

FOREST ASSESSMENT AND LANDSCAPE ECOLOGY STUDY IN THAILAND

Suwit Ongsomwang^{1*}

Received: October 28, 2014; Revised: December 10, 2014; Accepted: December 15, 2014

Abstract

The main objective of the paper is to provide an overview of a new concept and method for managing forest resources with a new tool of landscape ecology. Herein, the development of forest assessment in Thailand, the basic concepts and principles of landscape ecology with its application on forest management, and recent research topics on landscape ecology were reviewed for forest managers and researchers.

Keywords: Forest assessment, landscape ecology, remote sensing

Introduction

The forests of Thailand represent extremely valuable natural resources which are directly and indirectly beneficial to the economic and social development of the country. So, forest resources must be properly utilized and there must be planning on a long-term basis. The forest managers must know where the forest resources occur and what their conditions are in order to decide how best to balance the many demands on the resources for the best utilization of future generations (Ongsomwang, 2001).

Unfortunately, deforestation has taken place over many areas in the country due to natural and human disturbances. TFSMP (1993) stated that the 2 main underlying causes of deforestation in the past were the increasing demand of land for agriculture to meet the needs of the growing population, and commercial logging. Demand

for land depends on land prices, agricultural productivity, prices of agricultural products, alternative sources of off-farm employment and income, and population growth.

While landscape ecology has made tremendous progress in theory and practice during the past 30 years and has been described and analyzed in Naveh and Lieberman (1990), Zonneveld (1989), Forman and Godron (1986), Turner and Gardner (1990), Forman (1995), Farina (1998), Klopatek and Gardner (1999), Turner *et al.* (2001), Burel and Baudry (2003), Wiens and Moss (2005), Wu and Hobbs (2007) and Farina (2010), it plays a vital role as a tool for solving problems about resource management and conservation. This role concerns not only ecological vision but also integration with other disciplines in the study of different processes at

School of Remote Sensing, Institute of Science, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand. E-mail: suwit@sut.ac.th

** Corresponding author*

the different spatial scale. The methodological development evolves from qualitative analysis and descriptions to quantitative analysis, as well as ecological process modeling. Landscape ecology has become a new area of study which aims to understand the patterns of interaction and connections of the biological and cultural communities with the effects of both natural and human disturbances across the landscape (Turner *et al.*, 2001).

In recent years, national and international political momentum has increased the dedication for conservation of biodiversity and forest sustainable development (Noss, 1999; Lindenmayer *et al.*, 2000; Lindenmayer, 2009; GIZ, 2012). So, forest managers need to collect new kinds of forest landscape information to complement the traditional forest databases and field observations. Meanwhile remote sensing and a geographic information system (GIS) have emerged as key geospatial tools to satisfy the increasing information needs of resource managers (Frohn, 1998; Franklin, 2001; Wulder *et al.*, 2004; Horning *et al.* 2010). Concurrently, landscape pattern analysis approaches have also become widespread to collaborate in achieving valuable information in the same field (Naveh and Lieberman, 1990; Turner and Gardner, 1990; Farina, 1998, 2010; Klopatek and Garden, 1999; Turner *et al.*, 2001; Burel and Baudry, 2003; Peano *et al.*, 2011).

Therefore, the main objective of the paper is to review the development of forest assessment in Thailand, some basic concepts and principles of landscape ecology, examples of landscape ecology application on forest management, and key research topics in landscape ecology for forest managers and researchers.

Development of Forest Assessment in Thailand

The first project concerned with forest resources assessment in Thailand was conducted by the Ordnance Survey Department (now Royal Thai Survey Department (RTSD)) in 1961. Panchromatic aerial photographs of a medium scale 1: 50000 were visually interpreted for the main land use classifications. It reported that the existing forest area of Thailand in 1961

amounted to 273628.50 sq. km or 53.33 percent of the country. In 1975, aerial photographs of a larger scale 1:15000 were applied to cadastral surveying for land titling and other multi-purpose uses in Thailand. The Royal Forest Department (RFD) utilized these photographs to interpret the forest types for inventory purposes. However, the aerial photographs for the whole country which were produced by the RTSD are rapidly going out of date and are time-consuming for interpretation and mapping. The successful forest type map for the southern region of Thailand was only produced at the scale of 1: 50000 (Ongsomwang, 2002).

In 1970 the National Aeronautics and Space Administration (NASA) introduced the usefulness and possible applications of data from the Earth Resources Technology Satellite (now called Landsat) to the Government of Thailand (Klankamsorn, 1992). After that, the Thailand National Remote Sensing Program was set up in 1971 by cabinet resolution as a new technology, under which the National Research Council of Thailand formulated the outline of the remote sensing development policy indicating the long range framework and guidelines. The Thailand Remote Sensing program was later accepted by NASA in 1972 to participate in Landsat missions. This created the availability of up-to-date and accurate information required by the various government agencies concerned with the planning for development and management of natural resources. Landsat data have been applied in various disciplines. Moreover, remote sensing technology has been accepted by the National Economic and Social Development Board as a tool to investigate natural resources (Sabhasri *et al.*, 1980).

Early in 1973, several government agencies used Landsat-1 imagery in their activities, including forestry, and it was proved to be an important tool for natural resource surveys and management by the government agencies. The RFD established the Remote Sensing and Forest Mapping Sub-division under the Forest Management Division (now the Forest Survey and Assessment Division under the Forest Management Office) and started to use the Landsat imagery for forest assessment

in 1973. The first forest assessment, which was conducted by visual interpretation of Landsat imagery at the scale of 1:250000, reported that the existing forest area of Thailand amounted to 221725 sq. km or 43.21 percent of the country. After the first successful forest assessment in 1973, the RFD adopted the method to conduct forest assessment for the country in 1976, 1978, 1982, 1985, 1988, 1989, 1991, 1993, 1995, and 1998 as routine work.

In 1999 the RFD initiated a 2-year project on forest land use assessment. Under the project, remote sensing and GIS technologies were applied for forest land use assessment. Forest land use classes, including forest types and main land use types, were visually interpreted from Landsat imagery at the scale of 1:50,000 (instead of 1:250000) and the interpreted data were transformed into GIS databases for forest assessment. The project was completed and the final report on forest land use assessment was produced in 2000. The result showed that the forest land use data with the GIS database which were extracted from the Landsat imagery at the medium scale (1:50000) could provide more useful information than the smaller scale 1:250000 (Ongsomwang, 2002). Later on, this procedure was further applied for forest assessment in 2004, 2008, and 2013 (Table 1 and Figure 1).

In general, the derived information on the existing forest areas is directly used for forest management in multiple aspects such as forest rehabilitation, conservation, protection, and prevention.

Basic Concepts and Principle of Landscape Ecology

Landscape ecology is an interdisciplinary and a relatively new science with the interrelationship between human society and its living space and is now widely recognized as a distinct perspective in resource management and ecological science.

The term landscape ecology was first introduced by the German bio-geographer Carl Troll in 1939, arising from the European tradition of regional geography and vegetation

science and motivated particularly by the novel perspective offered by aerial photography. Landscape ecology essentially combined the spatial approach of the geographer with the functional approach of the ecologist (Turner *et al.*, 2001). Landscape ecology is the study of the structure, function, and changes in heterogeneous land areas composed of interacting organisms. It is the study of the interaction between landscape patterns and ecological processes, especially the influence of landscape on the flows of water, energy, nutrients, and biota (Bourgeron and Jensen, 1994). It emphasizes and investigates the effects and interactions between spatial patterns and ecological processes that are the causes and consequences of spatial heterogeneity across a range of scales (Turner *et al.*, 2001).

To study the landscape ecology, at least 3 basic elements must be understood including structure, function, and change (Turner, 1989; Forman, 1995).

(1) Landscape structure generally refers to the distribution of energy, material, and species. The spatial relationships of landscape elements are characterized as a landscape pattern in 2 ways. First, the simple number and amount of different spatial elements within a landscape is generally defined as the landscape composition. Second, the arrangement, position, shape, and orientation of spatial elements within a landscape are generally defined as the landscape configuration (McGarigal and Marks, 1995; Remmel and Csillag, 2003).

(2) Landscape function generally refers to the flow of energy, materials, and species and the interactions between the mosaic elements (Forman, 1995). Examples range from fundamental abiotic processes, such as the cycling of water, carbon, and minerals (Waring and Running, 1998), to biotic processes, including forest succession (Oliver and Larson, 1996), and the dispersal and gene flow of wildlife. Such biotic and abiotic flows are determined by the landscape structures present, and, in turn, landscape structure is created and changed by these flows.

(3) Landscape change generally refers to the alteration in the structure and function

of the ecological mosaic through time (Forman and Godron, 1986). The main processes or flows generating landscape structure formation and landscape change over time can be considered as natural and anthropogenic disturbances (e.g., wildfire, insect infestation, and harvesting);

biotic processes (e.g., succession, birth, death, and dispersal); and environmental conditions (e.g., soil quality, terrain, and climate) (Levin, 1978).

Furthermore, some relevant ecological theories and models which are incorporated in the disciplinary body of landscape ecology

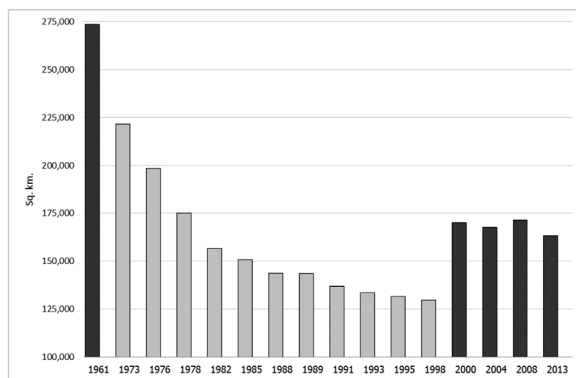


Figure 1. Forest areas of Thailand between 1961 and 2013

Table 1. Existing forest area in Thailand during 1961-2008

Year	Existing Forest area (sq.km)	Percent	Scale of Imagery
1961	273628.50	53.33	1:50000
1973	221725.00	43.21	1:250000
1976	198417.00	38.67	1:250000
1978	175224.00	34.15	1:250000
1982	156600.00	30.52	1:250000
1985	150866.10	29.40	1:250000
1988	143803.40	28.03	1:250000
1989	143417.00	27.95	1:250000
1991	136698.00	26.64	1:250000
1993	133521.00	26.03	1:250000
1995	131485.00	25.62	1:250000
1998	129722.00	25.28	1:250000
2000	170110.78	33.15	1:50000
2004	167590.98	32.66	1:50000
2008	171585.65	33.44	1:50000
2013	163391.26	31.57	1:50000

Source: Charupatt (1993); Royal Forest Department (2013).

should be well understood. Farina (2010) summarized the well-known theories and models with references, as follows:

(1) Hierarchy theory (Allen and Starr, 1982; O'Neill *et al.*, 1986) is relevant for exploration of the landscape processes. The hierarchy concept is consistent with the structural (patches) and functional (ecotopes) components of a landscape.

(2) Heterogeneity model (Gardner *et al.*, 1987) appears useful to evaluate the degree of connectivity of the landscape mosaic as perceived by a species.

(3) Meta-population theory (Levins, 1970) considers the distribution of populations across fragmented and isolated habitats. The colonization/extinction rate is considered a central mechanism to maintain meta-population health.

(4) Source-sink models (Pulliam 1988, 1996) analyze population survival in terms of the balance between reproduction and death within a seasonal cycle. Such models are strictly related to habitat quality and, consequently, to the patterned landscape.

(5) Ecotones are emergent characteristics of mosaic heterogeneity, and exist across spatial and temporal scales. They are species-specific and represent the position in the space-time context in which a particular organism perceives changes in environmental properties (Farina, 2010).

Landscape Metrics

With the definition as the study of the effect of landscape patterns on ecological processes, it requires specific methods to quantify the landscape patterns linked to the ecological processes. The common method for quantifying landscape patterns is to capture information of a particular spatial pattern into a single variable as landscape metrics or landscape pattern indices.

Landscape metrics are algorithms that quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics. These metrics are focused on the characterization of the geometric and spatial properties of categorical map patterns represented at a single scale (grain and extent) (McGarigal and Marks, 1995). Landscape metrics

can be defined at 3 levels: patch-level, class-level, and landscape-level metrics (McGarigal *et al.*, 2002):

(1) Patch-level metrics are defined for individual patches, and characterize the spatial character and context of patches.

(2) Class-level metrics are integrated over all the patches of a given type. These may be integrated by simple averaging, or through some sort of weighted-averaging scheme that biases the estimate to reflect the greater contribution of large patches to the overall index. There are additional aggregate properties at the class level that result from the unique configuration of patches across the landscape.

(3) Landscape-level metrics are integrated over all patch types or classes over the full extent of the data (i.e. the entire landscape). Like class metrics, these may be integrated by a simple or weighted averaging, or may reflect aggregate properties of the patch mosaic.

The landscape metrics can be categorized into 8 major groups (McGarigal and Marks, 1995; Häusler *et al.*, 2000) as follows:

(1) Area metrics describe the extent of patches, classes or the total landscape. This can be done in an absolute value, as mean values, or in percentages.

(2) Edge metrics describe the number of edges occurring between patches or classes. This is done by perimeter calculations of each patch. In that way, these indices can give information about the spatial variance of an area. A high number of edges can indicate variable ecological conditions which is, e.g., necessary for the occurrence of specific species. Low edge frequencies typically indicate monotonous conditions for the subject/species of interest.

(3) Shape metrics are based on perimeter-area relationships of the patches where, e.g., the perimeter of a patch is compared to the perimeter of a square with the same area (Frohn 1998). High values may indicate the occurrence of many patches with complex and convoluted shapes, while a low value represents the dominance of simple geometric shapes, like rectangular or circular shapes.

(4) Core area metrics compute statistics regarding the inner/central parts of patches in

relation to the total patches. The core area is defined as the area within a patch beyond a certain edge distance or buffer width. These metrics can give information about habitat quality for certain species.

(5) Patch metrics describe the total number of patches and their relative proportions (if more classes are present) in a given area.

(6) Nearest neighbor metrics are based on the distances from patches to the nearest neighboring patch of the same type/class. These indices are calculated by using the minimum distance measured as an edge to edge distance, from 1 patch to the nearest neighboring patch of the same class type. These measurements can be used for describing the migration possibilities of species or species interaction of separated populations.

(7) Diversity metrics measure the landscape composition and area function of the richness and evenness of the patch types in the landscape.

(8) Contagion/interspersion metrics are calculated using the actual rate of adjacency of

each occurring class type with all other class types. The resulting values express the probability of adjacency of different class types. Contagion can give an idea about the extent of aggregation or clumping of patches. High values indicate big continuous areas, while small values represent many small, dissected areas. On the other hand, juxtaposition and interspersion metrics indicate how “well mixed” the patches are in the landscape.

Figure 2 demonstrates examples of the spatial metrics and their values in each group of landscape metrics.

Landscape Ecology Study in Thailand

Two cases of landscape ecology study relating to forest assessment, which apply the basic landscape metrics to quantify and evaluate the characteristics of forest landscape, are reviewed here consisting of objective, methodology, results, and discussion.

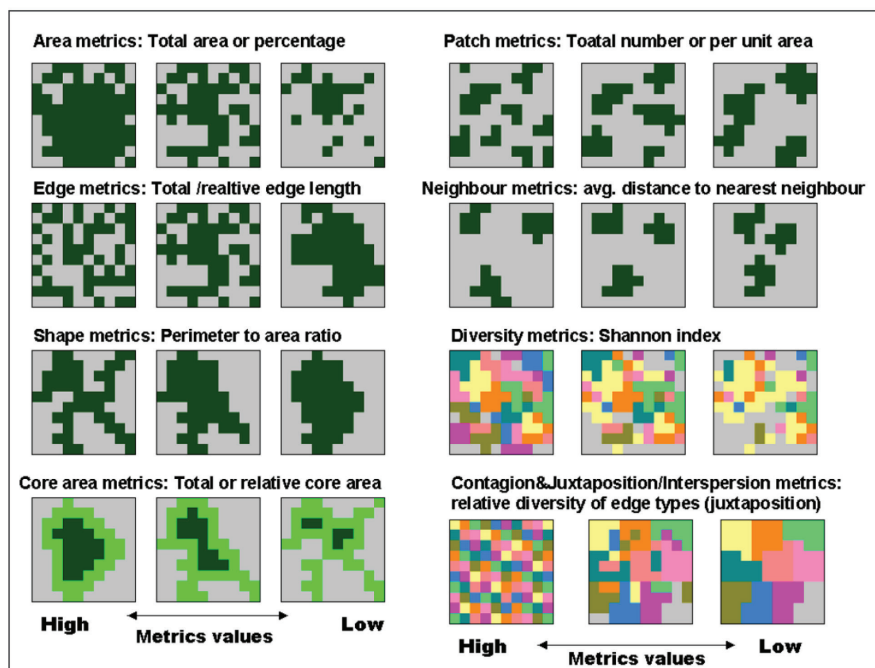


Figure 2. Examples of the spatial landscape metrics (Nielsen, 2001)

Integration of Geoinformatics and Landscape Metrics for Forest Resources and Land Use Landscapes Assessment in Thap Lan National Park, Thailand

Ongsomwang and Srisuwan (2012) introduced the integration of geoinformatics and landscape metrics for forest resource and land use landscape assessment in Thap Lan National Park in the Dong Phrayayen - Khao Yai Forest Complex World Heritage site (DPKY-FCWH), which was inscribed in 2005 by UNESCO. The DPKY-FCWH contains more than 800 fauna species, including 112 species of mammals, 392 species of birds, and 200 species of reptiles and amphibians. It is internationally important for the conservation of globally threatened and endangered mammal, bird, and reptile species that are recognized as being of outstanding universal value (UNESCO, 2010). The main objective of the study is to assess the status and change of landscape types and landscape using geoinformatics and landscape metrics.

In this study, Landsat-TM data (bands 3, 4, and 5) acquired in 1987, 2005, and 2007 were firstly used to digitally classify and visually interpret 14 land use and land cover classes (LULC) including urban and built-up areas, paddy fields, crop fields, perennial cultivation and orchards, dry evergreen forests, mixed deciduous forests, dry dipterocarp forests, bamboo forests, natural forest succession and forest plantations, grasslands, shrubs, natural water bodies, reservoirs, and miscellaneous land (old clearings, uncultivated land, barren land/bare land). Then, the 14 LULC classes were reclassified into 7 landscape types including urban and built-up (ULT), agriculture (ALT), forest (FLT), natural forest succession and forest plantation (NFT), grassland (GLT), water body (WLT), and miscellaneous (MLT) landscapes to assess status and its change at landscape types and landscape levels using landscape pattern metrics.

For basic data analysis, all landscape types in 1987, 2005, and 2007 were compared by the post-classification comparison change detection algorithm to quantify status and change of landscape types.

For landscape ecology analysis, the selected landscape pattern metrics at the class-level, including class area (CA), number of patches (NP), patch density (PD), mean patch size (MPS), mean nearest neighbor distance (MNND), and interspersion and juxtaposition index (IJI), were calculated using the FRAGSTATS software. Meanwhile, 3 landscape metrics at landscape-level, including dominance (D), contagion (C), and fractal dimension (F), were used to compute the whole landscape. In addition, change in the landscape was further analyzed by calculation of the 3-dimensional Euclidean distance that define the distance between landscapes in pattern space as follows:

$$Change = [(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2]^{1/2}$$

where X_1 and X_2 is dominance, Y_1 and Y_2 is contagion, and Z_1 and Z_2 is fractal dimension from 2 dates.

Landscape Type Change Using Post-classification Comparison Algorithm

Distribution of landscape types in 1987, 2005, and 2007 are displayed in Figure 3, while Tables 2 and 3 present the landscape type changes before and after the declaration of the national park as a World Heritage site. It was found that the urban and built-up, grassland, water body, and miscellaneous landscape types had increased by 9.87, 8.17, 30.57, and 42.83 sq. km, respectively, between 1987 and 2005 or with an annual increasing rate of 0.55, 0.45, 1.70, and 2.38 sq. km per year, respectively. On the contrary, the agriculture, forest, and natural forest succession and forest plantation landscape types had lost areas of 9.49, 45.37, and 36.57 sq. km, respectively, or with annual decreasing rates of 0.53, 2.52, and 2.03 sq. km per year, respectively. Most of the natural forest landscape type was converted into agriculture, water body, and miscellaneous landscape types, while most of the natural forest succession and forest plantation landscape type was converted into natural forest, water body, and urban and built-up landscape types.

Similarly, it was found that the urban and built-up, grassland, water body, and miscellaneous landscape types had increased by 0.54, 6.40,

20.32, and 168.62.26 sq. km, respectively, between 2005 and 2007 or with an annual increasing rate of 0.27, 3.20, 10.16, and 84.31 sq. km per year, respectively. On the contrary, the agriculture, forest, and natural forest succession and forest plantation landscape types had lost areas of 136.42, 56.52, and 2.94 sq. km, respectively, or with annual decreasing rates of 68.21, 28.26, and 1.47 sq. km per year, respectively. Most of the natural forest landscape type was converted into miscellaneous, water body, and agriculture landscape types, while most of the natural forest succession and forest plantation landscape type was converted into water body and miscellaneous landscape types.

Status and Change of Landscape Types Using Landscape Metrics

At the class level, the status and change of the landscape type is presented in Table 4 and Figure 4 to describe the composition,

fragmentation, and connectivity and adjacency of landscape types in 2 periods (1987-2005 and 2005-2007). The characteristics of each index are separately summarized and discussed as follows:

Class area (CA), which equals the sum of the area of the corresponding patch type, showed that areas of forest, natural forest succession and forest plantation, and agriculture landscape types had continuously decreased in the 2 periods. At the same time, the urban and built-up, grassland, water body, and miscellaneous landscape types had continuously increased. This result implies that interchange occurs among the landscape types in the 2 periods.

Number of patches (NP) represents an individual class within the landscape and indicates the level of fragmentation in a geographical area. During 1987-2005 the number of patches of all landscape types increased and the most severe fragmentations

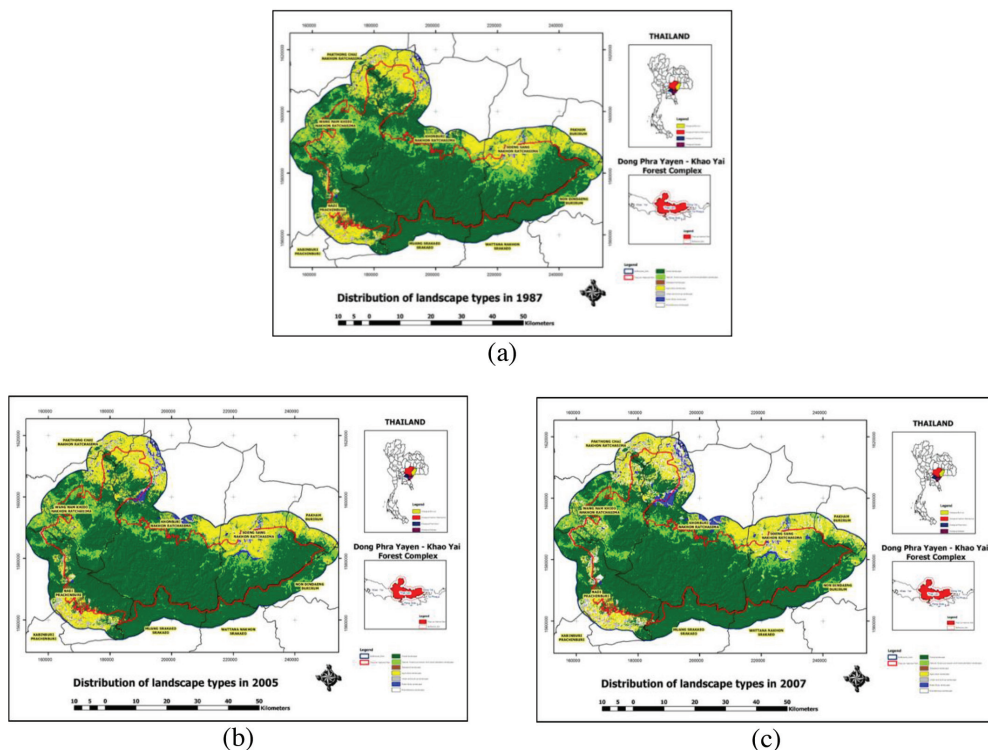


Figure 3. Distribution of landscape types in Thap Lan National Park and its 5 km buffer zone: (a) in 1987, (b) in 2005, and (c) in 2007

were the agriculture, forest, and miscellaneous landscape types. However, the agriculture, forest, natural forest succession and forest plantation, water body, and miscellaneous landscape types were more compact during 2005-2007.

Patch density (PD), which represents the number of patches per unit area, serves as a

comparison of landscapes of different sizes. During 1987-2005, the patch size of all the landscape types decreased, except the natural forest succession and forest plantation type. However, the patch size of the forest, natural forest succession and forest plantation, water body, and miscellaneous landscape types

Table 2 Change matrix of landscape types between 1987 and 2005

Landscape type in 1987	Landscape types in 2005 (Unit: sq. km)							Total
	ULT	ALT	FLT	NLT	GLT	WLT	MLT	
Urban and built-up (ULT)	55.86	0.92	0.13	0.04	0.01	0.05	0.70	57.71
Agriculture (ALT)	5.31	625.77	1.23	0.29	8.82	8.49	28.34	678.25
Forest (FLT)	3.20	40.99	2,539.79	1.80	0.19	15.04	14.96	2,615.97
Natural forest succession and forest plantation (NLT)	2.07	0.54	29.34	334.81	0.04	7.25	0.21	374.26
Grassland (GLT)	0.01	0.08	0.06	0.72	20.41	0.01	0.06	21.35
Water body (WLT)	0.22	0.17	0.01	0.01	0.00	32.34	0.14	32.89
Miscellaneous (MLT)	0.91	0.28	0.04	0.02	0.05	0.28	42.23	43.81
Total	67.58	668.75	2,570.60	337.69	29.52	63.46	86.64	3,824.24
Area of change (sq. km)	9.87	-9.50	-45.37	-36.57	8.17	30.57	42.83	
Rate of annual change (sq. km/year)	0.55	-0.53	-2.52	-2.03	0.45	1.70	2.38	

Table 3. Change matrix of landscape types between 2005 and 2007

Landscape types in 2005	Landscape types in 2007 (Unit: sq. km)							Total
	ULT	ALT	FLT	NLT	GLT	WLT	MLT	
Urban and built-up (ULT)	65.27	0.43	0.26	0.07	0.01	0.07	1.47	67.58
Agriculture (ALT)	1.16	522.84	1.56	0.93	7.07	9.18	126.01	668.75
Forest (FLT)	0.39	7.59	2,511.48	1.04	0.36	9.46	40.28	2,570.60
Natural forest succession and forest plantation (NLT)	0.22	0.48	0.45	332.45	0.03	2.22	1.84	337.69
Grassland (GLT)	0.16	0.38	0.10	0.03	28.37	0.01	0.47	29.52
Water body (WLT)	0.06	0.12	0.03	0.03	0.01	62.45	0.76	63.46
Miscellaneous (MLT)	0.86	0.49	0.20	0.20	0.07	0.39	84.43	86.64
Total	68.12	532.33	2,514.08	334.75	35.92	83.78	255.26	3,824.24
Area of change	0.54		-56.52	-2.94	6.40	20.32	168.62	
Area per annum (sq. km)	0.27	-68.21	-28.26	-1.47	3.20	10.16	84.31	

increased during 2005-2007. This implies that more aggregation occurred in these landscape types.

Mean patch size (MPS), which is an extremely important metric, indicates the level of fragmentation. During 1987-2005, the mean patch size of the forest, natural forest succession and forest plantation, agriculture, and grassland landscape types decreased. This implies that fragmentation occurred in these landscape types in this period. However the forest, natural forest succession and forest plantation, water body, and miscellaneous landscape types were more

compact during 2005 and 2007 because of the increase of mean patch size. At the same time, the urban and built-up, agriculture, and grassland landscape types were more fragmented.

Mean nearest neighbor distance (MNND) represents the average nearest neighbor distance for patches within individual classes at the class level. During 1987-2005 the mean Euclidean nearest neighbor distance of the urban and built-up, agriculture, forest, grassland, water body, and miscellaneous landscape types decreased. This implies more new patches occurring in these landscape types in this period. In contrast,

Table 4. Landscape metric at class level of Thap Lan National Park and its 5 km buffer zone

Year	Landscape type	CA	NP	PD	MPS	MNND	IJI
1987	Urban and built-up (ULT)	5,771.44	156.00	0.02	37.00	686.69	66.05
	Agriculture (ALT)	67,824.00	2,574.00	0.37	26.35	133.93	83.16
	Forest (FLT)		4,097.00	0.59	63.85	120.34	55.87
	Natural forest succession and forest plantation (NLT)	37,425.25	6,570.00	0.95	5.70	155.88	35.84
	Grassland (GLT)	2,134.31	875.00	0.13	2.44	352.55	66.27
	Water body (WLT)	3,289.69	1,544.00	0.22	2.13	250.62	63.33
	Miscellaneous (MLT)	4,380.88	4,241.00	0.61	1.03	163.01	66.61
2005	Urban and built-up (ULT)	6,758.50	180.00	0.03	37.55	583.91	74.42
	Agriculture (ALT)	66,875.25	3,749.00	0.54	17.84	109.40	84.79
	Forest (FLT)		5,473.00	0.79	46.97	106.48	66.07
	Natural forest succession and forest plantation (NLT)	33,768.50	6,571.00	0.95	5.14	156.41	44.71
	Grassland (GLT)	2,951.50	1,639.00	0.24	1.80	250.22	65.64
	Water body (WLT)	6,344.94	1,731.00	0.25	3.67	243.13	75.40
	Miscellaneous (MLT)	8,664.19	6,593.00	0.95	1.31	134.13	67.64
2007	Urban and built-up (ULT)	53,232.81	3,721.00	0.91	14.31	120.92	80.04
	Agriculture (ALT)	6,812.19	191.00	0.34	35.67	594.48	76.61
	Forest (FLT)		4,313.00	0.54	58.29	122.09	70.43
	Natural forest succession and forest plantation (NLT)	33,474.25	6,270.00	0.03	5.34	160.62	51.73
	Grassland (GLT)	3,592.50	2,353.00	0.62	1.53	220.66	72.99
	Water body (WLT)	8,378.25	1,558.00	0.23	5.38	307.82	77.15
	Miscellaneous (MLT)	25,524.06	5,794.00	0.84	4.41	129.18	77.01

new patches of the grassland and miscellaneous landscape types occurred during 2005-2007.

Interspersion and juxtaposition index (IJI), which quantifies patch adjacency and patch configuration for classes or for the entire landscape, measures the adjacency and configuration of 1 class in relation to the other classes at the class level. In the 2 periods, the IJI of the urban and built-up, forest, natural forest and forest plantation, water body, and miscellaneous landscape types continuously increased. This implies that new patches of these landscape types continuously occurred in the 2 periods. Meanwhile, new patches of the agriculture landscape type occurred during 1987-2005 and no new patches of the agriculture

landscape type occurred during 2005-2007. Conversely, no new patches of the grassland landscape type occurred during 1987-2005, but new patches of the grassland landscape type occurred during 2005-2007.

Status and Change of Landscape Using Landscape Pattern Metrics

At the landscape level, all 3 landscape pattern metrics, namely dominance (D), contagion (C), and fractal dimension (F), of Thap Lan National Park and its 5 km buffer zone in 1987, 2005, and 2007 had continued to decrease. In fact, the dominance value decreased from 0.497 in 1987 to 0.461 in 2005 and to 0.412 in 2007, while the contagion value decreased

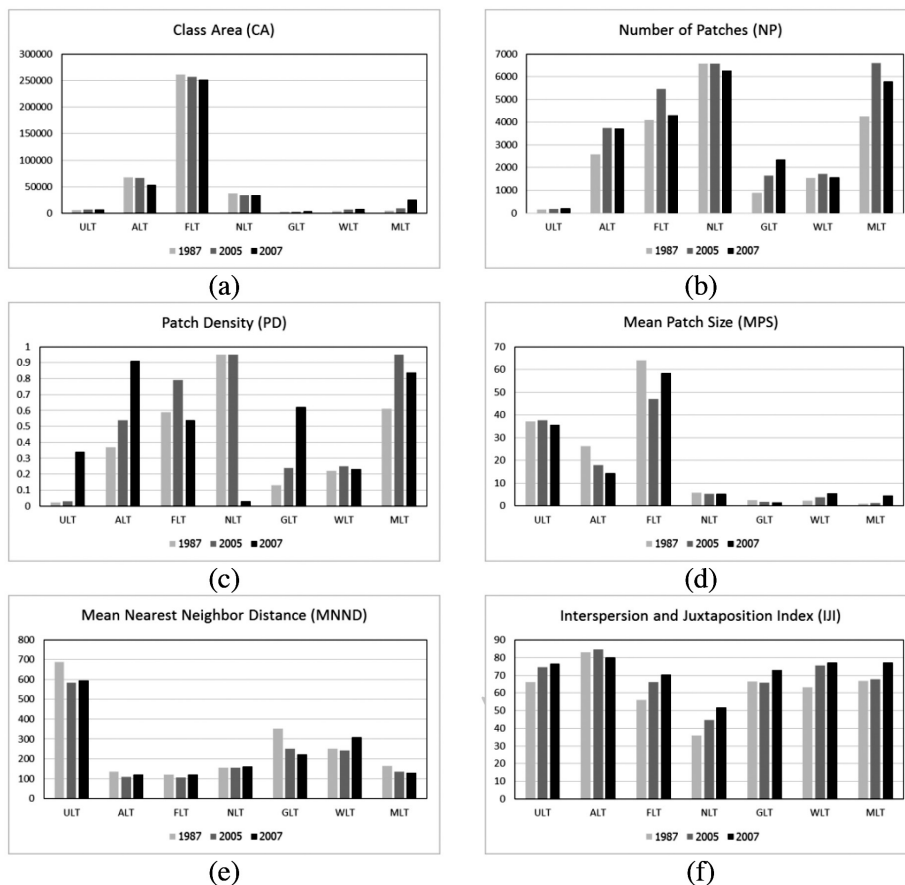


Figure 4. Comparison of landscape metrics at class level of Thap Lan National Park and its 5 km buffer zone: (a) class area, (b) number of patches, (c) patch density, (d) mean patch size, (e) mean nearest neighbor distance, and (f) interspersion and juxtaposition index

from 0.697 in 1987 to 0.673 in 2005 and to 0.645 in 2007. Similarly, the fractal dimension decreased from 1.279 in 1987 to 1.277 in 2005 and to 1.254 in 2007, reflecting that the landscape came to be a simple patch. These results imply that the study area has become a more fragmented landscape in the past 20 years.

In addition, it was found that the landscape change by 3-dimensional Euclidean distance was 0.044 during 1987-2005 and was 0.060 during 2005-2007. These results imply that the change of the landscape in Thap Lan National Park and its 5 km buffer after the declaration of the DPKY - FCWH in 2005 was an increase.

Ongsomwang and Srisuwan (2012) concluded that geoinformatics and landscape metrics can be used to assess and monitor forest resources and land use landscapes types. In addition, 3-dimensional Euclidean distance, which defines the distance between landscapes in pattern space at the landscape level, can be used to define the direction and magnitude of change through time in a long-term monitoring program.

Integration of Remotely Sensed Data and Forest Landscape Pattern Analysis in Sakaerat Biosphere Reserve

Ongsomwang and Sutthivanich (2014) utilized remotely sensed data and forest landscape pattern analysis to determine the priority for forest restoration and management plans in Sakaerat Biosphere Reserve (SBR) in Nakhon Ratchasima, Thailand. SBR is one of 4 biosphere reserve areas which were established to sustain the balance between the goals of conserving biological diversity, promoting economic development, and maintaining cultural values (TISTR, 2014). The specific objectives of the research were to monitor temporal landscape changes during 1980-2010, and 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 plans recommendation.

In this study, 3 sets of high spatial remote sensing data acquired in 1980, 2002, and 2010 were visually interpreted for 9 LULC types

and reclassified into 6 landscape types, including agricultural, natural forest, disturbed forest, forest plantation, urban and built-up, and miscellaneous landscapes. After that, the forest landscape pattern was analyzed by landscape metrics and an evaluation was made of the gain and loss of the natural forest, disturbed forest, and forest plantation landscapes for the forest landscape restoration and management plans recommendation in each management zone of the SBR.

Twelve landscape metrics were applied for the forest landscapes pattern analysis in 4 aspects, including (1) area/density/edge metrics: number of patch (NP), total edge (TE), and edge density (ED); (2) shape metrics: mean shape index (MSI) and mean patch fractal dimension (MPFD); (3) core area metrics: total core area (TCA), mean core area (MCA), total core area index (TCAI), and core area density (CAD); and (4) interspersions/isolation metrics: interspersions and juxtaposition index (IJI), mean proximity index (MPI), and mean nearest neighbor distance (MNND). Then, the trends of change on an increasing (gain) or decreasing (loss) basis 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 the forest landscape restoration and management plans in terms of forest ecology context with the following conditions:

Condition of landscape metrics	Interpretation of ecological context		Priority	Score
	1980-2002	2002-2010		
1	gain	gain	Low	1
2	loss	gain	Moderate	3
3	gain	loss	High	5
4	loss	loss	Urgent	7

After that, the simple additive weighting (SAW) method with an equal weight was applied to justify the final priority level for the restoration and management plans in each of the forest landscape types. The overall score (12 to 84) from the SAW operation was equally divided into 4 priority levels: low (12.0-30.0), moderate

(30.0-48.0), high (48.0-66.0), and urgent (66.0-84.0). The final priority levels for the forest landscape restoration and management plans of each of the forest landscape types in the SBR management zones were, therefore, derived for the forest landscape restoration and management plans recommendations associated with the purposes and regulations of the biosphere reserve establishment.

Landscape Type Distribution and Assessment in SBR

The areas and percentages of the SBR landscape types during 1980 to 2010 are reported

in Table 5. The classification 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 agriculture landscape. On the contrary, the least dominant landscape type was miscellaneous landscape, including water body, which covered an area of 1.29% in 1980 but slightly increased from 3.4% to 3.64% in 2002 and 2010, respectively.

The distribution of forest landscapes over the SBR management zones, the core, buffer,

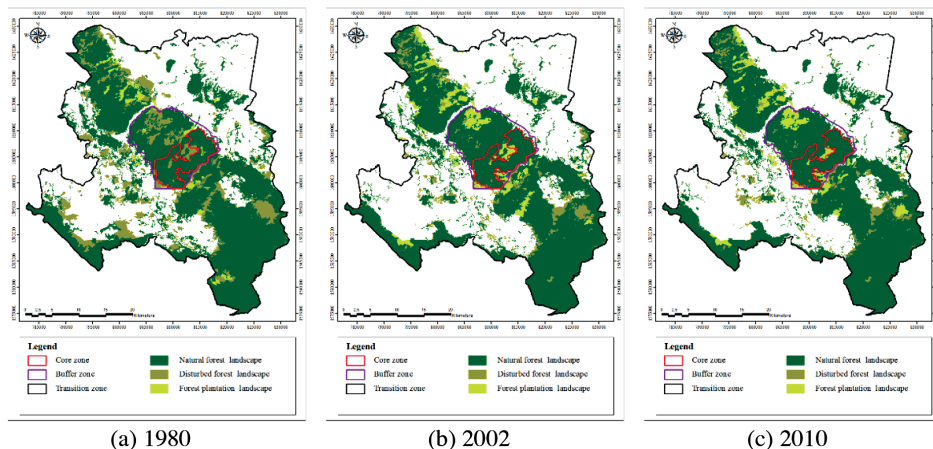


Figure 5 Forest landscape type distribution in each SBR management zone: (a) in 1980, (b) in 2002, and (c) in 2010

Table 5. Areas and percentages of SBR landscape types from 1980 to 2010

Landscape Type	1980		2002		2010	
	Area (sq. km)	%	Area (sq. km)	%	Area (sq. km)	%
Agricultural	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	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

and transition zones, is presented in Figure 5, whereas the areas and percentages are reported in Table 6. It was found that the 3 SBR management 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. Similarly, the forest plantation landscape exhibited an increasing trend in the buffer and transition zones from 2.62% to 17.43%, and from 2.88% to 6.01%, respectively. On the other hand, the disturbed forest landscape showed the reverse trend, decreasing in all the management zones, particularly in the buffer and transition zones, which showed it sharply decreased from 24.65% to 2.26% and 17.57% to 9.02%, respectively.

Forest Landscape Pattern Analysis in SBR Management Zones

Landscape pattern analysis focused on

the forest landscapes, including natural forest, disturbed forest, and forest plantation landscapes, based on the 12 selected landscape indices in 4 landscape pattern measurements. The interpretation of the landscape pattern metrics are summarized in Table 7 and separately described and discussed for each of the forest landscapes in each management zone as followings:

Natural Forest Landscape Metric Analysis

In the core zone, area/density/edge metrics (NP, TE, and ED) were slightly changed and revealed less fragmentation, whereas, shape metrics (MPFD and MSI) implied that the shape complexity was rather stable. Similarly, core area metrics (TCA, MCA, TCAI, and CAD) were very slightly changed indicating that the core areas were somewhat stable. Meanwhile, interspersions/isolation metrics (IJI, MPI, and

Table 6. Areas and percentages of forest landscape types in SBR management zones from 1980 to 2010

1980	Core zone		Buffer zone		Transition zone	
	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%
Natural forest landscape	53.52	93.52	77.41	72.73	623.7	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	106.44	100	784.01	100
2002	Core zone		Buffer zone		Transition zone	
	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%
Natural forest landscape	55.13	96.36	81.70	78.32	587.7	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	57.21	100	104.31	100	706.97	100
2010	Core zone		Buffer zone		Transition zone	
	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%
Natural forest landscape	55.61	97.19	83.4	80.31	585.77	84.97
Disturbed forest landscape	0.54	0.95	2.35	2.26	62.21	9.02
Forest plantation landscape	1.06	1.86	18.1	17.43	41.43	6.01
Total area	57.21	100	103.85	100	689.41	100

Table 7. Landscape indices assessment in each SBR management zone for each forest landscape

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	21/94	6/614	4/711	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	302.25/-9.06
	ED(m/m ²)	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/-0.00/-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	98.11/75.54/79.48	0.33/7.95/2.64	0.02/-0.36/-1.11
	CAD (ha)	0.050.33/0.10	0.050.14/0.28	0.050.16/0.23	0/-0.19/0.18	0.00/0.02/-0.05
	III	93.17/12.62/20.47	86.87/3.49/45.65	95.92/63.54/8.72	-6.30/60.87/25.18	9.05/-9.84/3.07
	NPI	59.45/10.42/0.58	72.46/5.81/6.70	93.47/14.38/3.12	13.00/-6.61/6.12	21.00/10.77/-3.38
	MNND (m)	21.21/463.48/172.45	26.28/720.79/202.98	31.92/279.25/450.65	5.07/257.31/20.53	5.64/-341.54/247.67
	NP	29/35/16	43/31/14	41/29/10	14/-4/-2	-2/-2/-4
Buffer	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/m ²)	34.33/20.92/3.19	29.90/6.39/11.97	28.05/5.51/10.68	-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	1.11/1.10/1.10	0.00/0.00/-0.01	0.00/0.00/0.01
	TCA (ha)	7.356.33/2.389.73/243.63	7.845.33/247.90/1.810.30	8.035.11/178.24/1.691.1	488.82/2.141.83/1.566.7	189.76/-69.66/-19.29
	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	96.01/78.09/93.41	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
	III	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
	NPI	7.500.67/704.85/13.42	7.956.58/4.24/1.455.46	15.197.95/31.54/91.72	455.91/-670.61/1.442.04	7.241.37/2.70/1.363.74
	MNND (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
	NP	42/54/30.100	484/389/85	463/380/85	59/-41/-15	-21/-90
	TE (km)	3.499.81.590.06/279.840	3.375.84/1.25/0.84/61.12	2.970.84/1.131.56/593.16	-123.96/334.98/181.28	-405/123.52/-67.96
	ED(m/m ²)	44.64/20.38/3.57	47.75/17.75/6.52	43.09/16.41/5.70	3.11/-2.53/2.95	-4.66/-1.34/-0.82
Transition	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)	58.722.23/12.18.48/1.955.84	54.234.8/5.586.2/4.008.28	54.384.116/4.711.28/3.592.96	-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	34.276.85/3.27	-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)	2.400.88/0.14	2.62/1.01/0.17	2.31/1.00/0.16	0.22/0.13/0.03	-0.31/-0.01/-0.01
	III	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
	NPI	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	-2.256.15/2.83/43.88
	MNND (m)	143.13/214.33/608.09	120.45/285.50/654.78	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

MNND) showed a trend of aggregation to each other.

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

In the transition zone, area/density/edge metrics fluctuated during the periods, indicating some occurrences of fragmentation and compactness due to human activities (i.e., forest disturbance or forest enrichment). Concurrently, shape and core area metrics slightly changed and revealed rather stable stages. Meanwhile, interspersions/isolation metrics showed the trends of dispersal, 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, area/density/edge metrics had a high degree of change which implied compactness and less fragmentation, for example the number of patches in 1980, 2002, and 2010 varied with 19, 6, and 7, respectively. Shape metrics revealed a stable complexity stage. Meanwhile, core area metrics decreased implying that a core area of disturbed forest was dramatically lost. Similarly, interspersions/isolation metrics highly fluctuated and implied a dynamic of dispersal; for example MPI index values indicated a change variation in these periods of 10.42, 3.81, and 14.58, respectively, while the MNND index fluctuated between 463.48, 720.79, and 379.25, respectively.

In the buffer zone, area/density/edge metrics were decreased indicating less fragmentation occurring in the disturbed forest landscape. At the same time, shape metrics revealed a rather stable complexity stage. Meanwhile, core area metrics had highly decreased which implied that there was a loss of the core area of the disturbed forest landscape. In contrast, interspersions/isolation metrics

showed a dispersal of disturbed forest patches away from each other.

In the transition zone, area/density/edge metrics were decreased and implied less fragmentation and compactness. At the same time, shape metrics revealed a rather stable complexity stage. In contrast, core area indices were decreased which implied a decreasing core area of the disturbed forest landscape. Meanwhile, interspersions/isolation metrics showed trends in dispersal and isolation.

Forest Plantation Landscape Metrics Analysis

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

In the buffer zone, area/density/edge metrics were decreasing and implied that the forest plantation became more aggregated. Likewise, shape metrics revealed a rather stable complexity. This indicated man management in the forest plantation. Meanwhile, core area metrics had slightly changed and implied that the core areas were in a relatively stable stage. In contrast, interspersions/isolation metrics showed some degree of dispersal.

In the transition zone, area/density/edge metrics were decreased and implied that less fragmentation and compactness occurred in the forest plantation landscape. Shape metrics revealed a rather stable complexity. Similarly, core area metrics had slightly changed and implied that the core areas were relatively stable. Meanwhile, interspersions/isolation metrics showed a trend in even distribution and isolation for forest plantation patches.

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

According to the landscape change, increasing or decreasing landscape indices of each of the forest landscape types in the SBR management zones occurred in 2 periods (1980-2002 and 2002-2010) (Table 7); the gain and loss (score values) in terms of forest ecology and the final derived priority levels for the restoration and management plans by the SAW operation for each forest landscape type in each

management zone of the SBR are reported in Table 8. These results dictated the priority level for the forest restoration and management plans. Meanwhile, details of the recommendations for the restoration and management plans of the SBR are summarized, as shown in Table 9, based on the typical forest restoration and management plan concepts that were suggested by many researchers including Sahunalu *et al.*, 1993; Hobbs and Norton, 1996; Noss, 1999; Stanturf *et al.*, 2001; Van Diggelen *et al.*, 2001; Botequilha-Leitao and Ahern, 2002; Stanturf and Madsen, 2002; Nagendra and Southworth, 2010.

Table 8. Evaluation on gain and loss for priority level set-up based on each landscape metrics change and the final score and priority level for the restoration and management plans in each forest landscape type of each SBR management zone

Landscape Metrics	Natural Forest Landscape		Priority (Score)	DisturbedForest Landscape		Priority (Score)	Forest Plantation Landscape		Priority (Score)
	1980-2002	2002-2010		1980-2002	2002-2010		1980-2002	2002-2010	
Core zone									
NP	Loss	Gain	Moderate	Gain	Loss	High	Loss	Gain	Moderate
TE	Gain	Loss	High	Gain	Loss	High	Loss	Gain	Moderate
ED	Gain	Loss	High	Gain	Loss	High	Loss	Gain	Moderate
MSI	Loss	Gain	Moderate	Gain	Gain	Low	Loss	Loss	Urgent
MPFD	Gain	Loss	High	Gain	Loss	High	Loss	Loss	Urgent
TCA	Gain	Gain	Low	Loss	Gain	Moderate	Gain	Loss	High
MCA	Gain	Gain	Low	Loss	Gain	Moderate	Loss	Loss	Urgent
TCAI	Gain	Gain	Low	Loss	Loss	Urgent	Gain	Loss	High
CAD	Gain	Gain	Low	Loss	Gain	Moderate	Gain	Loss	High
IJI	Loss	Gain	Moderate	Gain	Loss	High	Gain	Gain	Low
MPI	Loss	Loss	Urgent	Gain	Loss	High	Loss	Gain	Moderate
MNND	Loss	Loss	Urgent	Loss	Gain	Moderate	Loss	Loss	Urgent
Overall score	42			50			56		
Priority level for planning	Moderate			High			High		
Buffer zone									
NP	Loss	Gain	Moderate	Gain	Gain	Low	Gain	Gain	Low
TE	Gain	Gain	Low	Gain	Gain	Low	Loss	Gain	Moderate
ED	Gain	Gain	Low	Gain	Gain	Low	Loss	Gain	Moderate
MSI	Loss	Loss	Urgent	Loss	Loss	Urgent	Gain	Gain	Low
MPFD	Gain	Gain	Low	Gain	Gain	Low	Loss	Gain	Moderate
TCA	Gain	Gain	Low	Loss	Loss	Urgent	Gain	Loss	High
MCA	Loss	Gain	Moderate	Loss	Loss	Urgent	Gain	Gain	Low
TCAI	Gain	Gain	Low	Loss	Loss	Urgent	Gain	Gain	Low
CAD	Gain	Loss	High	Gain	Loss	High	Gain	Loss	High
IJI	Gain	Loss	High	Gain	Loss	High	Loss	Loss	Urgent
MPI	Loss	Loss	Urgent	Gain	Gain	Low	Loss	Gain	Moderate
MNND	Gain	Loss	High	Loss	Loss	Urgent	Gain	Loss	High
Overall score	40			50			38		
Priority level for planning	Moderate			High			Moderate		
Transition zone									
NP	Loss	Gain	Moderate	Gain	Gain	Low	Gain	Loss	High
TE	Gain	Gain	Low	Gain	Gain	Low	Loss	Gain	Moderate
ED	Loss	Gain	Moderate	Gain	Gain	Low	Loss	Gain	Moderate
MSI	Loss	Loss	Urgent	Gain	Loss	High	Gain	Loss	High
MPFD	Loss	Gain	Moderate	Gain	Gain	Low	Gain	Loss	High
TCA	Loss	Gain	Moderate	Loss	Loss	Urgent	Gain	Loss	High
MCA	Loss	Gain	Moderate	Loss	Loss	Urgent	Gain	Gain	Low
TCAI	Loss	Gain	Moderate	Loss	Loss	Urgent	Loss	Gain	Moderate
CAD	Gain	Loss	High	Gain	Loss	High	Gain	Loss	High
IJI	Gain	Loss	High	Gain	Loss	High	Loss	Gain	Moderate
MPI	Gain	Gain	Low	Gain	Loss	High	Gain	Loss	High
MNND	Gain	Loss	High	Loss	Loss	Urgent	Loss	Gain	Moderate
Overall score	42			52			46		
Priority level for planning	Moderate			High			High		

Ongsomwang and Sutthivanich (2014) concluded that 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 forest resources restoration and management plans.

Table 9. Restoration and management plans for forests landscapes of 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 regular monitoring 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 regular monitoring by patrolling.	Minimal requirement for management by forest patrolling, forest fire prevention, and regular forest patrol.
Buffer	Natural Forest	Moderate	Moderate requirement for restoration by rehabilitation and regular monitoring 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 regular forest fire control.	High requirement for management by forest fire prevention, rehabilitation, and reforestation.
	Forest Plantation	Moderate	Moderate requirement for restoration by tree enrichment and regular monitoring 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 and regular forest patrol 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 regular forest fire control.	Moderate requirement for management in government land by forest fire prevention and reforestation.
	Forest Plantation	High	High requirement for restoration by reforestation in government land and regular forest patrol and forest fire prevention.	Moderate requirement for management in government land by forest patrolling, forest fire prevention, and reforestation.

Key Research Topic in Landscape Ecology

Due to the growth of landscape ecology in both theory and practice, Wu and Hobbs (2002) synthesized and suggested the top 10 priority research topics that covered a wide range of theoretical, methodological, and applied issues including (1) ecological flows in landscape mosaics, (2) causes, processes, and consequences of land use and land cover change, (3) nonlinear dynamics and landscape complexity, (4) scaling, (5) methodological development, (6) relating landscape metrics to ecological processes, (7) integrating humans and their activities into landscape ecology, (8) optimization of landscape patterns, (9) landscape sustainability, and (10) data acquisition and accuracy assessment.

Recently, Wu (2013) has revised the suggested 10 key research topics due to the advances in the field of landscape ecology, as follows:

(1) Pattern–process–scale relationships of landscapes. Developing and testing hypotheses and principles of the flows and redistributions of organisms, materials, and energy in dynamic landscape mosaics of different types; developing a landscape mosaic theory of population, community, and ecosystem processes.

(2) Landscape connectivity and fragmentation. Typology, measurements, and ecological relevance of different kinds of connectivity; ecological and genetic effects and mechanisms of connectivity and fragmentation; relative importance of and interactions between habitat loss and fragmentation per se in dynamic landscapes.

(3) Scale and scaling. Underlying mechanisms of scale effects; scaling relations; effective scaling methods; hierarchical linkages of patterns and processes across landscapes in space and time.

(4) Spatial analysis and landscape modeling. Relating landscape metrics and spatial statistics to ecological functions; developing landscape functional indicators; promoting use-inspired, place-based, and mechanistic landscape models.

(5) Land use and land cover change. Developing a general understanding of the relationship among spatiotemporal patterns, drivers, and ecological impacts of land use and land cover change; the relationship of biodiversity, ecosystem function, and environmental conditions to dynamic land use and land cover patterns; understanding and predicting ecological and environmental effects of urbanization on multiple scales.

(6) Landscape history and legacy effects. Documenting and understanding impacts of past land use and historical events on biodiversity and ecological processes in different types of landscapes; developing a general understanding of landscape legacy effects on the composition, configuration, and functions of the present and future landscapes.

(7) Landscape and climate change interactions. Understanding the effects of a changing landscape pattern on local and regional climate processes; landscape-based approaches to climate change mitigation and adaptation; landscape ecological studies of urban heat islands.

(8) Ecosystem services in changing landscapes. Characterizing and quantifying spatiotemporal patterns, source-sink dynamics, tradeoffs, and synergistic interactions of provisioning, regulating, and cultural ecosystem services at the landscape and regional levels; assessing and projecting responses of these ecosystem services to environmental and landscape changes; developing place-based landscape theories of ecosystem services.

(9) Landscape sustainability. Dynamic relationship between landscape/ ecosystem services and human well-being; policy impacts on the relationship; alternative ways of sustaining ecosystem services and human well-being particularly through landscape design and planning as longitudinal experiments; key factors and mechanisms of landscape resilience and its relationship to landscape sustainability.

(10) Accuracy assessment and uncertainty analysis. Systematically assessing the accuracy of landscape analysis based on multi-source and multi-scale datasets; quantifying scaling errors;

categorizing the kinds, causes, and consequences of uncertainties in landscape studies; developing solutions to uncertainty problems; evaluating implications of uncertainties in landscape research for management and policy making.

Conclusions

Forest assessment in Thailand has been developed by the RFD since 1973 and has continuously been implemented by the responsible unit, namely the Forest Survey and Assessment Division of the Forest Management Office, until the present time. The derived datasets on forest assessment are directly applied for forest management in multi-aspects such as forest rehabilitation, conservation, protection, and prevention. Concurrently, landscape ecology, which is an interdisciplinary and transdisciplinary science of understanding and improving the relationships between spatial patterns and ecological processes on a range of scales (Wu, 2013), plays an important role as a tool for solving problems about resource management and conservation. Unfortunately, concepts and principles of landscape ecology which provide more valuable information to forest managers or researchers do not apply to the existing forest assessment datasets. Therefore, the application of landscape ecology on forestry in multi-aspects including forest management, forest rehabilitation, forest conservation, protection, and prevention will be a challenge to forest managers and researchers. However, successful projects or research works require an understanding of the basic landscape elements and their interrelationships between spatial patterns and ecological processes for making better management and decisions, especially the interpretation of landscape metrics in terms of ecology for forest management.

Reference

- Allen, T.F.H. and Starr, T.B. (1982). *Hierarchy, Perspectives for Ecological Complexity*. The University of Chicago Press, Chicago, IL, USA, 310p.
- Botequilha-Leitao, A. and Ahern, J. (2002). Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape Urban Plan.*, 59(2):65-93.
- Bourgeron, P.S. and Jensen, M.E. (1994). An overview of ecological principles for ecosystem management. In: *Ecosystem Management: Principles and Application*. Jensen, M.E. and Bourgeron, P.S., (eds). Oregon State University, Portland, OR, USA, p. 45-57.
- Burel, F. and Baudry, J. (2003). *Landscape Ecology: Concepts, Methods and Applications*. Science Publishers, Inc., Enfield, NH, USA, 378p.
- Charupatt, T. (1998). Forest Situation of Thailand in the Past 37 Years (1961-1998). *Forest Resources Assessment Division, RFD, Bangkok*, 116p. (in Thai)
- Farina, A. (1998). *Principles and Methods in Landscape Ecology*. Chapman and Hall, London, UK, 235p.
- Farina, A. (2010). *Ecology, Cognition and Landscape: Linking Natural and Social Systems*. Springer Science & Business Media, Dordrecht, Netherlands, 169p.
- Forman, R.T.T. and Godron, M. (1986). *Landscape Ecology*. John Wiley & Sons, NY, USA, 619p.
- Forman R.T.T. (1995). *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge University Press, Cambridge, UK, 632p.
- Franklin, S.E. (2001). *Remote Sensing for Sustainable Forest Management*. CRC Press LLC, Boca Raton, FL, USA, 470p.
- Frohn, R.C. (1998). *Remote Sensing for Landscape Ecology: New Metric Indicators for Monitoring, Modeling, Assessment of Ecosystems*. CRC Press LLC, Boca Raton, FL, USA, 99p.
- Gardner, R.H., Milne, B.T., Turner, M.G., and O'Neill, R.V. (1987). Neutral models for the analysis of broad-scale landscape pattern. *Landscape Ecol.*, 1(1):19-28.
- GIZ (Gesellschaft für International Zusammenarbeit). (2012). *Committed to Biodiversity*. Metzgerdruck GmbH, Obrigheim, Germany, 71p.
- Häusler, T., Akgöz, E., Gallaun, H., Schardt, M., Ekstrand, S., Löfmark, M., Lagarde, I., Pelz, D.R. and Obergföll, P. (2000). *Monitoring Changes and Indicators for Structural Diversity of Forested Areas* [Online]. Available from: http://rogow99.sggw.waw.pl/08_session_4/07/.
- 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, NY, USA, 467p.
- Klankamsorn, B. (1992). *GIS and Tropical Forest Monitoring*. In *Proceedings of the UFRO S4.02.05: Remote Sensing and Permanent Plot Techniques for World Forest Monitoring*;

- Kasetsart University, Bangkok, p. 195-198.
- Klopatek, J.M. and Gardner, R.H. (eds). (1999). *Landscape Ecological Analysis: Issues and Applications*. Springer Verlag, New York, NY, USA, 400p.
- Levin, S. A. (1978). Pattern formation in ecological communities. In: *Spatial Pattern in Plankton Communities*. Steele, J.S., (ed.). American Mathematical Society, Providence, RI, USA, p. 77-107.
- Levins, R. (1970). Extinction. In: *Some Mathematical Questions in Biology*. (Lectures in Mathematics in the Life Sciences). Gertenshaubert, M., (ed.). American Mathematical Society, Providence, RI, USA, p. 77-107.
- Lindenmayer, D.B, Margules, C.R., and Botkin, D.B. (2000). Indicators of biodiversity for ecologically sustainable forest management. *Conserv. Biol.*, 14(4):941-950.
- Lindenmayer, D. (2009). *Forest Pattern and Ecological Process: a Synthesis of 25 Years of Research*. CSIRO Publishing, Collingwood, Vic., Australia, 320p.
- 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, OR, USA, 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 from: <http://www.umass.edu/landeco/research/fragstats/fragstats.html>.
- Nagendra, H. and Southworth, J. (2010). *Reforestation Landscapes: Linking Pattern and Process*. Springer Science, New York, NY, USA, 386p.
- Naveh, Z. and Lieberman, A.S. (1990). *Landscape Ecology: Theory and Application*. Springer Science & Business Media, NY, USA, 356p.
- Nielsen, N. C. (2001). The potential of landscape metrics from remote sensing data as indicators in forest environment [On-line]. Available from: http://www2.dmu.dk/1_Viden/2_Miljoe-tilstand/3_natur/nordlam/nldocs/wsOct01T4/NielsChrNielsen.pps.
- Noss, R.F. (1999). Assessing and monitoring forest biodiversity: A suggested framework and indicators. *Forest Ecol. Manag.*, 115:135-146.
- Oliver, C.D. and Larson, B.C. (1996). *Forest Stand Dynamics*. John Wiley & Sons, NY, USA, 520p.
- O'Neill, R.V., DeAngelis, D.L., Waide, J.B., and Allen, T.F.H. (1986). *A Hierarchical Concept of Ecosystems*. Princeton University Press, Princeton, NJ, USA, 257p.
- Ongsomwang, S. (2001). *National Policy, Planning and Management of Mangrove Forest*. Paper presented at the International Workshop on Mangrove Forests; Pathum Thani, Thailand, 7p.
- Ongsomwang, S. (2002). *Forest Assessment and Conservation in Thailand*. Paper presented at the Workshop on Tropical Forest Assessment and Conservation Issues in Southeast Asia; February 12-14, 2002; Dehra Dun, India, 10p.
- Ongsomwang, S. and Srisuwan, A. (2012). Integration of geoinformatics and landscape metrics for forest resources assessment in Thap Lan National Park. *Thai J. For.* 31(2):29-41.
- Ongsomwang, S. and Sutthivanich, I. (2014). Integration of remotely sensed data and forest landscape pattern analysis in Sakaerat Biosphere Reserve. *Suranaree J. Sci. Technol.* Available from: <http://ird.sut.ac.th/ejournal/Journal/pdf/1303634.pdf>.
- 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, Dordrecht, Netherlands, p. 198-215.
- Pulliam, H.R. (1988). Sources-sinks, and population regulation. *Am. Nat.*, 132:652-661.
- Pulliam, H.R. (1996). Sources and sinks: Empirical evidence and population consequences. In: *Population Dynamics in Ecological Space and Time*. Rhodes, O.E., Chesser, R.K., and Smith, M.H., (eds.). The University of Chicago Press, Chicago, IL, USA, p. 105-127.
- Rommel, T.K. and Csillag, F. (2003). When are two landscape pattern indices significantly different? *J. Geogr. Syst.*, 5:331-351.
- Royal Forest Department. (2013). *Forestry Statistics Data 2013*. Royal Forest Department, Bangkok, Thailand, 152p.
- Sabhasri, S., Cheosakul, P., Indrambarya, B., and Vibulsresth, S. (1980). *National remote sensing program of Thailand*. Proceedings of the 1st Asian Conference on Remote Sensing; November 5-7, 1980; Bangkok, Thailand.
- 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 of Thailand. Faculty of Forestry, Kasetsart University, Bangkok, Thailand.
- Stanturf, J.A., Schoenholtz, S.H., Schweitzer, C.J., and Shepard, J.P. (2001). Indicators of 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.
- TFSMP. (1993). *Thai Forestry Sector Master Plan*. Volume 5 Subsectoral plan for people and forestry environment. RFD, Bangkok, Thailand, 192p.
- TISTR. (Thailand Institute of Scientific and Technological

- Research). (2009). General information. Available from: www.tistr.or.th/sakaerat/index.php. Accessed date: Oct 29, 2014.
- Turner, M.G. (1989). Landscape ecology: The effect of patterns on process. *Annu. Rev. Ecol. Syst.*, 20:171-197.
- Turner, M.G. and Gardner, R.H. (eds). (1990) *Quantitative Methods in Landscape Ecology*. Springer Verlag, New York, NY, USA, 536p.
- Turner, G.M., Gardner, R.H., and O'Neill, R.V. (2001). *Landscape Ecology in Theory and Practice: Pattern and Process*. Springer Verlag, New York, NY, USA, 401p.
- UNESCO (United Nations Educational, Scientific and Cultural Organization). (2010). Dong Phrayayen - Khao Yai Forest Complex. Available from <http://whc.unesco.org/en/list/590>. Accessed date: Oct 29, 2014.
- 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*. 2nd ed. Academic Press, San Diego, CA, USA, 370p.
- Wiens, J. and Moss, M. (eds). (2005). *Issues and Perspectives in Landscape Ecology*. Cambridge University Press, Cambridge, UK, 390p.
- Wu, J. and Hobbs, R. (2002). Key issues and research priorities in landscape ecology: an idiosyncratic synthesis. *Landscape Ecol.*, 17:355-365.
- Wu J., and Hobbs, R. (eds). (2007). *Key Topics in Landscape Ecology*. Cambridge University Press, Cambridge, UK, 297p.
- Wu, J. (2013). Key concepts and research topics in landscape ecology revisited: 30 years after the Allerton Park workshop. *Landscape Ecol.*, 28:1-11.
- Wulder, M.A., Hall, R.J., Coops, N., and Franklin, S.E. (2004). High spatial detail remotely sensed data for ecosystem characterization. *BioScience*, 54(6) 511-521.
- Zonneveld, I.S. (1989). The land unit-a fundamental concept in landscape ecology, and its applications. *Landscape Ecol.*, 3:67-86.