G	Moderate
ED	G	L	High	G	L	High	L	G	Moderate
MSI	L	G	Moderate	G	G	Low	L	L	Urgent
MPFD	G	L	High	G	L	High	L	L	Urgent
TCA	G	G	Low	L	G	Moderate	G	L	High
MCA	G	G	Low	L	G	Moderate	L	L	Urgent
TCAI	G	G	Low	L	L	Urgent	G	L	High
CAD	G	G	Low	L	G	Moderate	G	L	High
IJI	L	G	Moderate	G	L	High	G	G	Low
MPI	L	L	Urgent	G	L	High	L	G	Moderate
MNN	L	L	Urgent	L	G	Moderate	L	L	Urgent
Buffer zone									
NP	L	G	Moderate	G	G	Low	G	G	Low
TE	G	G	Low	G	G	Low	L	G	Moderate
ED	G	G	Low	G	G	Low	L	G	Moderate
MSI	L	L	Urgent	L	L	Urgent	G	G	Low
MPFD	G	G	Low	G	G	Low	L	G	Moderate
TCA	G	G	Low	L	L	Urgent	G	L	High
MCA	L	G	Moderate	L	L	Urgent	G	G	Low
TCAI	G	G	Low	L	L	Urgent	G	G	Low
CAD	G	L	High	G	L	High	G	L	High
IJI	G	L	High	G	L	High	L	L	Urgent
MPI	L	L	Urgent	G	G	Low	L	G	Moderate
MNN	G	L	High	L	L	Urgent	G	L	High
Transition zone									
NP	L	G	Moderate	G	G	Low	G	L	High
TE	G	G	Low	G	G	Low	L	G	Moderate
ED	L	G	Moderate	G	G	Low	L	G	Moderate
MSI	L	L	Urgent	G	L	High	G	L	High
MPFD	L	G	Moderate	G	G	Low	G	L	High
TCA	L	G	Moderate	L	L	Urgent	G	L	High
MCA)	L	G	Moderate	L	L	Urgent	G	G	Low
TCAI	L	G	Moderate	L	L	Urgent	L	G	Moderate
CAD	G	L	High	G	L	High	G	L	High
IJI	G	L	High	G	L	High	L	G	Moderate
MPI	G	G	Low	G	L	High	G	L	High
MNN	G	L	High	L	L	Urgent	L	G	Moderate

Note: G is gain and L is loss

amount of phytomass; however, stand density was possible to control by the approach of natural dry evergreen but this was not comparable to the natural forest since it was composedof only 1 upper layer of perennial tree, while the abandoned area was highly diverse but mostly composed of unvaluable species. Doi and Ranamukhaarachchi (2009) also investigated the effects of *Acacia auriculiformis* rehabilitation on degraded land in Sakaerat and commented that most of the soil characteristics were rehabilitated 18 to 19 years after the planting and the soil was still in the process of full recovery when compared to the evergreen forest soil.

For the restoration and management plan of the SBR, it was found that in all the management zones the natural forest and disturbed forest landscapes revealed moderate and high priority levels for restoration and management plans, respectively, whereas in the forest plantation landscape, the priority levels in the core, buffer, and transition zones were high, moderate, and high, respectively. Details of the restoration and management plan of the SBR are summarized in Table 7.

Conclusions

The forest landscape pattern assessment in the SBR indicated that natural forest landscape dominated over the other forest landscapes and had relatively maintained its status, whereas the disturbed forest and forest plantation landscapes showed distinctively dynamic stagesfrom 1980 to 2010. The landscape metrics measurement in the SBR management zones, the core, buffer, and transition zones, revealed that all the forest landscape types in the core zone had improved in status. The natural forest and disturbed forest landscapes showed less fragmentation, while the forest plantation landscape gained in area. The shape complexity and core areas of the 3 forest landscapes showed similar trends inslight changes from relatively stable to less complex. The changes mostly occurred in the transition zone where human activities were not strictly prohibited based on the regulations of the biosphere reserve. Results from the landscape metrics analysis have been used to determine the priority levels for the forest restoration and management plan by setting them to urgent, high, moderate, and low. According to the restoration and management concepts that were reviewed by numerous researchers, this study has developed recommendations for forest landscape type restoration and management plans for each of the SBR management zones. As a result, the recommendations in the core zone of the

Table 6. Final score and priority levelfor restoration and management plan for each forest landscape type of each of the SBR management zones

Forest landscape	Management zones	Total scores	Priority level
Natural Forest	Core	42	Moderate
	Buffer	40	Moderate
	Transition	42	Moderate
Disturbed forest	Core	50	High
	Buffer	50	High
	Transition	52	High
Forest Plantation	Core	56	High
	Buffer	38	Moderate
	Transition	46	High

natural forest, disturbed forest, and forest plantation landscapes were strictly for minimum restoration and management, but not limited to natural regeneration and succession. Meanwhile, forest rehabilitation and reforestation, including regular patrolling and forest fire control, were recommended in the buffer and transition zones. In conclusion, the integration of remotely sensed data and landscape metrics can be efficiently applied to quantify landscape pattern characteristics that directly relate to forest landscape ecology and to obtain important ecological landscape information for a forest resources restoration and management plan.

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Table 7. Restoration and management plans for the forests landscapes of the SBR

Management zone	Forest landscape	Priority level	Action plan	
			Restoration plan (10-20 Years)	Management plan (5-10 Years)
Core	Natural forest	Moderate	Minimal requirement for restoration by natural succession and regularly monitor natural forest by patrolling.	Minimal requirement for management by regular forest patrolling and forest fire prevention.
	Disturbed forest	High	Minimal requirement for restoration by natural regeneration and succession.	Minimal requirement for management by forest rehabilitation and forest fire control.
	Forest plantation	High	Minimal requirement for restoration by leaving forest plantation to grow naturally and regularly monitor by patrolling.	Minimal requirement for management by forest patrolling, forest fire prevention, and regular forest patrolling.
Buffer	Natural forest	Moderate	Moderate requirement for restoration by rehabilitation and regularly monitor natural forest by patrolling.	Moderate requirement for management by forest patrolling, forest fire prevention, rehabilitation, and reforestation.
	Disturbed forest	High	Moderate requirement for restoration by means of rehabilitation and reforestation and regularforest fire control.	High requirement for management by forest fire prevention, rehabilitation, and reforestation.
	Forest plantation	Moderate	Moderate requirement for restoration by tree enrichment and regularly monitor by patrolling.	Moderate requirement for management by forest patrolling, forest fire prevention, and tree enrichment programs.
Transition	Natural forest	Moderate	Moderate requirement for restoration in government land by reforestation, regular forest patrolling, and forest fire prevention.	High requirement for management by forest patrolling, forest fire prevention, and reforestation.
	Disturbed forest	High	Moderate requirement for restoration in government land by reforestation and regularforest fire control.	Moderate requirement for management in government land by forest fire prevention and reforestation.

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References

Botequilha Leitao, A. and Ahern, J. (2002). Applying landscape ecological concepts and metrics in sustainable landscape planning. Landscape Urban Plan., 59(2):65-93.

Burel, F. and Baudry, J. (2003) Landscape Ecology: Concepts, Methods and Applications. Science Publishers Inc., Enfield, NH, USA, 362p.

Congalton, R.G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. Remote Sens. Environ., 37:35-46.

Congalton, R.G. and Green, K. (2009). Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. CRC Press, Boca Raton, FL, USA, 192p.

Corry, R.C. and Nassauer, J.I. (2005). Limitations of using landscape pattern indices to evaluate the ecological consequences of alternative plans and designs. Landscape Urban Plan., 72(4): 265-280.

Dhanmanonda, P. (1992). The forest growth cycle in dry dipterocarp forest. Thai J. Forestry, 11:66-79.

Doi, R. and Ranamukhaarachchi, S.L. (2009). Community-level physiological profiling in monitoring rehabilitative effects of Acacia auriculiformis plantation on degraded land in Sakaerat, Thailand. Silva Fenn., 43(5): 739–754.

Farina, A. (1998). Principles and Methods in Landscape Ecology. Chapman and Hall, London, UK, 234p.

Franklin, S.E. (2001). Remote Sensing for Sustainable Forest Management. CRC Press, Boca Raton, FL, USA, 470p.

Gesellschaft für International Zusammenarbeit GmbH. (2012). Committed to Biodiversity. Metzgerdruck GmbH, Obrigheim, Germany, 71p.

Hobbs, R.J. and Norton, D.A. (1996). Towards a conceptual framework for restoration ecology. Restor. Ecol., 4(2):93-110

Horning, N., Robinson, J. A., Sterling, E. J., Turner, W., and Spector, S. (2010). Remote Sensing for Ecology and Conservation: A Handbook of Techniques. Oxford University Press, Oxford, UK, 467p.

Kenk, G. and Guehne, S. (2001). Management of transformation in central Europe, Forest Ecol. Manag., 151:107-119.

Landis, J. and Koch, G. (1977). The measurement of observer agreement for categorical data. Biometrics, 33:159-174.

Lindenmayer, D. (2009). Forest Pattern and Ecological Process: a Synthesis of 25 Years of Research. CSIRO Publishing, Melbourne, Australia, p. 215-245.

McGarigal, K. and Marks, B.J. (1995). FRAGSTATS. Spatial Pattern Analysis Program for Quantifying Landscape Structure. Reference Manual. Forest Science Department Oregon State University, Corvallis, Oregon. 122p.

McGarigal, K., Cushman, S.A., Neel, M.C., and Ene, E. (2002). Fragstats: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst, MA, USA. Available at the following web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html

Mladenoff, D.J. and. Host, E.G. (1994). Ecological perspective: Current and potential applications of remote sensing and GIS to ecosystem analysis. In: Remote Sensing and GIS in ecosystem management. Sample, V.A. (ed), Island Press, Washington, DC, USA, p. 218-242.

Mladenoff, D.J., White, A.M., Crow, R.T., and Pastor, J. (1994). Applying principles of landscape design and management to integrate old-growth forest enhancement and commodity use. Cons. Biol., 8(3):752-762.

Mladenoff, J.D. and Baker, L.W. (1999). Advances in Spatial Modeling of Forest Landscape Change: Approaches and Applications. Cambridge University Press, Cambridge, UK, 353p.

Nagendra, H. and Southworth, J. (2010). Reforesting Landscapes: Linking Pattern and Process. Springer Science + Business Media B.V. Dordrecht, Netherlands, 386p

Natural Resources Defense Council. (2010). What is a Biosphere Reserve? Available from: www.nrdc.org/land/wilderness/fbios.asp. Accessed date: Jan 30, 2010.

Noss, R.F. (1999). Assessing and monitoring forest biodiversity: A suggested framework and indicators. Forest Ecol. Manag., 115:135-146.

Nyland, R.D. (2003). Even-to-uneven-aged: the challenges of conservation. Forest Ecol. Manag., 172:291-300.

Ongsomwang, S. (1986). Application of natural color and color infrared aerial photographs in evaluation of land use: its change and impact of Sakaerat Environmental Research Station, Amphoe Paktongchai, Nakhon Ratchasima province, [MSc. thesis]. Faculty of Forestry, Kasetsart University, Bangkok, Thailand, 104p.

Peano, A., Bottero, M., and Cassatella, C. (2011). Proposal for a set of indicators.In: Landscape Indicators Assessing and Monitoring Landscape Quality. Cassatella, C. and Peano, A. (eds). Springer Science + Business Media B.V., Dordrecht, Netherlands, p.198-215.

Rempel, R.S. and Carr, A.P. (2012). Patch analyst and Patch Grid. Ontario Ministry of Natural Resources. Centre for Northern Forest Ecosystem Research, Thunder Bay, ON, Canada.

Sahunalu, P., Dhanmanonda, P., Jamroenpruksu, M., and Khemnark, C. (1993). Effects of restoration, abandoned areas and natural forests on Sakaerat environment. Final report submitted to the National Research Council. Faculty of Forestry, Kasetsart University, Bangkok, Thailand.

Spiecker, H., Hansen, J., Klimo, E., Skovsgaard, J.P., Sterba, H., and von Teuffel, K.V. (2004). Norway spruce conversion: options and consequences. European Forest Institute Research Report 18:1-269.

Stanturf, J.A., Schoenholtz, S.H., Schweitzer, C.J., and Shepard, J.P. (2001). Achieving restoration success: myths in bottomland hardwood forests. Restor. Ecol., 9(2):189-200.

Stanturf, J.A. and Madsen, P. (2002).Restoration concepts for temperate and boreal forests of North America and Western Europe. Plant Biosyst., 136:143-158.

Sutthivanich, S. (1989). Effects of fire frequency on vegetation in dry dipterocarp forestat Sakaerat, Changwat Nakhonratchasima, [MSc. Thesis]. Faculty of Forestry, Kasetsart University, Bangkok, Thailand, 89p.

Thailand Institute of Scientific and Technological Research. (2009). General information. Available from: www.tistr.or.th/sakaerat/index.php. Accessed date: Sep 1, 2009.

Trisurat, Y. (2010). Land use and forested landscape changes at Sakaerat Environmental Research Station in Nakhon Ratchasima Province, Thailand, Ekol. Bratislava, 29:99-109.

Trisurat, Y. and Duengkae, P. (2011). Consequences of land use change on bird distribution at Sakaerat Environmental Research Station. J. Ecology Field Biology, 34(2):203-214.

Turner, G.M. Gardner, R.H., and O'Neill, R.V. (2001). Landscape Ecology in Theory and Ppractice: Pattern and Process. Springer-Verlag, NY, USA, 352p.

Turner, G.M. (2010). Disturbance and landscape dynamics in a changing world. Ecology, 91(10): 2833-2849.

Van Diggelen, R., Grootjans, A.P., and Harris, J.A. (2001). Ecological restoration: state of the art or state of the science? Restor. Ecol., 9(2):115-118.

Waring, R.H. and Running, S.W. (1998). Forest Ecosystems Analysis at Multiple Scales. California Academic Press, San Diego, CA, USA, 370p.

Wulder, M.A., Hall, R.J., Coops, N., and Franklin, S.E. (2004). High spatial detail remotely sensed data for ecosystem characterization. Bio Science, 54(6):511-521.

Wulder, M.A. and Franklin, S.E. (2007). Understanding Forest Disturbance and Spatial Pattern: Remote Sensing and GIS Approaches. Taylor & Francis. NY, USA, 246p.