INTEGRATION OF LANDSCAPE ECOLOGY METRICS WITH REMOTELY SENSED DATA FOR FOREST RESTORATION AND MANAGEMENT IN SAKAERAT BIOSPHERE RESERVE, NAKHON RATCHASIMA, THAILAND

Intareeya Sutthivanich

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Geoinformatics

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การบูรณาการดัชนีนิเวศภูมิทัศน์ด้วยข้อมูลจากระยะไกล เพื่อการฟื้นฟูและการจัดการป่าไม้ ในพื้นที่สงวนชีวมณฑลสะแกราช นครราชสีมา ประเทศไทย

นางสาวอินทรียา สุทธิวานิช

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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อินทรียา สุทธิวานิช : การบูรณาการดัชนีนิเวศภูมิทัศน์ด้วยข้อมูลจากระยะไกล เพื่อการฟื้นฟูและการจัดการป่าไม้ ในพื้นที่สงวนชีวมณฑลสะแกราช นครราชสีมา ประเทศไทย (INTEGRATION OF LANDSCAPE ECOLOGY METRICS WITH REMOTELY SENSED DATA FOR FOREST RESTORATION AND MANAGEMENT IN SAKAERAT BIOSPHERE RESERVE, NAKHON RATCHASIMA, THAILAND) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.สุวิทย์ อ๋องสมหวัง, 180 หน้า.

งานวิจัยนี้มีเป้าหมายเพื่อตรวจสอบการเปลี่ยนแปลงทางด้านรูปแบบ นิเวศภูมิทัศน์ในพื้นที่สงวนชีวมณฑลสะแกราช โดยมีวัตถุประสงค์หลักคือ (1) จำแนกและประเมินการเปลี่ยนแปลงประเภทการใช้ที่ดินและสิ่งปกคลุมดินในหลายช่วงเวลา (2) ตรวจวัดและประเมินการเปลี่ยนแปลงรูปแบบภูมิทัศน์และภูมิทัศน์ป่าไม้ โดยใช้ดัชนีนิเวศภูมิทัศน์ และ (3) เสนอแนะแผนการฟื้นฟูและแผนการจัดการภูมิทัศน์ป่าไม้

ผลการศึกษาการจำแนกและประเมินการเปลี่ยนแปลง การใช้ที่ดินและสิ่งปกคลุมดิน ใน 9 ประเภทการใช้ที่ดินและสิ่งปกคลุมดิน พบว่า ประเภทการใช้ที่ดินและสิ่งปกคลุมดินเด่น ได้แก่ ป่าธรรมชาติ พืชไร่ และที่นา ซึ่ง ครอบครองพื้นที่ ส่วน ใหญ่ ของ พื้นที่ศึกษา การ ประเมิน การเปลี่ยนแปลงที่เกิดขึ้นในพ.ศ. 2523 2545 และ 2553 พบว่าความผกผันเกิดขึ้นมากในพื้นที่ป่าไม้โดยป่าธรรมชาติ มีการเปลี่ยนแปลง ลดลงในพ.ศ. 2523-2545 แต่มีแนวโน้มคงที่ ในพ.ศ. 2545-2553 เพราะเหตุนี้ พื้นที่ป่า ถูกบุกรุกอย่างรุนแรงเกิดขึ้นในพ.ศ. 2523-2545 และมีแนวโน้มลดลงต่อเนื่องในพ.ศ. 2545-2553

ผลการประเมินรูปแบบนิเวศภูมิทัศน์ใน 6 ประเภทภูมิทัศน์ พบว่าภูมิทัศน์ป่าธรรมชาติเป็นภูมิทัศน์หลัก ตามด้วยภูมิทัศน์การเกษตรและภูมิทัศน์ป่าที่ถูกบุรุก นอกจากนี้ การเปลี่ยนแปลงสภาพภูมิทัศน์ เกิดขึ้นมากในภูมิทัศน์ป่าที่ถูกบุกรุก ภูมิทัศน์ป่าปลูก และภูมิทัศน์เมืองและสิ่งปลูกสร้าง สำหรับการวิเคราะห์ ค่าดัชนีนิเวศภูมิทัศน์ 14 ดัชนี ได้แก่ การแตกแยกออกจากกัน ความซับซ้อนของรูปร่าง พื้นที่ภายใน และความหลากหลาย /การกระจายตัว /ความ ห่างไกล พบว่ารูปแบบภูมิทัศน์ของพื้นที่สงวนชีวมณฑล สะแกราชมีการเปลี่ยนแปลงผันแปรในด้านการแตกแยกออกจากกัน ความซับซ้อนของรูปร่าง พื้นที่ภายใน และความหลายหลาก โดยเกิดการแตกแยกออกจากกันและ มีความหลากหลายมากขึ้น แต่ความซับซ้อนของรูป ร่างและขนาดพื้นที่ภายในลดลงในพ.ศ. 2523-2545 และค่าดัชนีทั้งหมด มีการเปลี่ยนแปลงเล็กน้อยตั้งแต่ พ.ศ. 2545-2553 ในขณะเดียวกัน แนวโ น้มของการแปลงแปลงในทิศทางที่มากขึ้นหรือน้อยลงของค่าดัชนีภูมิทัศน์ป่าธรรมชาติ ภูมิทัศน์ป่าที่ถูกบุกรุก และภูมิทัศน์ป่าปลูก ในแต่ละเขตการจัดการ (เขตแกนกลาง เขตกันชน และเขตรอบนอก) ของพื้นที่สงวนชีวมณฑลสะแกราชได้ถูกนำมาใช้เชื่อมโยงในด้านการได้

และเสียในเชิงนิเวศภูมิทัศน์ เพื่อจัดระดับความสำคัญในการเสนอแนะแผนการฟื้นฟูและ แผนการจัดการภูมิทัศน์ป่าไม้ ผลการประเมินพบว่าระดับความสำคัญของภูมิทัศน์ป่าธรรมชาติและภูมิทัศน์ป่าที่ถูก บุกรุกอยู่ในระดับปานกลาง และสูง ตามลำดับในทุกเขตการจัดการ ในขณะที่ระดับความสำคัญของภูมิทัศน์ป่าปลูกอยู่ในระดับสูงในเขตแกนกลางและเขตรอบนอก ส่วนเขตกันชนอยู่ในระดับปานกลาง

ดังผลที่ได้รับ การเสนอแนะแผนการฟื้นฟูและ แผนการจัดการในภูมิทัศน์ป่าธรรมชาติ ภูมิทัศน์ป่าที่ถูกบุกรุกและภูมิทัศน์ป่าปลูกในเขตแกนกลางจะถูกจำกัดให้มีการฟื้นฟูและการจัดการเพียงเล็กน้อย แต่ไม่จำกัดในด้านการเกิดใหม่และการทดแทนตามธรรมชาติ ส่วนในเขตกันชนและเขตรอบนอกแนะนำให้ทำการฟื้นฟูป่าไม้ด้วยการปลูกฟื้นฟูสภาพป่าเดิม การปลูกป่าทดแทน รวมทั้งการตรวจลาดตระเวน การควบคุมและการป้องกันไฟป่า

จากผลการศึกษาสามารถสรุปได้ว่า การบูรณาการดัชนีนิเวศภูมิทัศน์ด้วยข้อมูลการรับรู้จากระยะไกล สามารถนำมาใช้ในการจำแนกรูปแบบภูมิทัศน์ที่สัมพันธ์โดยตรงกับนิเวศ ภูมิทัศน์ป่าไม้และนำข้อมูลทางนิเวศภูมิทัศน์ที่ได้ไปใช้ในการวางแผนการฟื้นฟูและการจัดการทรัพยากรป่าไม้

สาขาวิชาการรับรู้จากระยะไกล	ลายมือชื่อนักศึกษา______________
ปีการศึกษา 2555	ลายมือชื่ออาจารย์ที่ปรึกษา______________

INTAREEYA SUTTHIVANICH : INTEGRATION OF LANDSCAPE ECOLOGY METRICS WITH REMOTELY SENSED DATA FOR FOREST RESTORATION AND MANAGEMENT IN SAKAERAT BIOSPHERE RESERVE, NAKHON RATCHASIMA, THAILAND. THESIS ADVISOR : ASST. PROF. SUWIT ONGSOMWANG, Dr. rer. 180 PP.

LANDSCAPE ECOLOGY/LANDSCAPE METRICS/LAND USE AND LAND COVER/FOREST ECOLOGY/FOREST RESTORATION AND MANAGEMENT

This research aims to investigate the changes of landscape patterns in the Sakaerat Biosphere Reserve (SBR). The main objectives are (1) to classify and assess changes of multi-temporal land use and land cover, (2) to measure and assess the landscape patterns and forest landscapes using landscape metrics, and (3) to develop recommendations for forest landscape restoration and management plans.

Land use and land cover (LULC) classification and assessment of change on 9 different LULC classes indicated that the dominant LULC classes were natural forest, field crop, and paddy field, which occupied large parts of the study area. Change detection assessment in 1980, 2002, and 2012 found that fluctuation of changes appeared mostly within forest classes, with decreasing of natural forest in 1980 to 2002, but tended to be constant in 2002 to 2010. Consequently, severely disturbed forest appeared in 1980 to 2002 and was gradually decreased in 2002 to 2010.

Landscape pattern assessment on 6 landscape types showed that natural forest landscape was the major landscape type, followed by agriculture and disturbed forest landscapes. In addition, landscapes change had occurred mostly in disturbed forest, forest plantation and urban and built-up landscapes. For landscape metrics analysis with 14 indices, including fragmentation, shape complexity, core area, and diversity/interspersion/isolation, it was found that SBR landscape pattern change variation occurred with increasing in fragmentation and diversity but decreasing in core area and shape complexity from 1980 to 2002, and all of these were slightly changed from 2002 to 2010. Meanwhile, the trends of change in increasing or decreasing direction of indices values of natural forest, disturbed forest, and forest plantation landscapes in each SBR management zone (core, buffer, and transition zones) were further used in relation to gain and loss in the context of landscape ecology for setting up priority levels of recommendations for forest restoration and management planning. This evaluation showed that the priority level of natural forest and disturbed forest landscapes was moderate and high in all management zones, respectively, whereas the priority level of forest plantation landscape was high in the core and transition zones, and moderate in the buffer zone.

As a result, recommendations for restoration and management plans in natural forest, disturbed forest, and forest plantation landscapes in the core zone were strictly 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 regularly patrolling, and forest fire control and prevention were recommended.

In conclusion, integration of landscape ecology metrics with remotely sensed data can be 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 planning.

School of Remote Sensing Student’s Signature_____________________

Academic Year 2011 Advisor’s Signature_____________________

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Intareeya Sutthivanich

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LIST OF ABBREVIATIONS

A	=	Agricultural Land
ALT	=	Agriculture Landscape Type
CAD	=	Core Area Density
ED	=	Edge density
ERDAS	=	Earth Resource Data Analysis System
ESRI	=	Environmental Systems Research Institute
F	=	Forest Land
FC	=	Field Crop
FLT	=	Forest Landscape Type
GIS	=	Geographic Information System
GISTDA	=	Geo-Informatics and Space Technology Development Agency (public organization)
IJI	=	Interspersion Juxtaposition Index
LDD	=	Land Development Department
LPI	=	Landscape Pattern Indices
LULC	=	Land Use and Land Cover
LULCC	=	Land Use and Land Cover Change
M	=	Miscellaneous Land
Sq. Km	=	Square Kilometer

LIST OF ABBREVIATIONS (Continued)

MAB	=	Man and the Biosphere programme
MLT	=	Miscellaneous Landscape Type
MNN	=	Mean Nearest Neighbor
MOAC	=	Ministry of Agriculture and Cooperative
MPFD	=	Mean Patch Fractal Dimension
MPFD	=	Mean Patch Fractal Dimension Index
MPI	=	Mean Proximity Index
MSI	=	Mean Shape Index
NP	=	Number of Patches
OEA	=	Office of Economic and Agriculture
PF	=	Paddy Field
RS	=	Remote Sensing
RTSD	=	Royal Thai Survey Department
SBR	=	Sakaerat Biosphere Reserve
SDI	=	Shannon's Diversity Index
SEI	=	Shannon's Evenness Index
SUT	=	Suranaree University of Technology
TCA	=	Total Core Area
TCAI	=	Total Core Area Index
TE	=	Total Edge
THEOS	=	THailand Earth Observation System

LIST OF ABBREVIATIONS (Continued)

U	=	Urban and Built-up Area
ULT	=	Urban Landscape Type
UNESCO	=	United Nations Educational, Scientific and Culture Organization
UTM	=	Universal Transverse Mercator
W	=	Water Body
WGS-84	=	World Geodetic System 1984

CHAPTER I

INTRODUCTION

1.1 Background problem and significance of study

The second millennium year has recently pasted a decade, together with many extraordinary disaster phenomena have occurred all over the world. From Africa, Europe, Australia and New Zealand, Asian to America, nowhere seem exempted from terrify unusual natural crisis. From earthquakes, volcanic eruptions, flooding and landslide, tsunamis to tornadoes, these hazardous situations occurred more extremely and more frequently. The mother of nature is giving us a wake up and warning calls. The earth environmental systems have seriously changed; it might be time to the new world order. As we can see the consequents, unbalance consuming and conserving the natural resources have affected on humanity. Global warming, climate, and land use land cover change are present hot issues. Recently, in Thailand also encountered with severe natural devastating which it was believed that our natural environment, ecosystems and forests cover were destroyed repeatedly.

Forest habitat is prominent in some regions of Thailand, from highland mountainous of the north to the south. Changes in forest areas are apparently; natural disturbances and illegal logging alter the arrangement of forest pattern across the landscape and this in turn influences many species and ecosystem processes. Land use changes have also produced intense fluctuations in forest ecosystem over several centuries. Increasing residential development in rural areas is often concentrated within forest landscapes and also public lands. Because of the relationships between ecological pattern and process, landscape pattern analysis is a major focus of landscape ecology. Understanding these relationships is of fundamental importance in conservation because changes in amount and configuration of habitat for native species are major causes of species and population decline.

Landscape ecology is a relatively new area of study, which aims to understand the pattern of interaction and connections of biological and cultural communities across the landscape, and with the effects of both natural and human disturbances on the landscape. Because people have become one of the major biological forces on the planet, much of the activity in the field of landscape ecology focuses on interactions between people and the biosphere.

In recent years, international political energy dedicated to conservation of biodiversity and sustainable development has increased. And also conservation and sustainable forest management require the collection of new kinds of forest and land cover information to complement traditional forest databases, model outputs, and field observations. Remote sensing (RS) and geographical information systems (GIS) have emerged as key geospatial tools to satisfy increasing information needs of resource managers (Franklin, 2001). Concurrently, landscape pattern analysis approaches also widely spread to collaborate to achieve for valuable information in the same conduct.

Spatial patterning in forests and landscapes has long been of interest to ecologists, foresters, and managers because it is important for detecting and monitoring landscape and forest spatial pattern and changes. From the “natural” forces that shape landscapes (such as fire and insect outbreaks) to the cultural and anthropogenic forces (road building, urbanization, and harvesting). Since, remote sensing observations can be used to differentiate the spatial distribution of forest cover types on the basis of forest structure and species composition. Multi-temporal data can be also used to separate forest management treatments (such as cutovers, thinning, plantings), new roads, insect damage, wind throw and burned or flooded areas, from surrounding cover types over time. 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 or landscape pattern indices) is emphasized in an attempt not only to provide context for how pattern analysis is currently conducted but also to explore the ways in which pattern analysis might develop in the future. The study of spatial pattern has progressed rapidly, from the early days of spatial analysis (the 1970s), to the automated routines of GIS and image analysis software that can generate many of landscape pattern indices (LPIs). 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. Ecological processes such as plant succession, biodiversity, foraging patterns, predator-prey interactions, dispersal, nutrient dynamics, and the spread of disturbance all have important spatial components.

The Sakaerat Biosphere Reserve (SBR) is the first leading biodiversity hotspot in Thailand. It is one of four biosphere reserve areas which are created and established under the support of United Nations Educational, Scientific, and Cultural

Organization (UNESCO) on Man and the Biosphere (MAB) programme. Biosphere reserves are organized into three inter-related zones. This allows for clear separation of the different uses of the reserve. The core area exists for the long-term protection of biodiversity. This is surrounded by a buffer zone, used for recreation, education, research and sustainable resource use when this is compatible with the ecosystem conservation objectives. It also serves as a shield to protect the core from the direct impact of human activities. Outside the buffer is the transitional zone, used for agriculture and other rural activities, including human settlements.

Mapping and analyzing the spatial structure of critical habitats for endemic species in these hotspots provides important baseline information about vegetation types and land cover for biodiversity monitoring and management. Mapping and quantifying habitats in the SBR has relied on a variety of methods, primarily based on sample plots by ecologists. Up to date, newly development of integrations of GIS, advances high resolution of RS, and spatial pattern analysis have been comprehensive to be an effective approach for landscape and forest habitat mapping, updating spatial databases, delineation of protection zones, habitat corridors and landscape management planning.

1.2 Research objectives

The central ideas of this research are to investigate and discuss the changes observed in the SBR landscape composition, pattern, and structure over time in the context of landscape as a whole and forest pattern analysis, in order to protect of the existing natural resources, establish forest habitat linkages, reduce habitat fragmentation, enhance biodiversity, and restore ecosystems. The specific objectives are as follows:

(1) To classify and assess multi-temporal land-use and land-cover (LULC) of SBR using multi sources of remotely sensed and other available ancillary datasets;

(2) To measure, analyze and assess landscape pattern of SBR and forest pattern changes using landscape pattern metrics (indices);

(3) To develop recommendation for forest landscape restoration and management plan in SBR.

1.3 Scope and limitations of the study

Basically, spatial data commonly used in landscape ecology come from a variety of sources, such as field sampling, aerial photos, satellite images, topographic maps, or an existing GIS layers. The spatial data from these sources are created using different techniques, and have their own set of inherent assumptions. Different spatial data types also have different sources of error and provide information at different levels of resolution. Thus, the first step in using spatial landscape data often involves verifying the accuracy of the different sources of data as well as determining which sources fit the needs of the research study at hand. Thus, scope and some limitations of the study that should be addressed here are as following:

(1) Period of the study is based on available remotely sensed datasets which cover between year 1980, 2002, and 2010;

(2) In this study, aerial photographs, color orthophotomaps, and THEOS imagery datasets were used as of the year 1980, 2002, and 2010, respectively;

(3) Due to multi dates data used and time array is slightly wide as about 30 years, the initial time (1980) is far apart; therefore available remotely sensed data come from different source platforms. These bring to the issues of different data scales and resolutions which consider as one of limitation of the study. However,

many researches show that scale problem can be alleviated by research assumption and technical data preparation case by case depends upon how serious it might effect. Additionally, earlier studies suggested that changes in landscape pattern indices due to scale changes may not be extremely problematic. For example, aerial photograph used to create raster maps of varying pixels size (4-, 12-, 28-, to 80-m cell sizes) suggested that in some situations the effects of changing scale were not dramatic (Wickham and Riitters, 1995). Another early study found that while pattern indices were sensitive to change in grain, estimating landscape pattern indices at different scales was fairly feasible using aggregation algorithms (Benson and MacKenzie, 1995).

1.4 Study area

1.4.1 Background: The Sakaerat Environmental Research Station (SERS) was established by the Thai government on September 19, 1967. It administered by the Thailand Institute of Scientific and Technological Research as a facility for ecological and environmental research. Later on, SERS and the surrounded areas were declared as Sakaerat Biosphere Reserve (SBR) in 1977 in order to sustain balance between the goals of conserving biological diversity, promoting economic development, and maintaining cultural values.

The other biosphere reserves in Thailand are included; The Huai Tak Biosphere Reserve in Lamphang province and the Kog Ma-Mae Sa in Chiang-Mai province were established two years after the Sakaerat biosphere reserve. Huai Tak reserve contains the oldest teak plantations in Thailand and there are various teak research projects being conducted in the reserve. The Ranong Biosphere Reserve is the most recent reserve in Thailand, established in 1997. It is on the Andaman coast of Thai peninsula. Mangrove forests largely cover this reserve and the reserve is being used for a number of Thai and international mangrove ecology research projects. All reserves have a core area, surrounded by a buffer and a transitional zone.

Core Areas: These areas are securely protected sites for conserving biological diversity, monitoring minimally disturbed ecosystems, and undertaking non-destructive research and other low-impact uses (such as education).

Buffer Zones: These areas must be clearly identified, and usually surround or adjoin the Core Area. Buffer Zones may be used for cooperative activities compatible with sound ecological practices, including environmental education, recreation, ecotourism and applied and basic research.

Transition or Cooperation Zones: These areas may contain towns, farms, fisheries, and other human activities and are the areas where local communities, management agencies, scientists, non-governmental organizations, cultural groups, economic interests, and other stakeholders work together to manage and sustainable 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 (Figure 1.1).

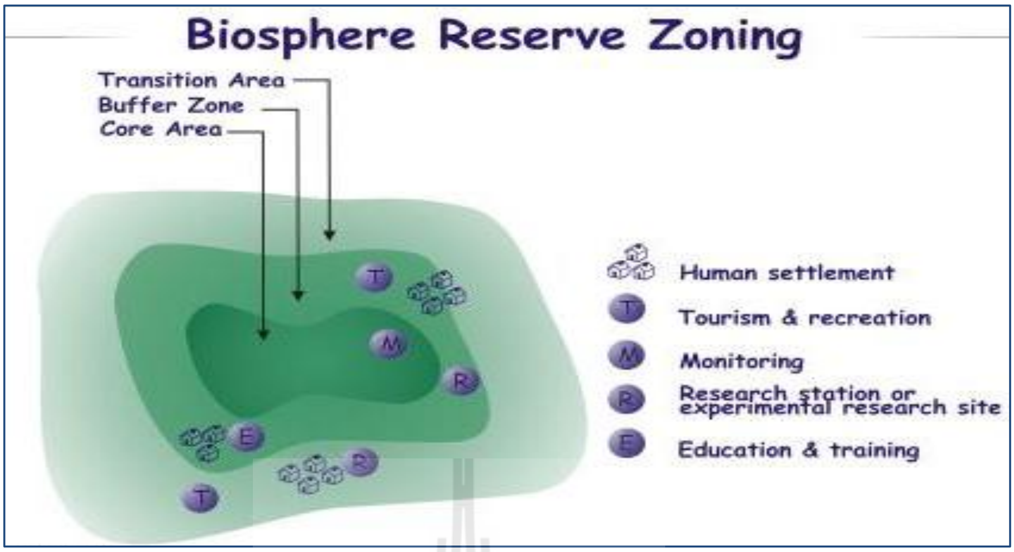


Figure 1.1 Biosphere reserve and management zones (Fundy Biosphere Reserve http//fundy-biosphere.ca/en)

1.4.2 Location and Boundaries: Sakaerat Environmental Research Station (SERS) is lies in Wang Nam Khieo and Pak Thong Chai district, Nakhon Ratchasima province. It is located about 300 kilometers from Bangkok and 60 kilometers from Nakhon Ratchasima province on highway 304. The research station grounds cover an area of 78 square kilometers (approximately 48,750 rai). Thereafter in 1977, SERS and the area around the station were declared as the Sakaerat Biosphere Reserve (SBR). The Sakaerat Biosphere Reserve is the first and the largest of Thailand's four biosphere reserves and the most active one. The core area of the biosphere reserve and some parts of the buffer region are included in the boundaries of the SERS. The core area is 58 km^2 and consists of natural, primary forest, some areas of natural regeneration and the SERS headquarters. The buffer zone area is 92 km^2. It contains all areas of reforestation. The largest area is the transitional zone covered area of 673 km^2 (Figure 1.2). Approximately 72,000 people in 159 villages live in this zone, and 84% of the households work in agriculture.

1.4.3 Geography/Climate: SBR is situated in mountainous terrain at an altitude of 280-762 meters above mean sea level. Important mountains on the station grounds are Khao Phiat (762 meters), Khao Khieo (790 meters), and Khao Sung (682 meters). The station office is at 390 meters. Average annual temperature at Sakaerat is 26 degrees Celsius and average annual rainfall is 1,260 millimeters.

1.4.4 Forest: SBR is covered by two major forest types, dry evergreen forest and dry dipterocarp forest. The vegetation in dry evergreen forest includes trees like *Hopea adorata*, and *Hydrocarpus illicifolius*. Vegetation in dry dipterocarp forest is more seasonal and includes *Shorea obtusa*, *Shorea siamesis*, and *Shorea floribunda*. Together, the two forest types cover 70 percent of the station grounds. Other areas have bamboo, plantation forests, and grasslands.

1.4.5 Wildlife: Some 380 vertebrate species of vertebrates are known to be present at SERS. Mammals comprise 70 of these species. They include Barking Deer and Common Wild Pigs, Birds comprise 200 species, and include *Siamese Firebacks*, *Red Jungle Fowl*, among others. Amphibians comprise 25 species and reptiles 82 species. Occasional endangered visitors to SERS may include tigers, sambar deer, *Black Giant Squirrels*, *Green Pea fowl*, and *Silver Pheasants*. (http://www.tistr.or.th/sakaerat/index.php).

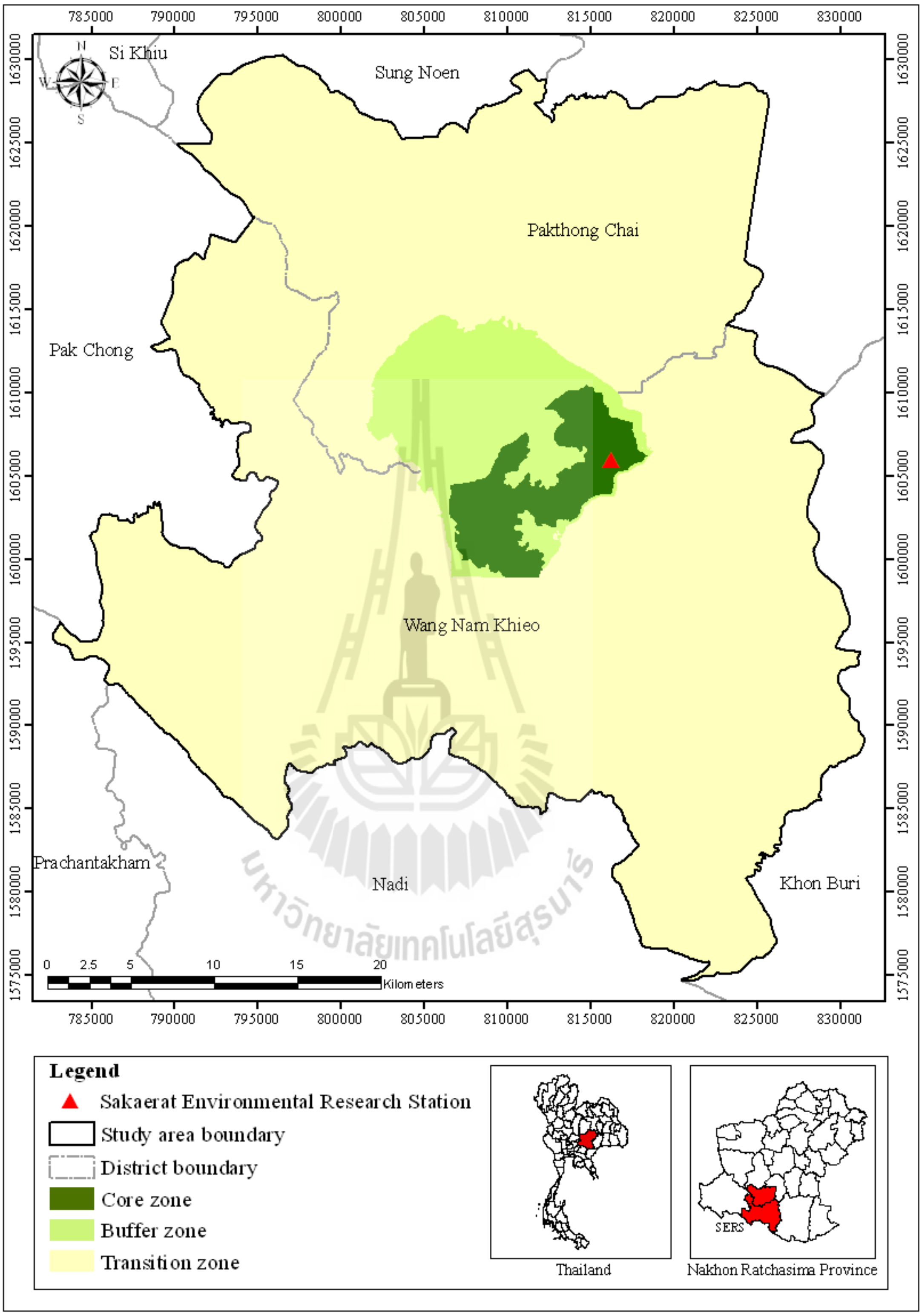


Figure 1.2 Study area location and boundary.

1.5 Benefits of the study

Benefits of the study aim to gain the knowledge and information from the research finding to enrich habitat and biodiversity, maintain natural landscape processes, and improve health, and better connection to natures and their environment. The specific benefits of this study are as following:

1. Understanding the historical and current status of SBR landscape pattern.

2. Obtaining ecological information of SBR landscape and specially forest pattern condition, distribution, and changes in order to balance sustainable forest conservation and community forest services.

3. Updating knowledge and information to develop a basis for improving the relationship between people and the environment.

CHAPTER II

LITERATURE REVIEW

2.1 Concepts and principles of landscape ecology

A landscape is a heterogeneous area composed of a cluster of interacting ecosystems that are repeated in various sizes, shapes, and spatial relationships throughout the landscape. Additionally, landscape can view as a mosaic of habitat patches across which organisms move, settle, reproduce, and eventually die. Landscapes have different land forms, vegetation types, and land uses. Landscapes can be observed from many points of view, and ecological processes in landscapes can be studied at different spatial and temporal scales. Three landscape characteristic that are especially useful to consider are structure, function, and change (Forman, 1995; and Turner, 1989).

Various definitions of landscape ecology were defined. It is an interdisciplinary and a relatively new science with the interrelationship between human society and our living space and is now widely recognized as a distinct perspective in resource management and ecological science. The term landscape ecology was first arising from European traditional of regional geography and vegetation science. The consideration of spatial patterns distinguishes landscape ecology from traditional ecological studies, which assume that systems are spatially homogeneous. Landscape ecology emphasizes and investigate the effects and interactions between spatial pattern and ecological process (Turner, 1989), that is, the causes and consequences of spatial heterogeneity across a range of scales.

When studying the ecology of landscapes, at least three basic elements must be considered and understood: structure, function, and change (Forman, 1995; and Turner, 1989). Landscape *structure* generally refers to the distribution of energy, material, and species. The spatial relationships of landscape elements are characterized as landscape pattern in two ways (McGarigal and Marks, 1995; Remmel and Csillag, 2003). 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 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. 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, harvesting); biotic processes (e.g., succession, birth, death, and dispersal); and environmental conditions (e.g., soil quality, terrain, and climate). With the definition as the study of the effect of landscape pattern on ecological processes, it is clearly that the methods are needed to quantify landscape pattern so that measurable links to ecological processes can be determined. The common method for quantifying landscape patterns is to capture information of a particular spatial pattern into a single variable. Such variables are commonly referred to as landscape metrics or landscape pattern indices. The common terms and their definition in landscape ecology study are briefly summarized as shown in Table 2.1 and Figure 2.1.

Table 2.1 Common terms and their definition in landscape ecology study. (Adapted from Forman, 1995).

Term	Definition
Configuration	Specific arrangement of spatial elements, often used synonymously with spatial structure or patch structure.
Connectivity	Spatial continuity of a habitat or cover type across a landscape.
Corridor	Relatively narrow strip of a particular type that differs from the areas adjacent on both sides.
Cover type	Category within a classification scheme defined by the user to distinguish among the different habitats, ecosystems, or vegetation types on a landscape.
Edge	Portion of an ecosystem or cover type near its perimeter and within which environment conditions may differ from interior location in the ecosystem, also used as a measure of the length of adjacency between cover types on a landscape.
Fragmentation	Breaking up of a habitat or cover type into smaller, disconnected parcels.
Heterogeneity	Quality or state of consisting of dissimilar elements, as with mixed habitat or cover types occurring on a landscape; opposite of homogeneity, in which elements are the same.
Landscape	Area that is spatially heterogeneous in at least one factor of interest.
Matrix	Background cover type on a landscape, characterized by extensive cover and high connectivity; not all landscape have a definable matrix.
Patch	Surface area that differs from its surroundings in nature or appearance.
Scale	Spatial or temporal dimension of an object or process, characterized by both grain and extent**.**

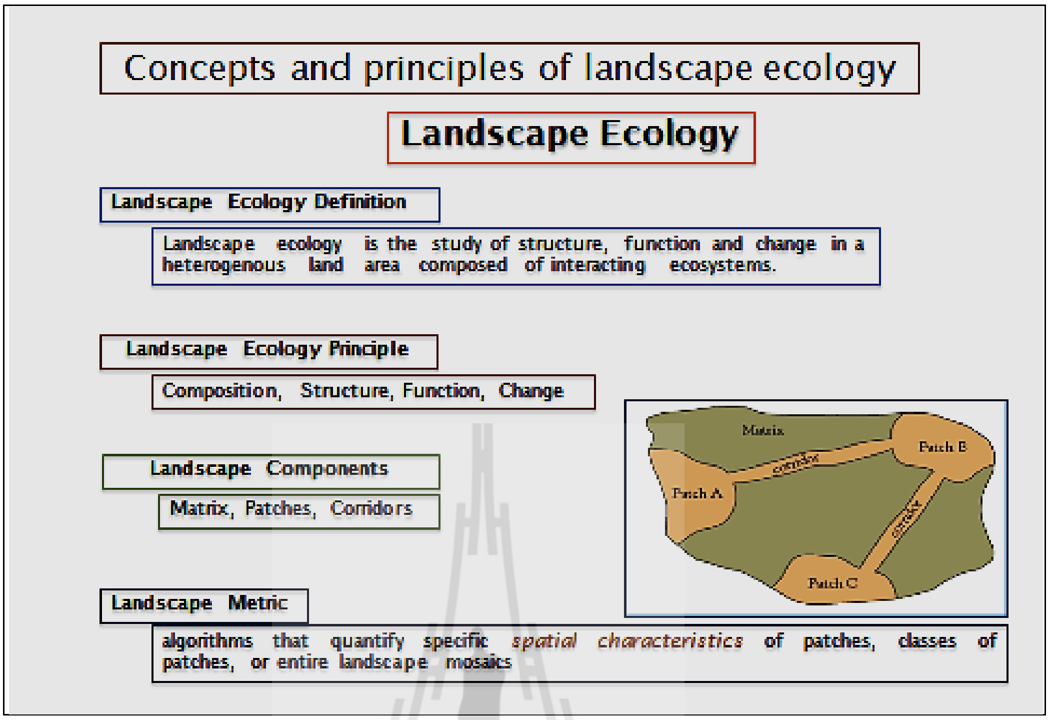


Figure 2.1 Concepts and principles of landscape ecology study (Modified from Forman, 1995; McGarigal and Marks, 1995).

2.2 Ecosystem and development of forestry

Ecosystems are not static; there are continual change in their structure, function, degree of complexity and the interaction between their components. Ecosystems change for a variety of reasons: change in climate, change in soil condition, change due to interactions between the members of the living community, and change caused by disturbances such as wind and fire. The process of change following disturbance is called ecological succession. For example, in some types of forest, the rate of change is slow; on others it is quite rapid. In some, the change is fairly continuous and small. In others, it is large scale and either frequent or in frequent. Over time, there is a series of living communities (plants, animals, and microbes) that successively occupy and are replaced on a particular area of land, with accompanying changes in soil and microclimate conditions. Some of the mechanisms of successional change are caused by the plants participating in succession: invasion of new species, alteration of the physical environment and the availability of resources, for instance, light, moisture, and nutrients (Polunin and Worthigton, 1990).

Forestry is the science, art, business, and practice of conserving and managing forests and forest lands to provide a sustained supply of forest products, forest conditions, or other forest values desired by the forest owner. It is a branch of human endeavor that has developed at various times in history and at various places in the world. It has always develops in response to the loss, or anticipated loss, of forest values caused by unregulated forest exploitation. Although the details of the evolution of forestry have varied from century to century, there is generally a rather predictable sequence of stages (Oliver and Larson, 1996).

Waring and Schlesinger (1985) explained that in the early stages of the development of a human society, the forest is simply a part of the environment, the habitat of both prey and enemies, and the provider of some of the necessities of life. As human numbers and the power of their technologies increase, unregulated forest removed begins to exceed the regenerative powers of the forest. With time this leads to regional deforestation, which may be solved by seeking supplies in more distant areas, either by trade or military control. The depletion of forest resources that results has always been the stimulus to develop forestry.

The first stage of forestry is typically based on a set of laws, regulations, and rules that lack any sensitivity to the ecological differences between different forest ecosystem types across the landscape. Failure to reflect the spatially variable and ever changing character of forest almost always results in the failure of the administrative stage of forestry to achieve its objectives. Lacking a sound ecological foundation, administrative forestry eventually gives way to an ecologically based stage. When well developed and implemented ecologically based forestry is usually successful in sustaining the functional process of ecosystems and their productivity of conventional forest products. However, it may not necessarily sustain all the values desired by a society. Silviculturally sustainable forests may not sustain the full range of biodiversity, aesthetics, and spiritual values of unmanaged forests. Consequently, this is not the final stage in the evolution of forestry.

The final stage is social forestry, which is both ecologically based and biologically sustainable, but also sustains a wide variety of social and environmental values in our forested landscapes. It is encouraging that in many countries around the world, forestry is now in transition from the administrative stage to the ecologically based stage. Unfortunately, up to now several large areas of Asian and Amazon forests are lost and several more degraded by improper use.

2.3 Forest landscapes: Remote sensing and GIS approaches

Forest succession and growth are well-established concepts, with a theoretical basis and well-defined means for characterization in the field and, increasingly, through remote sensing. From a baseline of information, such as a forest inventory, image classification, or permanent sample plot database, forest growth and succession may be modeled to produce management information products. Forest disturbance, on the other hand, typically must be captured by some independent means; one of the goals of this independent assessment is to ensure the quality of information products modeled from a baseline of information.

Landscape ecological principles enable an informed view of spatial and temporal patterns by relating pattern and processes and understanding the primary and feedback links (Wulder and Franklin, 2007). Remotely sensed and GIS data can be processed or combined to produce information depicting landscape patterns or structure, including land cover, biophysical or biochemical status of vegetation, or other attributes of interest (e.g., soil moisture). Information regarding the land cover representing a known time period may be produced through image classification. Change detection methods can then be applied to quantify the dynamics that have occurred or are presently active. Pattern analysis, in the form of landscape metrics or landscape pattern indices (LPIs) can then be applied to the land cover information produced through image classification, the disturbance information produced through change detection approaches, or both. This integration of forest change information with the tools of pattern analysis provides for unique insights into the outcomes of management decisions or disturbance events. Comparisons over space and time are then possible between the patterns that emerge from differing dynamics or against theoretical base conditions.

The fact that such databases as Landsat are familiar to, and routinely used by, those in a wide variety of environmental sciences is a major contribution to the environmental sciences. Interestingly, the latest advances in remote sensing techniques not only allow the analysis of these broad regions of interest to landscape ecology, but also now produce fine-scale, sub meter resolution data sources (e.g., using IKONOS, QuickBird). This fine scale was until recently the preview of field-sampling programs and the mainstay of traditional field ecology, forestry professionals, and field managers (Wulder et al., 2004).

The integration of remotely sensed and GIS data takes four forms: (a) GISs can be used to store multiple data types; (b) GIS analysis and processing methods can be used for raster data manipulation and analysis (e.g., buffer/distance operations); (c) remotely sensed data can be manipulated to derive GIS data; and (d) GIS data can be used to guide image analysis to extract more complete and accurate information from spectral data (Wulder and Franklin, 2007). Many researches reveal that including GIS data with remotely sensed data for the discrimination of land cover classes typically results in higher overall map accuracies (e.g., increases of 5–10% overall) over those produced using spectral-radiometric data alone.

2.4 Landscape pattern and its effects

Spatial pattern of landscape is a primary focus of landscape ecology, due to the relationship between spatial configuration and ecological processes. Development of quantitative indices of spatial pattern can be used to enhance our understanding of relationships between spatial pattern and ecological processes. Landscape ecology is an emerging discipline that considers the spatial and temporal patterns and exchanges across the landscape, the influences of spatial heterogeneity on ecological processes, and the management of spatial heterogeneity for society's benefit (Risser et al., 1984). Landscape ecologists have developed a useful suite of indicators of landscape pattern from remote sensing information. The primary categories of indicators describe the arrangement of habitat patches as dominance (few or many habitat types), contagion (like types clumped or not clumped), and fractal dimension (simple or complex patterns) (O'Neill et al., 1988a). The greatest interest to the analyst is the measurement of habitat fragmentation. The following parameters can be used to determine habitat patch size, edges, heterogeneity and dynamics, context, and connectivity within the landscape (Harris and Silva-Lopez, 1992):

(1) The amount, composition, and distribution of residual habitat;

(2) The abruptness of gradation between remaining patches;

(3) The continuity or disruption of the distribution and movement of native organisms;

(4) The composition and structure of the vegetation that now constitutes the landscape matrix;

(5) The compositional pattern of the overall landscape.

The size of habitat patches has important implications for ecological integrity (Figure 2.2). Small habitat patches (e.g., habitat islands) have fewer species than large patches and more isolated habitat patches have fewer species than less isolated patches (Hunter 1996). Large patches have more species because (1) a large patch will always have a greater variety of environments that provide niches for species that would be absent otherwise, (2) a large patch is likely to have both common and uncommon species while a small patch is likely to have only common species (not only are area-sensitive species excluded, but the sampling effect itself will result in fewer species in small patches), and (3) a small patch will have, on average, smaller populations that are more susceptible to becoming extinct. Even though the applicability of island biogeography theory (MacArthur and Wilson, 1967) is more limited for habitat patches than for true islands, the concept of increased extinction rates in smaller areas is important. Habitat patches that are isolated from similar habitat patches by great distances or inhospitable terrain are likely to have fewer species than less isolated patches because (1) relatively few individuals of a given species will immigrate into an isolated patch and (2) fewer mobile species will visit isolated patches because it is inefficient to do so (Hunter, 1996).

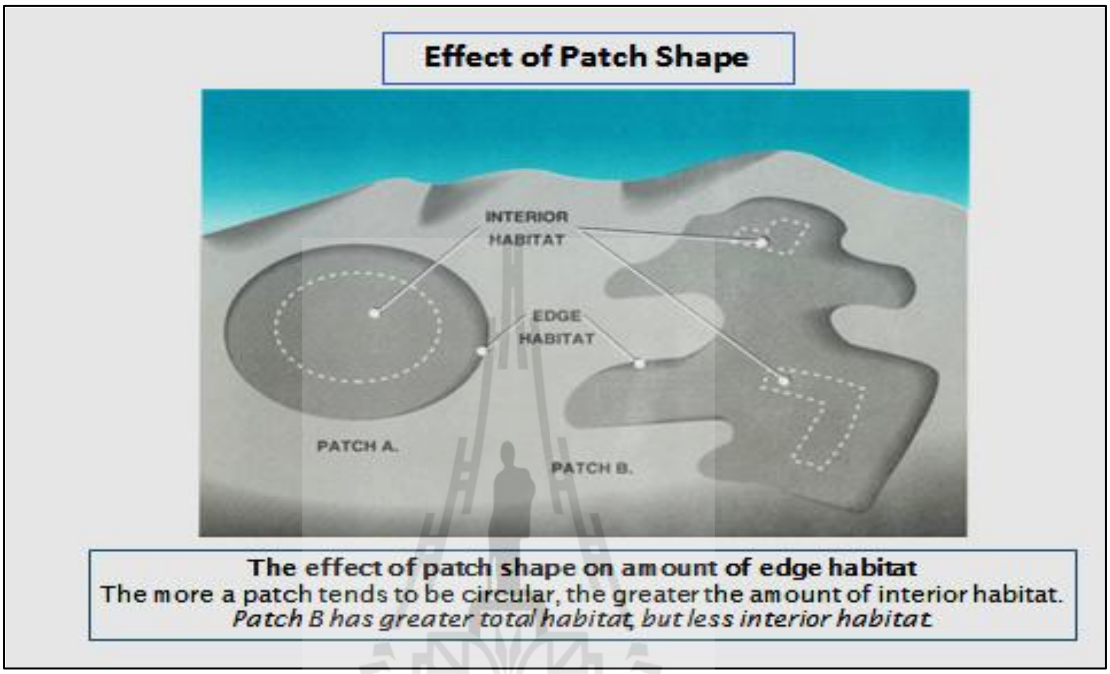


Figure 2.2 Effect of patch size and shape on habitat area (Hunter, 1996).

2.5 Classes of landscape pattern

Landscapes contain complex spatial patterns in the distribution of resources that vary over time; quantifying these patterns and their dynamics is the purview of landscape pattern analysis. Broadly considered, landscape pattern analysis involves four basic types of spatial data (McGarigal and Marks, 1995).

(1) Spatial point patterns represent collections of entities where the geographical locations of the entities are of primary interest, rather than any quantitative or qualitative attribute of the entity itself. A familiar example is a map of all trees in a forest stand, wherein the data consists of a list of trees referenced by their

geographical locations. The goal is to determine whether the points are more or less clustered than expected by chance and/or to find the spatial scale(s) at which the points tend to be non-randomly distributed.

(2) Linear network patterns represent collections of linear landscape elements that intersect to form a network. A familiar example is a map of streams or riparian areas in a watershed, wherein the data consists of nodes and linkages between nodes; the intervening area is considered the matrix and is typically ignored (i.e. treated as ecologically neutral). The goal is to characterize the physical structure (e.g. corridor density, mesh size, network connectivity, and circuitry) of the network, and a variety of metrics have been developed for this purpose.

(3) Surface patterns represent quantitative measurements that vary continuously across the landscape; there are no explicit boundaries (i.e. patches are not delineated). Here, the data can be conceptualized as a three-dimensional surface, where the measured value at each geographical location is represented by the height of the surface. A familiar example is a digital elevation model, but any quantitative measurement can be treated this way (e.g. plant biomass, soil nitrogen, density of individuals). Surface pattern analysis in ecology has largely been focused on estimating and modeling the spatial dependencies in the measured characteristic and a variety of techniques exist for this purpose. Here, the basic question is, ‘Are samples that are close together also similar with respect to the measured variable?’

(4) Categorical (or thematic; choropleth) map patterns represent data in which the system property of interest is represented as a mosaic of discrete patches. From an ecological perspective, patches represent discrete areas of relatively homogeneous environmental conditions at a particular scale. The patch boundaries are distinguished

by abrupt discontinuities (boundaries) in environmental character states from their surroundings of magnitudes that are relevant to the ecological phenomenon under consideration. A familiar example is a map of land cover types, wherein the data consists of polygons (vector format) or grid cells (raster format) classified into discrete land cover classes. The goal is to characterize the composition and spatial configuration of the patch mosaic, and a plethora of metrics has been developed for this purpose.

2.6 Landscape pattern metrics

The common usage of the term ‘landscape metrics’ refers exclusively to indices developed for categorical map. Landscape metrics are focused on the characterization of the geometric and spatial properties of categorical map patterns represented at a single scale (grain and extent). Landscape metrics can be defined at three levels (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 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; and

(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.

Landscape metrics are computed to describe patch, class, or landscape features. A “patch” is defined as each individual occurrence of a particular land cover type in the landscape. A “class” refers to all the occurrences of a particular cover type in the landscape. Metrics are computed and reported in terms of individual patches, by class, or for the landscape as a whole. There are eight basic categories of metrics that can be computed and their values as shown in Table 2.2 and Figure 2.3.

Table 2.2 Categories of metrics and their descriptions (McGarigal et al., 2002).

Category	**Description**
Area/density Metrics	Indices related to the number and size of class patches, and the amount of edge created by these patches.
Shape Metrics	Indices based directly on the shape of patches.
Core area Metrics	Indices based on internal core areas of patches
Isolation/proximity Metrics	Indices that measure relative isolation of class patches.
Contrast metrics	Indices that measure magnitude of difference between adjacent patch types.
Contagion/interspersion Metrics	Indices that measure landscape texture by examining the aggregation and intermixing of class patches.
Connectivity Metrics	Indices that attempt to measure the “structural connectedness” of patch types.
Diversity Metrics	Indices related to the number of patches and their distribution throughout the landscape. Useful for assessing landscape structure.

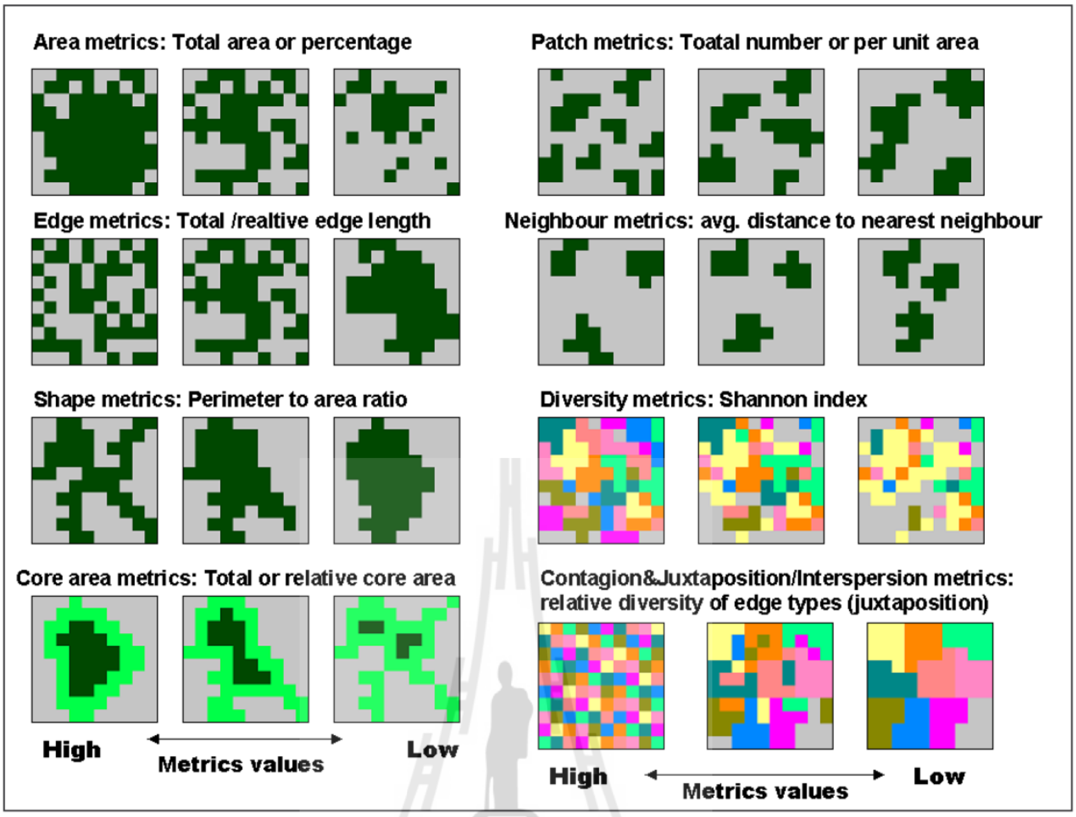


Figure 2.3 Example of categories metrics and their values (Nielsen, 2001).

McGarigal et al. (2002) make a critical comment that it is important to understand each landscape metric before it is selected for interpretation. Attempting to draw conclusions about the pattern of the landscape, the questions those should be considered of each metric are:

(1) Does it represent landscape composition or configuration, or both?

(2) What aspect of composition or configuration does it represent?

(3) Is it spatially explicit and if so at the patch, class, or landscape level?

(4) How is it affected by the designation of a matrix element?

(5) Does it reflect an island biogeographic or landscape mosaic perspective of landscape pattern?

(6) How does it behave or respond to variation in landscape pattern?

(7) What is the range of variation in the metric under an appropriate spatio-temporal reference framework?

2.7 Impacts of patterns on ecological processes

In recent years, an appreciation for the vast array of other species and habitats (e.g., old growth forests) that are potentially affected by human activities has arisen under the sign of biodiversity conservation. Conservation biologists have been virtually agreed in their controversy that it is the destruction of habitats worldwide that most threatens biodiversity and the sustainability of ecosystems. Within the landscape, certain habitats disproportionately contribute to ecosystem functioning. In general these are the remaining natural areas, especially those that integrate the flows of water, nutrients, energy, and biota through the watershed or region (Polunin and Worthington, 1990). The concept is similar to that of keystone species that have a disproportionate effect on community structure (Paine, 1969). Forests, rangelands, and aquatic ecosystems all have unique or critical habitats that support the provision of ecosystem services within the landscape. In addition, ecotones (the boundary or transition zone between plant communities) may be especially important for processing resources, as they frequently have more individuals and species (Hunter, 1990).

At the landscape level, natural ecosystems have a characteristic pattern and connectivity of habitat patches. The amount and combination of these patches supports the movement of species and the transfer of materials (energy and nutrients) among habitats. Prior to human settlement, natural landscapes were characterized by large expanses of contiguous habitat. The fragmentation of these areas into disconnected and isolated patches can significantly disrupt ecological integrity.

The fragmentation of habitat has been implicated in the decline of biological diversity and the ability of ecosystems to recover from disturbances (Flather et al., 1992). Habitat fragmentation is the process by which a natural landscape is broken up into small patches of natural ecosystems, isolated from one another in a matrix of lands dominated by human activities (Hunter, 1996). The principal cause of worldwide habitat fragmentation is the expanding human population converting natural ecosystems into human-dominated ecosystems, primarily agriculture. Obvious examples of anthropogenic effects on landscape patterns and connectivity include clear cutting for lumber, urbanization, construction of transportation corridors, the draining of wetlands, and the conversion of forest and prairies into crop and grazing systems.

2.8 Natural and human processes interacting to cause landscape change

Forest, rangeland, and aquatic ecosystems all have characteristic patterns of habitat patches; in addition, the larger landscape can be viewed as a mosaic of adjacent ecosystems. To understand a landscape's patterns (such as the mosaic of agricultural lands and forest), its elements (such as landscape corridors), and its processes (such as habitat fragmentation) requires a holistic approach (Barrett and Bohlen, 1991). It is important to note that all naturally regenerating forests are “patchy,” i.e., the trees and associated organisms do not occur in uniform patterns (Harris and Silva-Lopez, 1992). This ecological patchiness, however, generally involves natural gradations among forest types and is very different than the fragmentation that occurs when a formerly contiguous forest is converted into a matrix of forested and no forested habitat.

Ecological and evolutionary processes produce the pattern and connectivity of landscapes (Figure 2.4). For example, the biotic predator-prey interactions, combined with spatial movement, can result in patchy spatial patterns of populations. Paine and Levin (1981) demonstrated that natural regimes of disturbance and recovery also produce spatial pattern. In turn, landscape patterns influence the ways organisms move on the landscape and the ways they utilize resources (O'Neill et al., 1988b). Dispersal processes and spatial pattern interact to separate competitors and make coexistence possible (Comins and Noble, 1985).

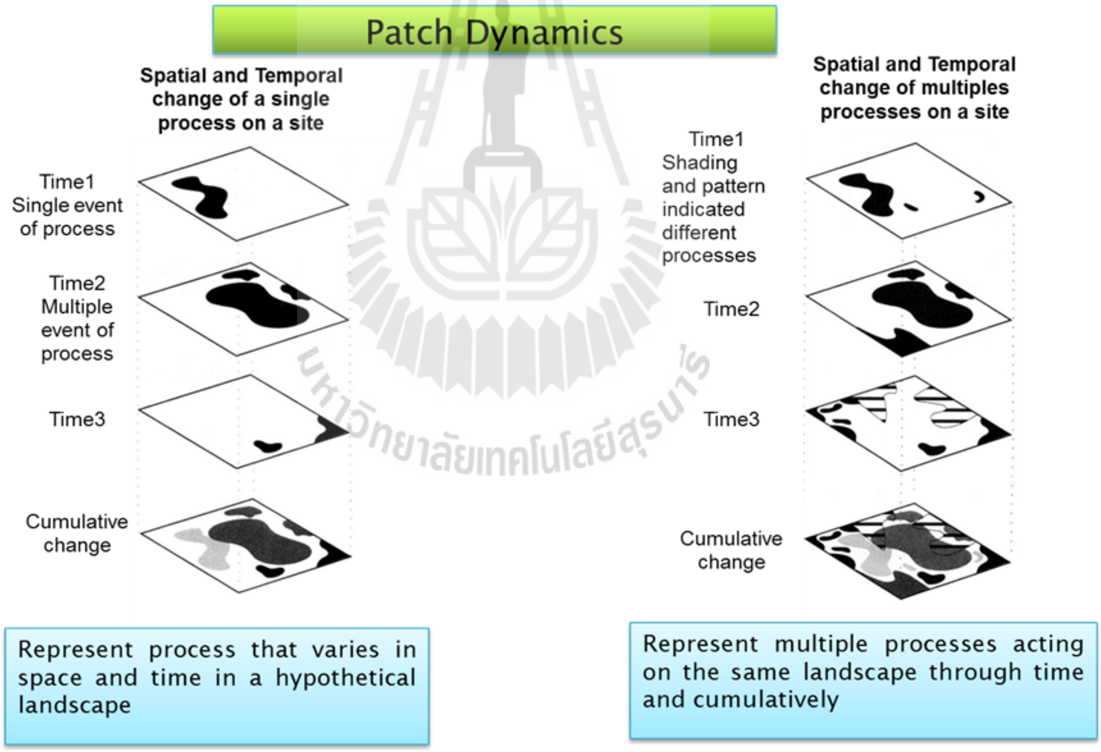


Figure 2.4 Impacts of patch dynamics on the process of landscape change (Wulder and Franklin, 2007).

Landscape connectivity involves the linkages of habitats, species, communities, and ecological processes at multiple spatial and temporal scales (Noss, 1990). In a natural landscape, connectivity among like habitats is usually high. Topography and microclimate difference may create barriers to species dispersal, especially between water bodies. In isolated habitats, populations are more susceptible to environmental catastrophes and invasion by exotic species (Harris, 1984; Soule, 1987).

Human activities can either reduce or increase connectivity. Humans have created artificial barriers to species dispersal, while at other times eliminating natural barriers. In the former situation, isolated populations become more vulnerable to extinction owing to reduced access to resources, genetic deterioration, increased susceptibility to environmental catastrophes and demographic accidents, and other problems (Harris, 1984; Soule, 1987). In the latter situation, it becomes easier for exotic organisms to invade native communities, resulting in the homogenization of floras and faunas. Forman (1995) has developed a terminology for describing the fragmentation phases as follows (Figure 2.5):

- **Perforation** of the landscape occurs when some of the natural habitats are converted into agricultural or other modified land uses;
- **Dissection** of a natural landscape begins with the building of a road or other linear feature;
- **Shrinkage** occurs when more of the landscape is converted so that the modified lands combine and the natural habitat patches are isolated from one another; and

- **Attrition** occurs when more of the natural patches are converted, becoming smaller and farther apart.

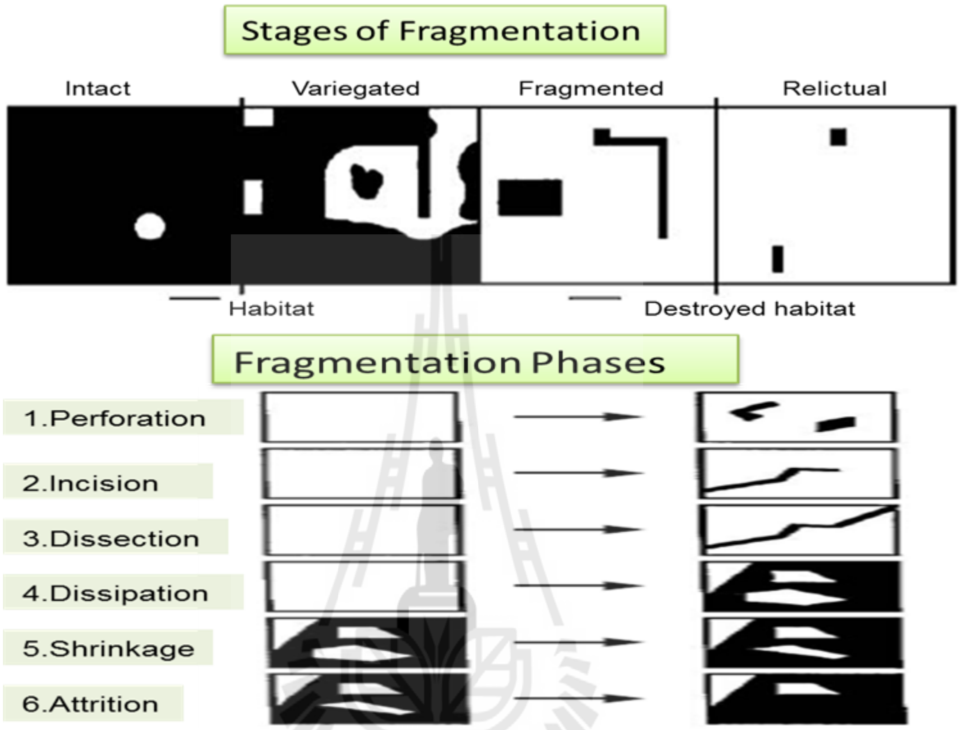


Figure 2.5 Pattern of fragmentation processes (Forman, 1995; Wulder and Franklin, 2007).

The permanent conversion of natural ecosystems to human land uses is an obvious case of fragmentation. In other cases, such as clear cutting areas that naturally regenerate, whether the activity constitutes fragmentation depends on whether the clear cut is extensive enough to constitute a significant barrier to the movement of plants and animals (Spies et al., 1994). In general, the greater the difference between the natural ecosystem and the human-dominated ecosystem, the more likely it is that the fragmentation will isolate the biota in the natural fragment. The degree of isolation depends on the species, its dispersal abilities, and its ability to survive in the modified environment. Although habitat loss itself is important, the consequences of fragmentation are greater than expected based solely on the area of habitat destroyed.

The most obvious example is area-sensitive species that cannot maintain populations in limited areas of even otherwise high quality habitat. Raptors, large cats, and grizzly bears are prominent examples of species that need extensive home ranges and thus avoid smaller habitat fragments. Road construction and second home development are fragmenting the remaining large expanses of wild lands needed for such large carnivores. Species with small home ranges, such as songbirds, may also avoid small fragments if they prefer the interior of large habitat patches (Robbins et al., 1989) or select patches large enough to support other members of their species as discussed above, population size is reduced in small habitat fragments. For example, the suburban sprawl that is reducing the coastal sage habitat area in southern California, may affect the viability of populations of gnatcatchers and other species (Reid and Murphy, 1995). In addition, the migration of animals that travel between habitats seasonally (e.g., birds and fish) or during their life cycle (e.g., amphibians) can be impeded by fragmentation. The segmentation of large rivers into series of reservoirs has had dramatic effects on the migration *of anadromous salmonids* across the country. Highway construction that dissects forest habitat affects the migration of several frog and salamander species to their spring breeding ponds, often resulting in major road kills. Over longer periods, climate change may require species to shift their entire geographic ranges, an impossibility when fragmentation has eliminated intervening suitable habitat (Peters and Lovejoy, 1992). Another important consequence of fragmentation is the increase in perimeter area or “edge” habitat (Hunter, 1996). Simple geometry dictates that small fragments have more edge in relation to their area than large fragments and that the less like a circle the fragment is the greater is its perimeter.

The consequences of increased edge include: (1) the change in physical conditions (organisms near the edge are subjected to more wind, less moisture, and greater temperature extremes), and (2) invasion by species from the surrounding disturbed habitat (e.g., competitors such as weeds and predators such as rats, cats, and people). Perhaps the best studied effects are the high levels of nest predation and brood parasitism on forest birds nesting near forest-farmland edges (Wilcove et al., 1986; Paten, 1994). Population declines in forest-interior birds, including many migratory songbirds, have been ascribed to these effects of fragmentation as well as to losses of wintering habitat in Latin America.

The fragmentation of habitat not only changes the biotic interactions that structure ecosystems, but can also adversely affect nutrient cycling. In terrestrial ecosystems, the most vulnerable abiotic factor is soil fertility; a condition that can be degraded by leaching of nutrients when vegetation-free patches are created. The loss of soil fertility can affect plant competition and influence the forage quality of plant parts. The leaching of nutrients also creates a burden for aquatic systems in the form of undesirable nutrient enrichment. Especially in warm, humid climates, the presence of actively growing vegetation can mean the difference between net retention and loss of nutrients; a process that is affected by the size and duration of vegetation-free patches. In general, there is a critical size of vegetation-free patch, probably a size that is unique to each combination of soil, vegetation, and climate, below which nutrient losses are likely to negligible.

2.9 Restoring and management of forest landscape

Forest landscape restoration deals with the integrated management of large forest systems. Its goal is to both regain ecological integrity and enhance human wellbeing. Achieving this objective requires equitable negotiations amongst all concerned stakeholders. Spatial data and their analysis can support negotiations and decision making by providing information on the status of the landscape and the likely impact of different restoration strategies (Sayer and Campbell, 2004). They also suggested that spatial analysis can help practitioners to:

(1) Identify priority areas for restoration;

(2) Identify and quantify the most important pressures on particular areas; and

(3) Define restoration goals and monitor progress towards them.

It is important to decide if and why restoration is required in particular contexts, and there are a variety of different biological and practical reasons why restoration activities are carried out. As discussed by Hobbs and Norton (1996), restoration is fundamentally conducted to improve or sustain ecosystem goods and services, which may include aesthetic and societal preferences. To achieve this broad goal, restoration activities may be required to reverse severe, localized disturbances, to reinstate productive capacity in degraded agricultural systems, to maintain or return conservation values in protected areas, or to reinstate broader landscape processes essential to the continuation of both rural and urban production and conservation enterprises.

Deciding how to restore a degraded landscape involves selecting from the current and expanding set of management options available, given limitations set by the system to be restored, and the financial resources and expertise available to do it.

Proximate considerations relate to the type and extent of damage being reversed. In some cases, the system can be left to regenerate on its own or simple inexpensive biotic manipulations may be all that is required. Alternatively, more expensive species introductions and plantings may be needed. In some cases, abiotic factors may need remediation first (Whisenant, 1999). Further considerations relate to the spatial scale of the restoration project. Nonetheless, even landscape restoration has to be conducted by treating individual landscape elements, and careful attention to spatial relations is essential. Guidance for making these restoration decisions comes from an understanding of successional dynamics at the site.

Additionally, Reid and Murphy (1995) mentioned that management of land development and mitigation of adverse impacts on the pattern and connectivity of landscape habitat should follow the conservation principles. For instances,

(1) Species that are well distributed across their native ranges are less vulnerable to extinction than a species confined to small portion of their ranges;

(2) Large blocks of habitat containing large populations of target species are superior to small blocks of habitat containing small populations;

(3) Blocks of habitat that are close together are better than blocks that are far apart habitat that occurs in blocks that are less fragmented internally is preferable to habitat that is internally fragmented;

(4) Interconnected blocks of habitat are better than isolated blocks, and habitat corridors or linkages function best when the habitat within them resembles habitat that is preferred by the target species; and

(5) Blocks of habitat that are road less or otherwise inaccessible to people better conserve target species then do road and easily accessible habitat blocks.

Noss (1999) provided more specific recommendations for managing habitat pattern and connectivity in forestry activities. He suggested that land management should mimic natural patch shapes and mosaics. In general, forest vegetation treatments should vary more in size and shape than under the current system, and they should be aggregated to increase effective patch size and minimize fragmentation. Additionally, forest management should both manage for linear features as well as for patches. If it is impossible to provide continuous corridors, linear archipelagoes of remnant patches may have value for more mobile species.

There are many examples of forest restoration that can be classified as afforestation, reclamation, or rehabilitation. Three steps are keys to planning forest restoration: (1) understanding current condition; (2) clarifying objectives and identifying an appropriate goal; and (3) defining feasible action that will move toward to desired condition (Stanturf, 2001).

Commonly used restoration terms can be understood within a conceptual framework (Figure 2.6) that takes into account the relationships between changes in forest cover and land use as shown in Figure 2.7 (Stanturf and Madsen, 2002). In particular, Stanturf (2005) discussed the restoration framework as degradation trajectory begins with the idealized forest at **Ω** as the starting point (Figure 2.6). The beginning point is culturally and situationallv determined. In some contexts, it may represent an actual historical reality, or it may be a conceptual model of the potential natural vegetation for an area. The degradation trajectory moves toward a degraded endpoint, A in Figure 2.6. The possible endpoints are shown in Figure 2.7; the most degraded states will include deforestation and conversion to non-forest land use. The intermediate points B1 to B3 represent forests degraded by air pollution, exploitive harvesting, natural disasters, etc. These degraded forests, as well as non-forest conditions (A), represent starting points for restoration trajectories. For ease of representation, the A to Ω trajectory is presented as linear; in reality it is probably more complex (Anand and Desrochers, 2004).

The path extending from A to Ω, labeled *Recreation*, represents the strictly defined ecological or historical restoration (SER, 2002). Re-creating the ideal natural or historical forest ecosystem is unlikely to be successful over large areas (van Diggelen et al., 2001) and will certainly be expensive. *Reconstruction* refers to restoration of forest conditions to agricultural land (Figure 2.7), through afforestation or natural invasion. The endpoint for reconstruction (B1 to B3) may be a less diverse natural forest (B2) or a mixed species plantation of native species (B3). Alternatively, a site may be so degraded that native species are replaced by exotics; this pathway (to C) would be termed replacement.

Reclamation begins with urban or built land-use and may require land stabilization as well as afforestation. For both reconstruction and reclamation, continuing intervention over time may move the forest condition closer to the natural endpoint (shown as a dashed line in Figure 2.6).

Rehabilitation of degraded forests has one of the intermediate conditions (B1 to B3) as a starting point; forest cover has been removed or degraded but no change to non-forest land use has occurred. Rehabilitation encompasses many techniques to restore stand structure, species composition, natural disturbance regimes, or to remove exotic plants. Specific forms of rehabilitation are termed conversion (Nyland, 2003; Spiecker et al., 2004) or transformation (Kenk and Guehne, 2001).

The conditions at C, D, and E represent *Replacement*; these are forests that deviate from the natural range of variability but restore forestry land use. Plantations of exotic species, for example, have a simple structure but high functioning as compared to non-forest land use (C). Over time, with or without further intervention, even replacement stands could move toward the natural endpoint by gaining structure or additional species. Conversion or transformation back to mixed broadleaved forests (C to B1 or to Ω) completes the restoration of a natural forest within the range of self-renewal processes. Starting point D represents the rehabilitation of forests with disrupted natural disturbance regimes.

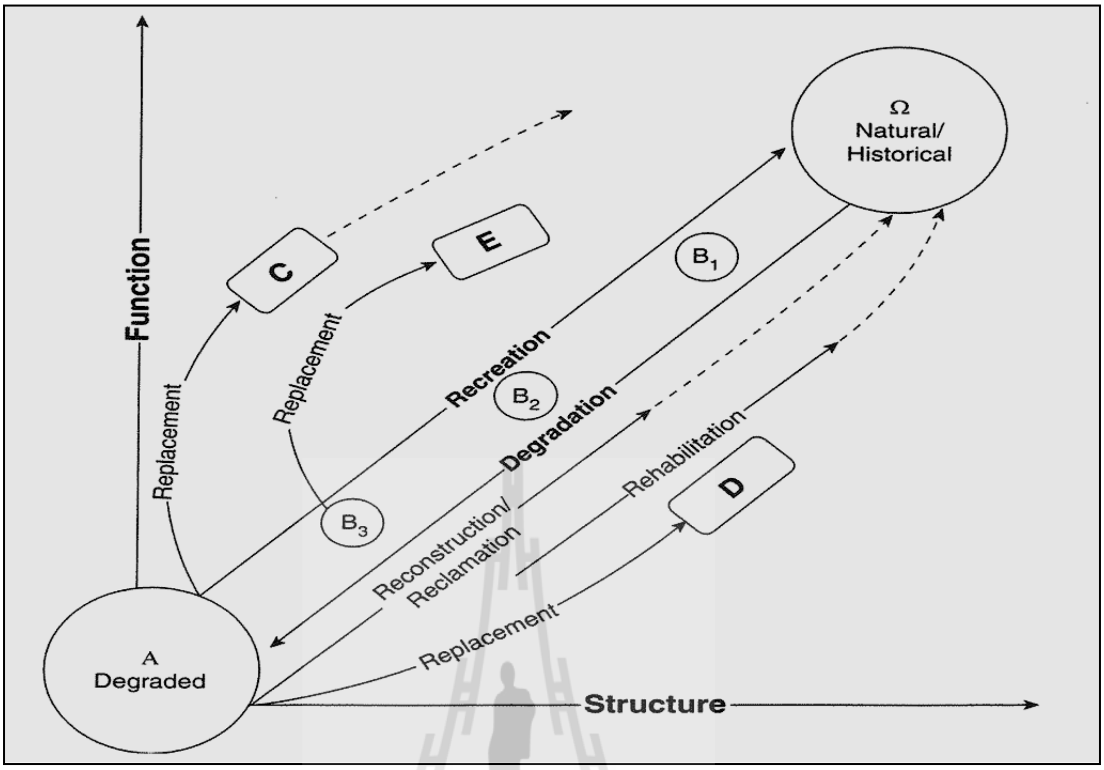


Figure 2.6 A conceptual framework for forest restoration: has a starting point of a degraded forest (A) and an idealized endpoint of a forest restored to some natural or historical end point (Ω). The symmetric degradation/re-creation paths have intermediate points that represent starting/ending points (B1 to B3) for reconstruction or reclamation of severely degraded forests (deforested and converted to other land use) or less severely degraded forests (rehabilitation). Replacement paths denote restored forests that lack the structure or species composition of native forests (Stanturf, 2005).

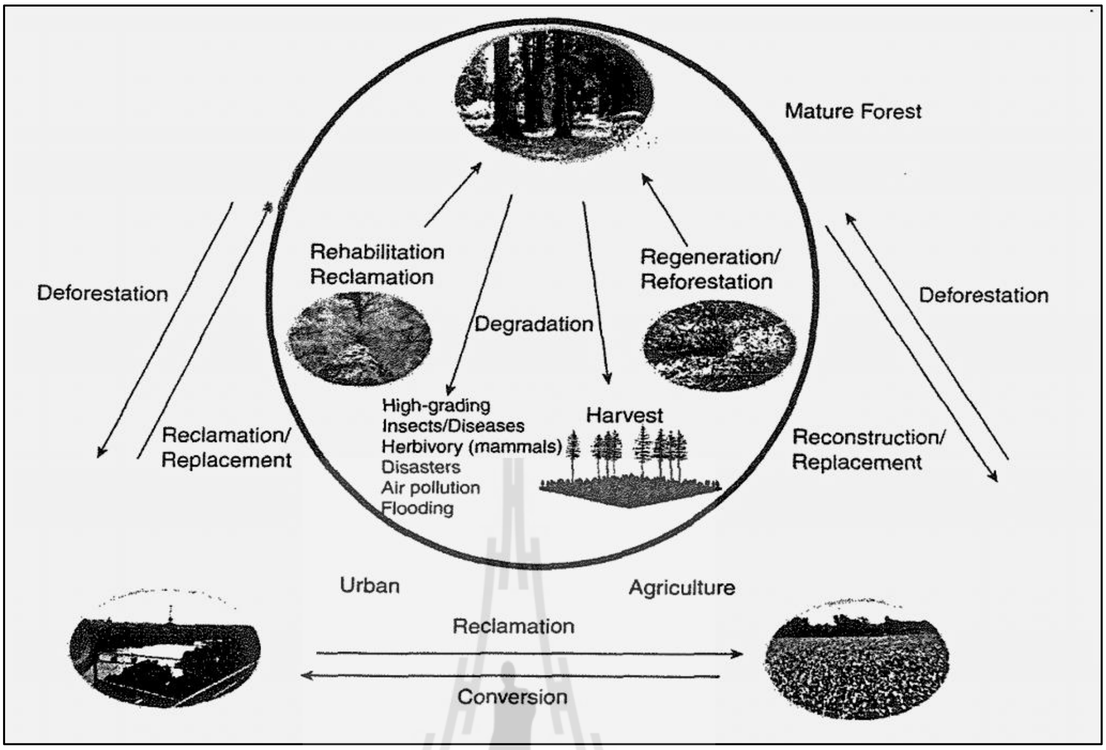


Figure 2.7 Forest restorations: begins with forests that have been degraded (rehabilitation) or after deforestation and conversion to other land uses (reconstruction or reclamation). Self-renewal processes operate within forests that are disturbed but not degraded (regeneration/reforestation) (Stanturf and Madsen, 2002).

Recent researches are numerous carried out. For example, Kintz et al. (2006) examines the spatial and temporal patterns of LULC change using landscape metrics and from-to change maps created by post classification change detection. The methods used in this study provide an effective way to monitor LULC change detection and support the management of protected areas and their surrounding environments. While, Kozak et al. (2007) develop a satellite-based methodology for implementation of two indicators: (1) area of forest cover, and (2) forest spatial pattern. They found a decrease of core forest and an increase of patch and perforated forest and conclude that the proposed methodology allows quantifying changes of forest cover and forest spatial pattern at 1 ha minimum mapping unit. Furthermore, Sano, Furuya, and Kogi (2009) using landscape metrics provided insights into the landscape structure of the study area and suggests that the landscape metrics provide an efficient tool for assessing the landscape structure that will result from management plans. In addition, Trisurat and Duengkae (2011) studied consequences of land use change on bird distribution at Sakaerat environmental research station used landscape indices found that distance to dry evergreen, to secondary growth and to road were important factors for *Black-crested Bulbul* distribution.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Dataset and equipment

Remotely sensed and GIS datasets had been collected for this study while basic equipment such as hardware and software were employed to data collection and data analysis which were shown in Table 3.1.

Table 3.1 Dataset and equipment.

Dataset and equipment	Date	Resolution/Scale	Source
1. Remote sensing datasets			
1.1 Black and white Aerial Photographs	1980	1:40,000 (2x2 m)	RTSD
1.2 Digital color orthophotomaps	2002	1:4,000	MOAC
1.3 THEOS Pansharpened	2010	2x2 m	GISTDA
2. GIS datasets			
2.1 Topographic map	1999	1:50,000	RTSD
2.2 Land use data	2007	1:25,000	LDD
3. Equipment			
3.1 Software			
3.1.1 ERDAS Imagine 9.2 (ERDAS, 2006)			Remote sensing Lab, SUT
3.1.2 ESRI ArcGIS 9.3, 10 (ESRI, 2008)			
3.1.3 Patch Analyst Version 5			
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 Cooperative, GISTDA = Geo-Informatics and Space Technology Development Agency (Public Organization), LDD = Land Development department, SUT = Suranaree University of Technology

3.2 Research methodology

Research methodology was designed to meet the objectives of the research**,** which was involved developing an understanding of the spatial landscape pattern and ecological processes interactions, and more concerns to evaluate and assess on forest pattern dynamic changes in SBR. The method consists of four parts as described below and in the framework flowchart (Figure 3.1):

Part 1. Classification land use and land cover (LULC) of SBR and assessment of change;

Part 2. Analysis and assessment of SBR landscape pattern using landscape metrics;

Part 3. Identification and analysis forest landscape patterns using selected landscape indices; and

Part 4. Interpretation indices value to create matrix of recommendation for forest restoration and management plan in SBR.

Detail of each research procedures and dataset input were orderly described in the following sections.

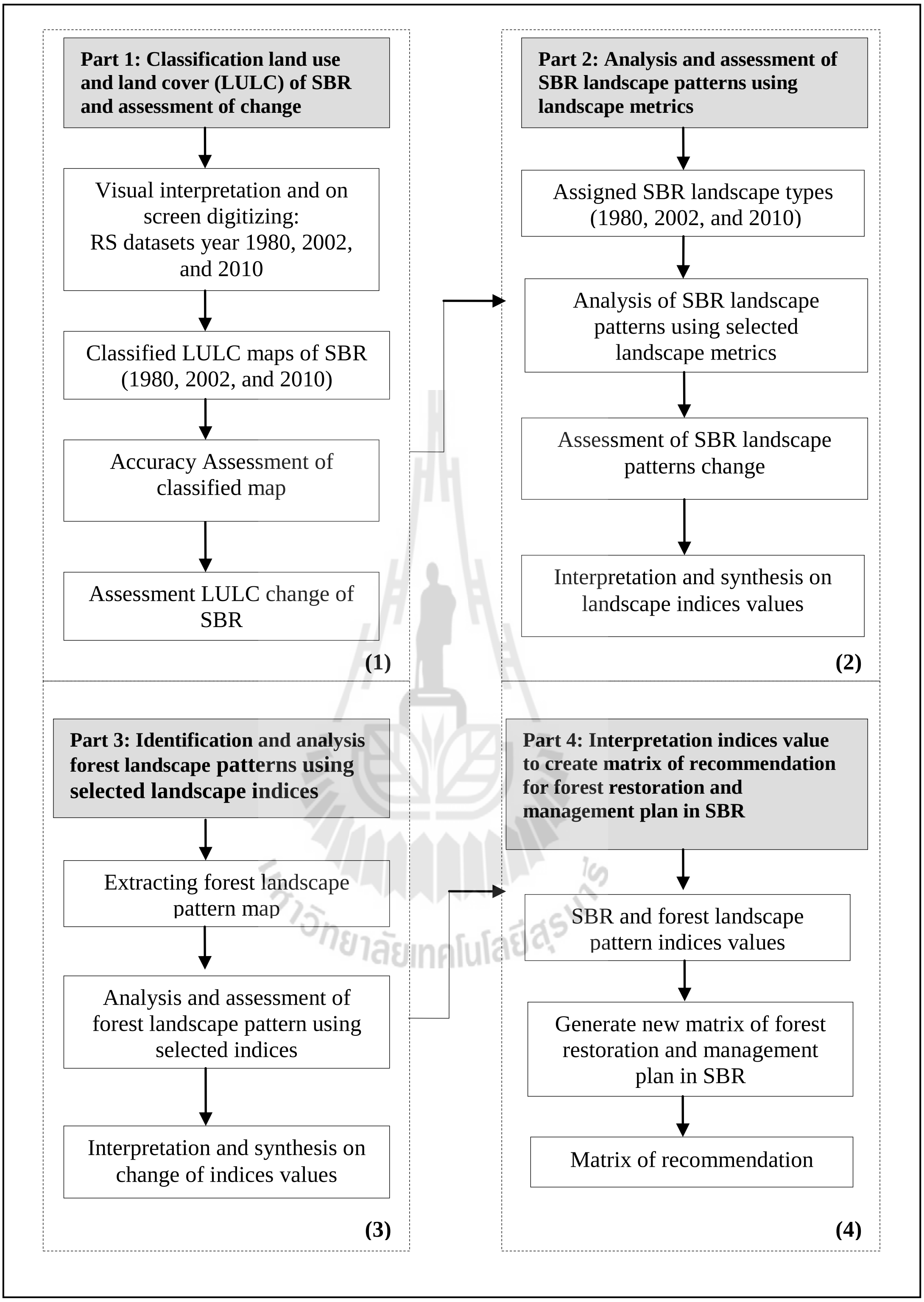


Figure 3.1 Research methodology frameworks.

3.2.1 Part 1. Classification land use and land cover (LULC) of SBR and assessment of change.

Four main steps of Part 1 were illustrated in Figure 3.2. The detail of each steps were described separately in the following sections.

3.2.1.1 Data preparation and preprocessing

Multi date datasets were used which included primary remotely sensed datasets of the study area and additional datasets, these consisted of:

(1) Totally 55 scenes of the black and white aerial photographs 1980 acquired by the Royal Thai Survey Department (RTSD) and were digitally scanning with 10 micron resolutions to produce digital aerial photographs files at approximately 2x2 m spatial resolution;

(2) Totally 425 scenes of the color orthophotomaps 2002 at 1:4,000 scale from the Office of Agricultural Economics (OAE), Ministry of Agriculture and Cooperative (MOAC) were used and converted to 18 enhanced compression wavelet file format made it easy and practical to use in later processes; and

(3) Totally 7 scenes of the THEOS pan sharpened imagery, path128/row49, and path128/row50, acquired in 2010 by the Geo-Informatics and Space Technology Development Agency (GISTDA) at 2x2 m spatial resolution.

Additionally, other available secondary datasets such as topographic, transportation, political boundary, villages and other settlement maps were included as ancillary data in image classification as needed.

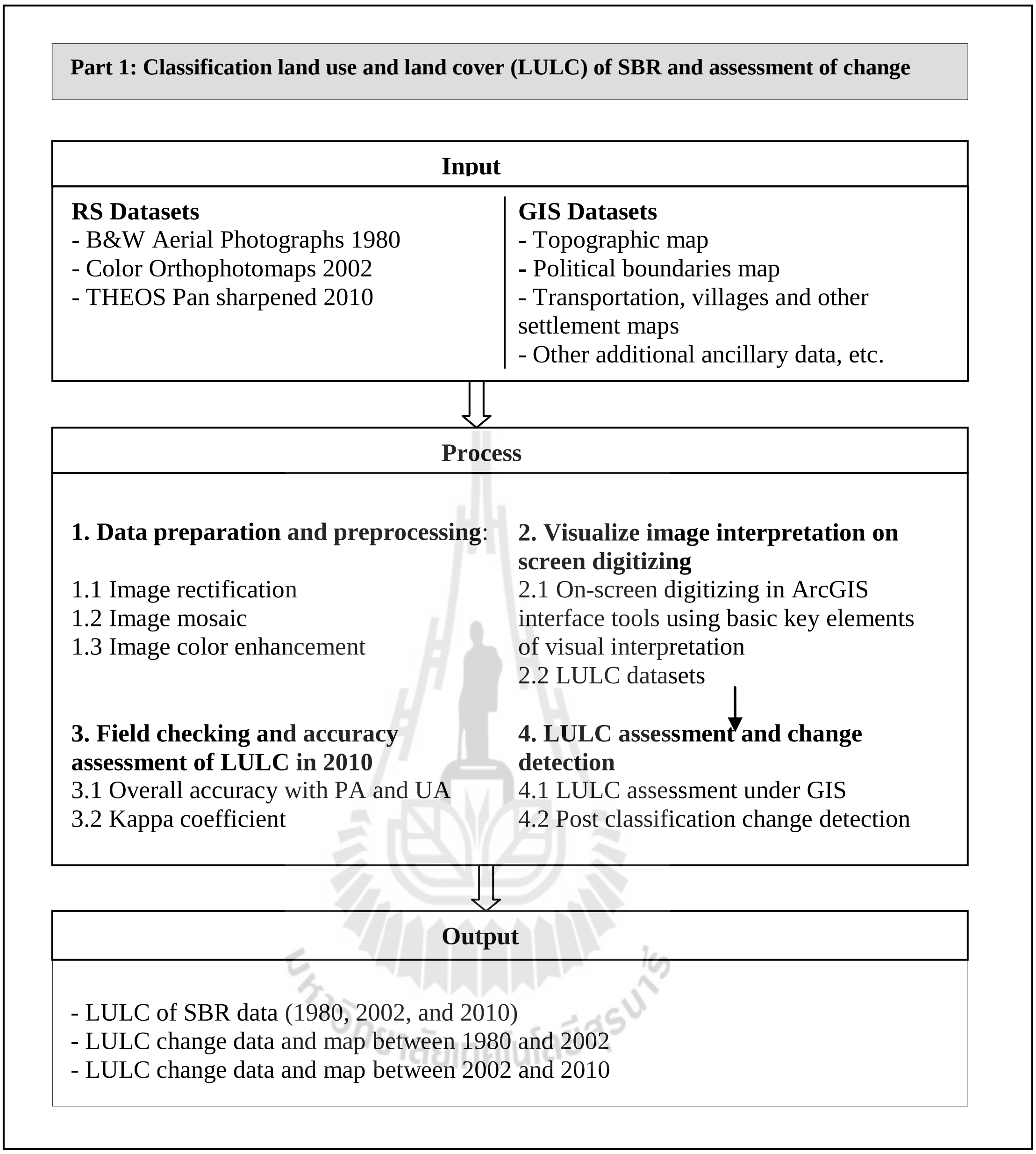


Figure 3.2 Classification land use and land cover (LULC) of SBR and assessment of change.

Firstly, image rectification was performed for geometric correction, with assumption that dataset of the color orthophotomaps 2002 were rectified and had high spatial accuracy and high resolution, it was confirmed by registry it with the World Geodetic System 1984 (WGS-84) and the Universal Transverse Mercator (UTM) geographic coordinate system. Thus, this dataset was used as the primary high accurate reference images, hereafter all the THEOS images and the aerial photographs were performed rectification by image to image procedure with map projection of WGS-84 and UTM zone 47 north coordinate system. All images rectification procedure were executed by ERDAS IMAGINE 9.2 version environment with first order polynomial transformation for spatial interpolation, resulting in the error of less than 0.5 of its pixel size and assumed all acceptable geo-referencing images products.

After all images were geometrically corrected, they were brought to the next step which was images mosaic. For seven THEOS pansharpened images were firstly mosaic by their path and row of coverage, then combined them all and clipped it with the study area boundary. Similarly to fifty-five of the aerial photographs but fewer steps of mosaic were performed. Due to, the large study area constitute of nine photo-flight lines while the aerial photographs were taken then mosaic started with photo-fight line by line until its completed. However, difficulty of this part payback to previous steps in geo-referencing because the time that aerial photographs were acquired far back in 30 years, then many obvious evidences and landmarks were difficult to locate. Assisting with ancillary data such as topographic map, and other historical maps made this step accomplish. Finally, three dates of study area images were adjusted for color enhancement which made them ready and clear for visual interpretation and on-screen digitizing.

3.2.1.2 Visual image interpretation and on-screen digitizing

LULC classification process employed visual interpretation using basic key elements of remotely sensed such as shape, tone/color, texture, location, and association, together with on-screen digitizing in ArcGIS 9.3 and 10 version interface tools. The study area was identified into five categories and nine different classes according to the following classification system.

(1) A: Agriculture Area	A1: Paddy field
	A2: Field crop
	A3: Orchard/Tree
(2) F: Forest Area	F1: Natural forest
	F2: Disturbed forest
	F3: Forest plantation
(3) U: Urban/Built-up land	U: Urban/Built-up land, Road
(4) W: Water Body	W: Stream/River, Reservoir/Canal/Well
(5) M: Miscellaneous	M: Idle/Abandon land/Miscellaneous

Three dates of the images were classified separately. Boucher et al. (2006) suggested starting with classifying the image that contains the most information relative to other images in the series rather than the first image in the series, these high confidence classifications can be used to better classify the data in other periods where classification is more uncertain. Thus, it is reasonable to first start interpreting with the color orthophotomaps 2002 (date-2) and on-screen digitizing, follows by the THEOS pansharpened 2010 (date-3) and the aerial photographs 1980 (date-1) respectively. According to Boucher's suggestion, adding images with high information content to a time series can increase the mapping accuracy by constraining the images carrying less information, in this case the color orthophotomaps of SBR assumed have the highest information content, concurrently the THEOS pansharpened imagery data were also have very close images characteristic to those of the color orthophotomaps of SBR. On the other hand, the aerial photographs were the most problematic interpretation and digitizing due to less information content and were in black and white color made difficult to discriminate and delineate their contents. However, using digitized template from the color orthophotomaps or the THEOS pansharpened imagery data superimposed onto the aerial photographs help increasing rate of efficiently digitizing. The outcomes from this step were LULC classification of SBR 1980, 2002, and 2010, the classified images were completed for accuracy assessment in the next step.

The example of LULC classes catalogue of datasets used in the study, which using as key for visual interpretation was presented in Figure 3.3.

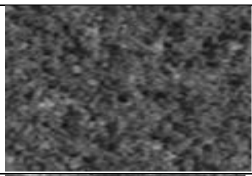
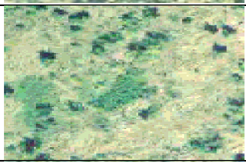
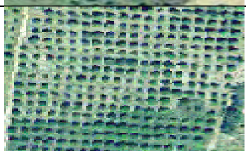
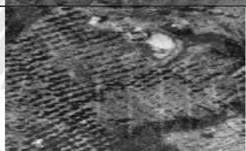
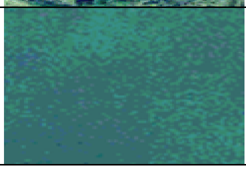
Color orthophotomaps	Aerial photographs	LULC Classes
		Natural forest
		Disturbed forest
		Forest plantation
		Paddy field
		Field crop
		Orchard/Tree
		Urban-Built up
		Miscellaneous (Idle/Abandon land)
		Water body

Figure 3.3 LULC classes catalogue for visual interpretation.

3.2.1.3 Accuracy assessment of classified maps

To perform solid classification accuracy assessment, it is required to compare between reference maps and the classified maps. Accuracy assessments determine the quality of the information derived from remotely sensed data. Assessments can be either qualitative or quantitative. For qualitative assessments, we determine if a classified map lookalike by comparing what we see in the imagery with what we see on the ground. This believes to be quick but unclean way for the first cut assessment. While quantitative assessments attempt to identify and measure remote sensing-based map error. In such assessments, we compare map data with reference or ground truth data where ground truth data is assumed to be all correct.

Theoretically, four measures were commonly used to assess the accuracy of the classified images namely, the overall classification accuracy, producer's accuracy, user's accuracy, and kappa statistic. Additionally, Congalton (1991) suggested good rule to collect ground truth data at a minimum of 50 samples for each land cover class in the error matrix. However, other researchers suggested at least 30 or correctly 40 sample sites better than to collect many of poor sample sites. Using this logic decision, for the SBR study area approximately 298 randomly selected reference sites should be assessed. However, the number of samples can also be adjusted based on how importance of that class within the objectives of the study, proportions of those classes present in the area, and samples location accessibility.

To create the error matrix, alternatively calls confusion matrix, or contingency table which is a multidimensional table, its cells contain two types of dataset, the columns contain the reference data and the rows represent the results of the remotely sensed classified data (Figure 3.4). This is an effective way to represent accuracy of each classified category. The statistical approach of the accuracy assessment consists of different simple and multivariate statistical analysis. The overall accuracy classification map was determined by dividing the total correct pixels by the total number of pixels in the error matrix as computed equation:

$$Overall\ accuracy = \frac{\sum_{i=1}^{k} X_{ii}}{N}, \tag{3.1}$$

where k is the number of rows in the matrix, X_{ii} is the number of observation in row i and column I, and N is the total number of observations (Congalton and Green, 2009).

Besides, accuracies of individual category can be computed in a similar manner. For producer's accuracy which computed as the total number of correct pixels in a category divided by the total number of pixels of that category as derived from the reference data. This indicates the probability of a reference pixel being correctly classified; put in the other word is how well a certain area can be classified. On the other hand, user's accuracy which computed as the total number of correct pixels in a category divided by the total number of pixels that were classified in that category. This indicates the probability that a pixel classified on the map or images actually represents that category on the ground.

Another used measure is KAPPA (Cohen, 1960), or the KHAT coefficient statistic ($\hat{K}$). It is designed to measure of overall agreement between image data and the reference (ground truth) data. The coefficient range fall on scale between 0 and 1, where it approaches 1 indicate high agreement, contrast approach 0 indicates poor agreement. The KHAT coefficient ($\hat{K}$) computes as:

$$\text{KHAT} = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+}x_{+1})}{N^2 - \sum_{i=1}^{k}(x_{i+}x_{+1})}, \tag{3.2}$$

where k is the number of rows in the matrix, x_{ii} is the number of observation in row i and column i, and x_{i+} and x_{+i} were the marginal totals for row i and column i respectively, and N is the total number of observations (Congalton and Green, 2009).

After the classified maps accomplished reliable accuracies, the results in the acceptable LULC classification maps were derived.

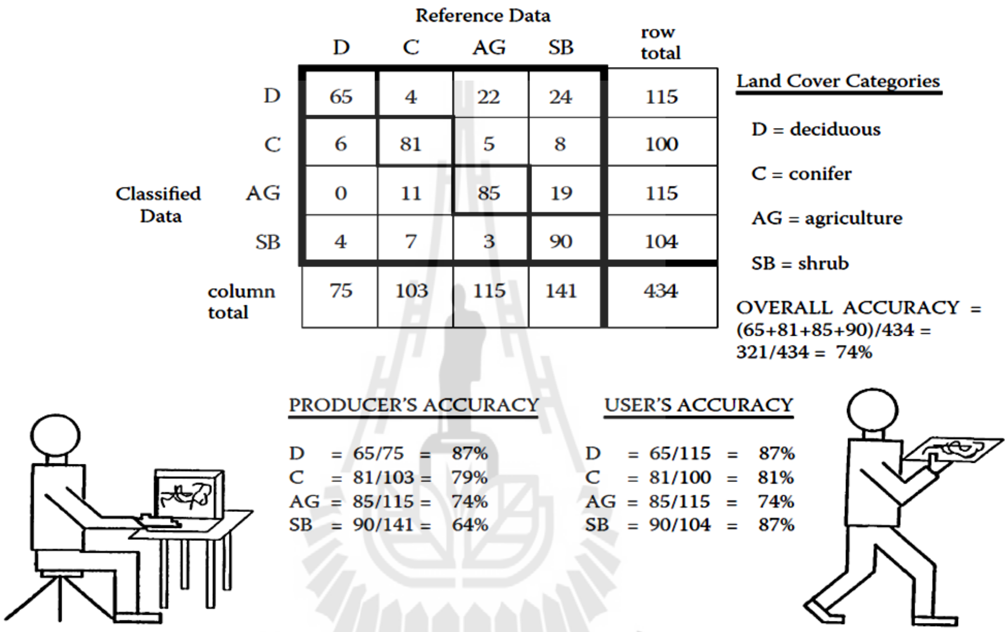


Figure 3.4 An example of error matrix (Congalton and Green, 2009).

3.2.1.4 Assessment of SBR LULC change

The last step was to detect changes; there are numerous methods of change detection have been developed because of the variation in the types of study areas, the types of land use and land cover changes being mapped, and the temporal and spatial resolution of the data. As a result of the variation in applications, study areas, and data constraints, appropriate algorithms need carefully determine to apply on. To this study case, the reasonable methods of choices to be selected which was post-classification comparison. In addition, matrix of changes as cross tabulation between LULC maps should be created in pairs to assess the changes of those classes.

Therefore, the LULC change matrix of SBR between 1980 and 2002; and between 2002 and 2010 were evaluated. After change detections were performed, change areas can be identified and reported as shown in the results and discussions chapter.

3.2.2 Part 2. Analysis and assessment of SBR landscape pattern using landscape metrics

In Part 2 (Figure 3.5), three dates of LULC maps of SBR created from part one were then be used to perform landscape types assigning. Landscape types were determined by grouping or recoding LULC classes into appropriate landscape types. Recode landscape types process may be adjusted and simplified to reasonable and reliable for further pattern analysis. The development and usage of landscape pattern indices (LPIs) originated when measure of similarity or dissimilarity among landscape were required by ecologists to answer process related research questions. Numerous studies compare and characterize landscape based on LPI values. It has also been hypothesized and demonstrated that information contained among LPIs is redundant and correlate, this forced ecologist, geographers, foresters, and other spatial analysts to select a suite of LPIs aimed at describing several components of landscape pattern. Spatial pattern analysis program in which to use for SBR pattern analysis was Patch Analyst version 5 (Rempel and Carr, 2012), and FRAGSTAT version 3.3 (McGarigal and Mark 1995). The software programs support on landscape pattern indices computation. Descriptions and formulae of selected indices at landscape and class levels for the study were summarized in Table 3.2. Outputs from this part were the measurement of indices values of SBR landscape pattern at landscape and class levels.

Part 2: Analysis and assessment of SBR landscape pattern using landscape metrics

Input

LULC of SBR data in 1980, 2002 and 2010

⇓

Process

1. Assigned SBR landscape type

Agriculture landscape (A)
Forest landscape (F)
(F1=Natural forest, F2=Disturbed forest and F3= forest plantation),
Urban-Built up landscape (U)
Miscellaneous and Water body (M)

2. Analysis of SBR landscape patterns using selected landscape metrics

Calculate selected landscape indices
At landscape level
At class level

3. Assessment of SBR landscape patterns change

Metrics of SBR landscape pattern changes between 1980 and 2002
Metrics of SBR landscape pattern changes between 2002 and 2010

⇓

Output

Tendency of SBR landscape metric values and its ecological implication

Single year 1980, 2002, and 2010
Change between 1980 and 2002
Change between 2002 and 2010

Figure 3.5 Analysis and assessment of SBR landscape pattern using landscape metrics.

Table 3.2 Description of selected landscape indices at landscape and class levels (Adapted from McGarigal and Mark, 1995).

	Area/density/edge Metrics
	1. Number of Patch
Formula	$NP = number\ of\ patch$
Unit	None
Range	NP ≥ 1, without limit.
Description	NP = 1 when the landscape contains only 1 patch *Number of patches* often has limited interpretive value by itself because it conveys no information about area, distribution, or density of patches. But, if total landscape area is held constant, then number of patches may be a useful index to interpret. Number of patches is probably most valuable as the basis for computing other more interpretable metrics.
	2. Total Edge
Formula	$TE = E$ E is total length (m) of edge in landscape
Unit	Meters
Range	TE ≥ 0, without limit
Description	TE = 0 when there is no edge in the landscape; when the entire landscape and landscape border, if present, consists of a single patch. *Total edge* is an absolute measure of total edge length of a particular patch type. In applications that involve comparing landscapes of varying size, this index may not be as useful as edge density. However, when comparing landscapes of identical size, total edge and edge density are the same.
	3. Edge Density
Formula	$ED = \frac{E}{A}$ E is total length (m) of edge in landscape A is total landscape area (m^2).
Unit	Meters per Square meter
Range	ED ≥ 0, without limit
Description	ED = 0 when there is no edge in the landscape; when the entire landscape and landscape border, if present, consists of a single patch. *Edge density* has the same utility and limitations as Total Edge, except that edge density reports edge length on a per unit area basis that facilitates comparison among landscapes of varying size.
	Shape Metrics
	1. Mean Shape Index
Formula	MSI = measure of shape complexity and is the sum of each patch's perimeter divided by the square root of patch area (in hectares) for all patches (when analyzing by landscape), and adjusted for circular standard (for polygons), or square standard (for rasters (grids)), divided by the number of patches.
Unit	None
Range	MSI ≥ 1, without limit

Table 3.2 (Continued).

Description	MSI = 1 when the patch is square and increases without limit as patch shape becomes more irregular. *Shape index* corrects for the size problem of the perimeter-area ratio index by adjusting for a square standard and, as a result, is the simplest and perhaps most straightforward measure of shape complexity.
	2. Mean Patch Fractal Dimension
Formula	MPFD= the sum of 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m2) for each patch in the landscape, divided by the number of patches. MPFD measures of shape complexity
Unit	**None**
Range	1 ≤MPFD ≥2
Description	MPFD measures of shape complexity. When it approaches one for shapes with simple perimeters and approaches two when shapes are more complex.
	Core Area Metrics
	1.Total Core Area
Formula	TCA**=** The total size of disjunctive core area patches
Unit	Hectares
Range	TCA ≥ 0, without limit TCA = 0 when every location within every patch is within the specified edge distance from the patch perimeters. TCA approaches total landscape area as the specified edge distance decreases and as patch shapes are simplified
Description	*Total core area* is defined the same as core area (CORE) at the patch level but here core area is aggregated (summed) over all patches.
	2. Mean Core Area
Formula	MCA**=** The average size of disjunctive core patches.
Unit	Hectares, Sq. m**.**
Range	MCA≥ 0, without limit
Description	The mean size of disjunctive core area patches
	3. Total Core Area Index
Formula	**TCAI** = Measure of amount of core area in the landscape. And is equals the sum of the core areas of each patch (m2), divided by the total landscape area (m2), multiplied by 100 (to convert to a percentage)
Unit	None
Range	0≤TCAI < 100
Description	Total core area index is a proportion of core area in the entire landscape and is equal to zero when no patches in the landscape contain core and approaches 100 as the relative proportion of core area in the landscape increases.
	4. Core Area Density
Formula	**CAD** = The relative number of disjunctive core patches relative to the landscape area.
Unit	Hectares
Range	CAD ≥ 0, without limit CAD = 0 when there are no core area
Description	The total number of all disjunctive patches divided by the landscape area (number of disjunctive core patches)

Table 3.2 (Continued).

	Diversity and Interspersion Metrics
	1. Shannon's Diversity Index
Formula	SDI=Measure of relative patch diversity
Unit	None
Range	SDI ≥ 0, without limit
Description	Shannon's diversity index is only available at the landscape level and is a relative measure of patch diversity. The index will equal zero when there is only one patch in the landscape and increases as the number of patch types or proportional distribution of patch types increases.
	2. Shannon's Evenness Index
Formula	SEI= Measure of patch distribution and abundance.
Unit	None
Range	0 ≤ SEI ≤1
Description	SEI = 0 when the landscape contains only 1 patch (no diversity) and approaches 0 as the distribution of area among the different patch types becomes increasingly uneven (dominated by 1 type). SEI = 1 when distribution of area among patch types is perfectly even (proportional abundances are the same).
	3. Interspersion Juxtaposition Index
Formula	IJI=Measure of patch adjacency (the same as contagion index)
Unit	None
Range	0 ≤ IJI ≤100 IJI approaches 0 when the distribution of adjacencies among unique patch types becomes increasingly uneven. IJI approaches 100 when all patch types are equally adjacent to all other patch types
Description	Interspersion requires that the landscape be made up of a minimum of three classes. At the landscape level it is a measure of the interspersion of the each patch in the landscape.
	4. Mean Proximity Index
Formula	MPI = Measure of the degree of isolation and fragmentation.
Unit	None
Range	MPI ≥ 0, without limit
Description	Mean proximity index is a measure of the degree of isolation and fragmentation of a patch. MPI = 0 if no patch has a neighbor of the same type within the specified search radius. MPI increases as patches become less isolated from patches of the same type and the patch types become less fragmented in distribution.
	5. Mean Nearest Neighbor
Formula	MNN = Measure of patch isolation.
Unit	Meters
Range	MNN ≥ 0, without limit
Description	The nearest neighbor distance of an individual patch is the shortest distance to a similar patch (edge to edge). The mean nearest neighbor distance is the average of these distances (meters) for individual classes at the class level and the mean of the class nearest neighbor distances at the landscape level.

3.2.3 Part 3. Identification and analysis of forest landscape patterns using selected landscape indices

Steps in Part 3 were illustrated as Figure 3.6 and details were described in the following sections.

In Part 3**,** three dates of SBR landscape pattern maps were extracted to obtain individually forest landscape map. Consequently, quantification and comparison of the spatial pattern forest landscapes were conducted based on selected landscape indices in SBR management zones as shown in Table 3.2; excepted for SDI and SEI indices. Landscape indices were calculated in the same manner as in part two using the software Patch Analyst Version 5, for all forest landscape polygons. The results were obtained the following characteristics of, for example, number of patch, shape complexity, core area, and etc. It is accepted that forest landscape were more heavily fragmented with increase in the number of patches and decrease in mean patch size and core area. Finally, valuable information of forest landscape composition, spatial structure was employed to generate recommendation matrix of restoration and management plan in Part 4.

Part 3: Identification and analysis of forest landscape patterns using selected landscape indices

Input

SBR landscape pattern data (1980, 2002, and 2010)

⇩

Process

1. Extracting forest landscape pattern data (1980, 2002, and 2010)

2. **Analysis and assessment of each forest landscape pattern using selected indices** (NP, TE, ED, MSI, MPFD, TCA, MCA, TCAI, CAD, IJI, MPI, MNN)
At each SBR management zones (Core, Buffer, Transition zone)

⇩

Output

Tendency of each forest landscape metric values and its ecological implication

Single year 1980, 2002, and 2010
Changed between 1980 and 2002
Changed between 2002 and 2010

Figure 3.6 Identification and analysis of forest landscape patterns using selected landscape indices.

3.2.4 Part 4. Interpretation indices values to create new matrix of recommendation for forest restoration and management plans in SBR

Steps in Part 4 were illustrated as Figure 3.7 and details were described in the following sections.

In the Part 4**,** each of landscape pattern indices and theirs change of natural forest (F1), disturbed forest (F2), and forest plantation (F3) were carefully evaluated for forest restoration and management plan recommendation. In practice, change of landscape indices of two periods (1980-2002 and 2002-2010) in each forest landscape from previously step was firstly evaluated in term of gain and loss for forest ecological meaning. The possibility of gain and loss of ecological meaning for each selected landscape metric and theirs priority for forest restoration and management plan were shown in Table 3.3. In the study, the priority level for forest restoration and management plan were assigned as score value as follows:

- Urgent priority equals 7;
- High priority equals 5;
- Moderate priority equals 3; and
- Low priority equals 1.

The score were applied for each landscape metrics to identify the final priority level for forest restoration and management plan in each forest landscape type: natural forest (F1), disturbed forest (F2) and forest plantation (F3). Herein, Simple Additive Weighting (SAW) method with equally weight was used to calculate overall score for priority level identification. Overall score (12 to 84) was then equally divided into 4 levels with equally level interval as follows:

(1) 12.0-30.0 Low priority for forest restoration and management plan;

(2) 30.0-48.0 Moderate priority for forest restoration and management plan;

(3) 48.0-66.0 High priority for forest restoration and management plan; and

(4) 66.0-84.0 Urgent priority for forest restoration and management plan.

The derived priority levels were used as an example to recommend for forest restoration and management plan as shown in Table 3.4.

Practically, restoration plan considers as a long term action and available in several options. The concept of restoration thresholds suggests that options are determined by the current state of the system. On the other hand, management considers shorter action plan however both restoration and management are as parts of land management. Clear understanding of the restoration and management options available is important task to the development of effective and easy working plan.

Part 4: Interpretation indices value to create new matrix of recommendation for forest restoration and management plans in SBR

Input

Forest landscape metrics and its change in each management zones
(Forest landscape change between 1908-2002 and 2002-2010)

⇓

Process

1. Forest Ecological Meaning Evaluation for Gain and Loss
   Priority level for forest restoration and management plan
2. Score Assignment based on its priority level
   (Urgent: 7/High: 5/Moderate: 3/Low: 1)
3. SAW Calculation

$$SAW = \sum_{1}^{i} x_i \cdot w_i$$

Priority level: 12.0 - 30.0 ⇒ Low, 30.0-48.0 ⇒ Moderate, 48.0 - 66.0 ⇒High, 66.0-84.0⇒Urgent

⇓

Output

Priority Level Evaluation for forest restoration and management plan
Restoration plan (long tern action: no need, need action)
Management plan (short term action: urgent need, intermediate need)

Figure 3.7 Interpretation indices value to create new matrix of recommendation for forest restoration and management plans in SBR.

Table 3.3 Ecological meaning of possibility for gain and loss of each selected landscape metrics and their priority level.

Landscape Metrics	Metric value change 1980 to 2002	Ecological meaning	Metric value change 2002 to2010	Ecological meaning	Priority Level
NP	Increase	Loss	Increase	Loss	Urgent
NP	Increase	Loss	Decrease	Gain	Moderate
NP	Decrease	Gain	Increase	Loss	High
NP	Decrease	Gain	Decrease	Gain	Low
TE	Increase	Loss	Increase	Loss	Urgent
TE	Increase	Loss	Decrease	Gain	Moderate
TE	Decrease	Gain	Increase	Loss	High
TE	Decrease	Gain	Decrease	Gain	Low
ED	Increase	Loss	Increase	Loss	Urgent
ED	Increase	Loss	Decrease	Gain	Moderate
ED	Decrease	Gain	Increase	Loss	High
ED	Decrease	Gain	Decrease	Gain	Low
MSI	Increase	Gain	Increase	Gain	Low
MSI	Increase	Gain	Decrease	Loss	High
MSI	Decrease	Loss	Increase	Gain	Moderate
MSI	Decrease	Loss	Decrease	Loss	Urgent
MPFD	Increase	Gain	Increase	Gain	Low
MPFD	Increase	Gain	Decrease	Loss	High
MPFD	Decrease	Loss	Increase	Gain	Moderate
MPFD	Decrease	Loss	Decrease	Loss	Urgent
TCA	Increase	Gain	Increase	Gain	Low
TCA	Increase	Gain	Decrease	Loss	High
TCA	Decrease	Loss	Increase	Gain	Moderate
TCA	Decrease	Loss	Decrease	Loss	Urgent
MCA	Increase	Gain	Increase	Gain	Low
MCA	Increase	Gain	Decrease	Loss	High
MCA	Decrease	Loss	Increase	Gain	Moderate
MCA	Decrease	Loss	Decrease	Loss	Urgent
TCAI	Increase	Gain	Increase	Gain	Low
TCAI	Increase	Gain	Decrease	Loss	High
TCAI	Decrease	Loss	Increase	Gain	Moderate
TCAI	Decrease	Loss	Decrease	Loss	Urgent

Table 3.3 (Continue).

Landscape Metrics	**Metric value change 1980 to 2002**	**Ecological meaning**	**Metric value change 2002 to2010**	**Ecological meaning**	**Priority Level**
CAD	Increase	Gain	Increase	Gain	Low
CAD	Increase	Gain	Decrease	Loss	High
CAD	Decrease	Loss	Increase	Gain	Moderate
CAD	Decrease	Loss	Decrease	Loss	Urgent
IJI	Increase	Gain	Increase	Gain	Low
IJI	Increase	Gain	Decrease	Loss	High
IJI	Decrease	Loss	Increase	Gain	Moderate
IJI	Decrease	Loss	Decrease	Loss	Urgent
MPI	Increase	Loss	Increase	Loss	Urgent
MPI	Increase	Loss	Decrease	Gain	Moderate
MPI	Decrease	Gain	Increase	Loss	High
MPI	Decrease	Gain	Decrease	Gain	Low
MNN	Increase	Loss	Increase	Loss	Urgent
MNN	Increase	Loss	Decrease	Gain	Moderate
MNN	Decrease	Gain	Increase	Loss	High
MNN	Decrease	Gain	Decrease	Gain	Low

Table 3.4 An example of recommendation for restoration and management action plans for disturbed forest landscape in buffer zone in each priority level.

	Action Plan	
Priority Level	Restoration Plan	Management Plan
Urgent	Need protection and management of the existing resource	Need protection and management of the existing resource
High	Need restoration or improvement of landscape	Need management or improvement of landscape
Moderate	Improvement of landscape	Improvement of landscape
Low	Maintenance of landscape	Maintenance of landscape

CHAPTER IV

RESULTS AND DISCUSSIONS

The contents of this chapter focus on the results and discussions of the research objectives which were described separately in each part as following;

4.1 Results of land use and land cover (LULC) classification of SBR and assessment of change

The classifications land use and land cover (LULC) of SBR were separately visual classified on multi dates as of 1980, 2002, and 2010 (Figure 4.1 to Figure 4.3); detail of the results were described below.

4.1.1 LULC classification assessment of SBR in 1980

In 1980, LULC of SBR was classified on black and white aerial photographs in which resulted the most dominant area of natural forest at 46.23% (754.63 sq. km) of the total area, followed by 27.79% (453.64 sq. km) of the field crop, and 8.84% (144.27 sq. km) of paddy field. Only these three major classes alone comprised up to almost 83 % of the total area, some others classes including disturbed forest, forest plantation, orchard/tree, and urban and built-up area were among minor classes composed up to about 16%; thereafter 1% consisted of water body, and miscellaneous area. Map of LULC classification and the areas with percentage of each class were shown in Figure 4.4 and Table 4.1

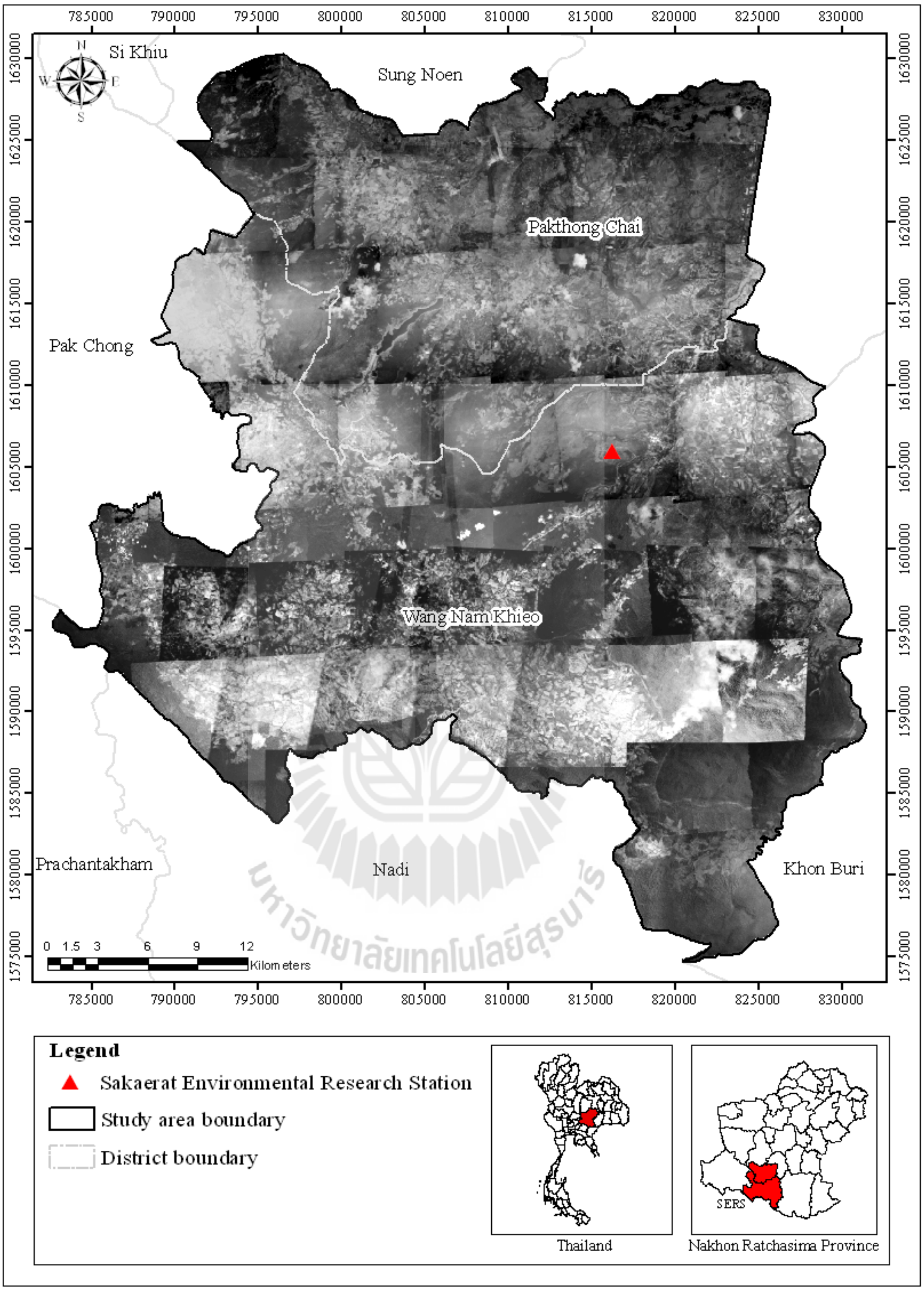


Figure 4.1 Aerial photographs of SBR in 1980.

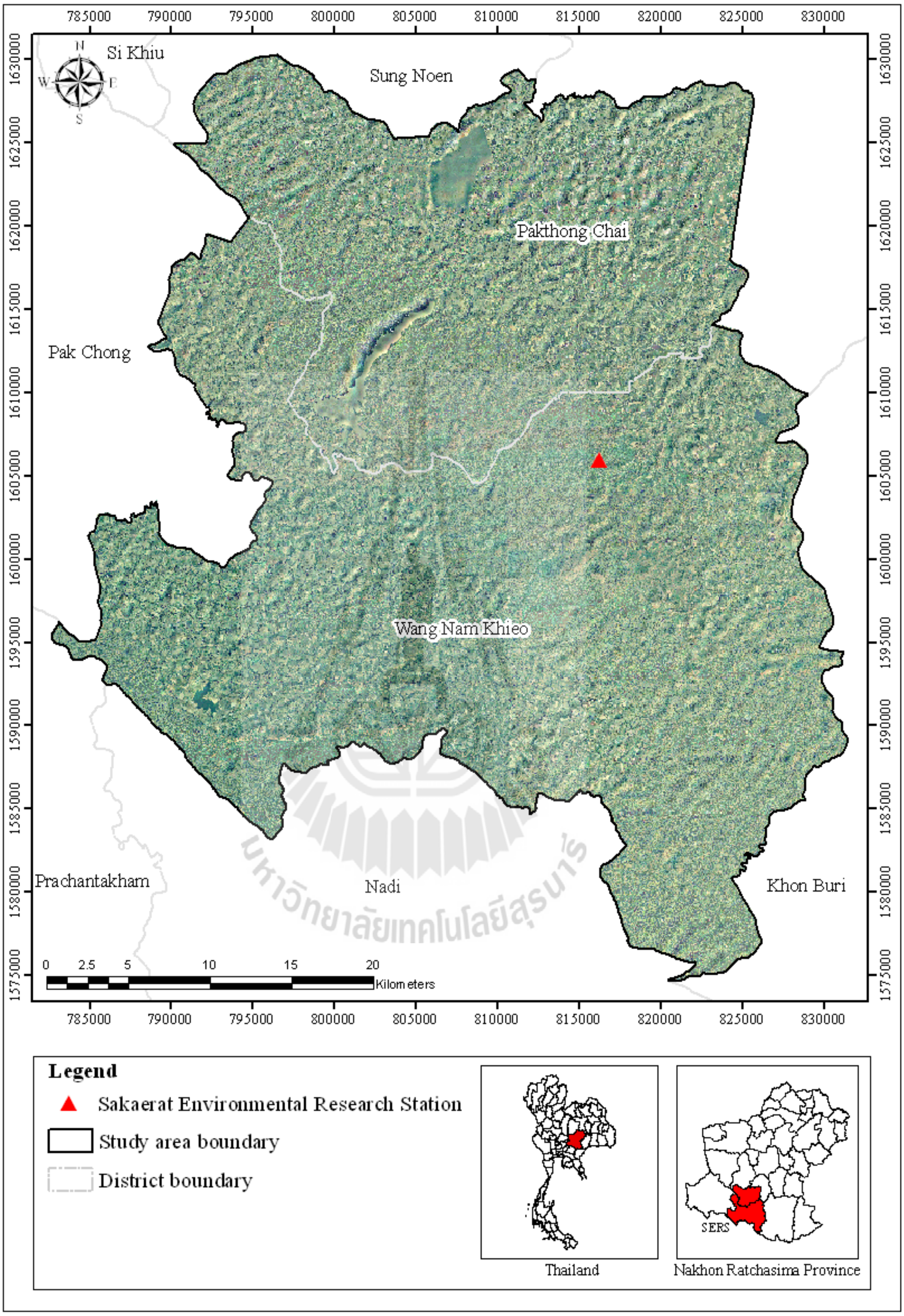


Figure 4.2 Color orthophotomaps of SBR in 2002.

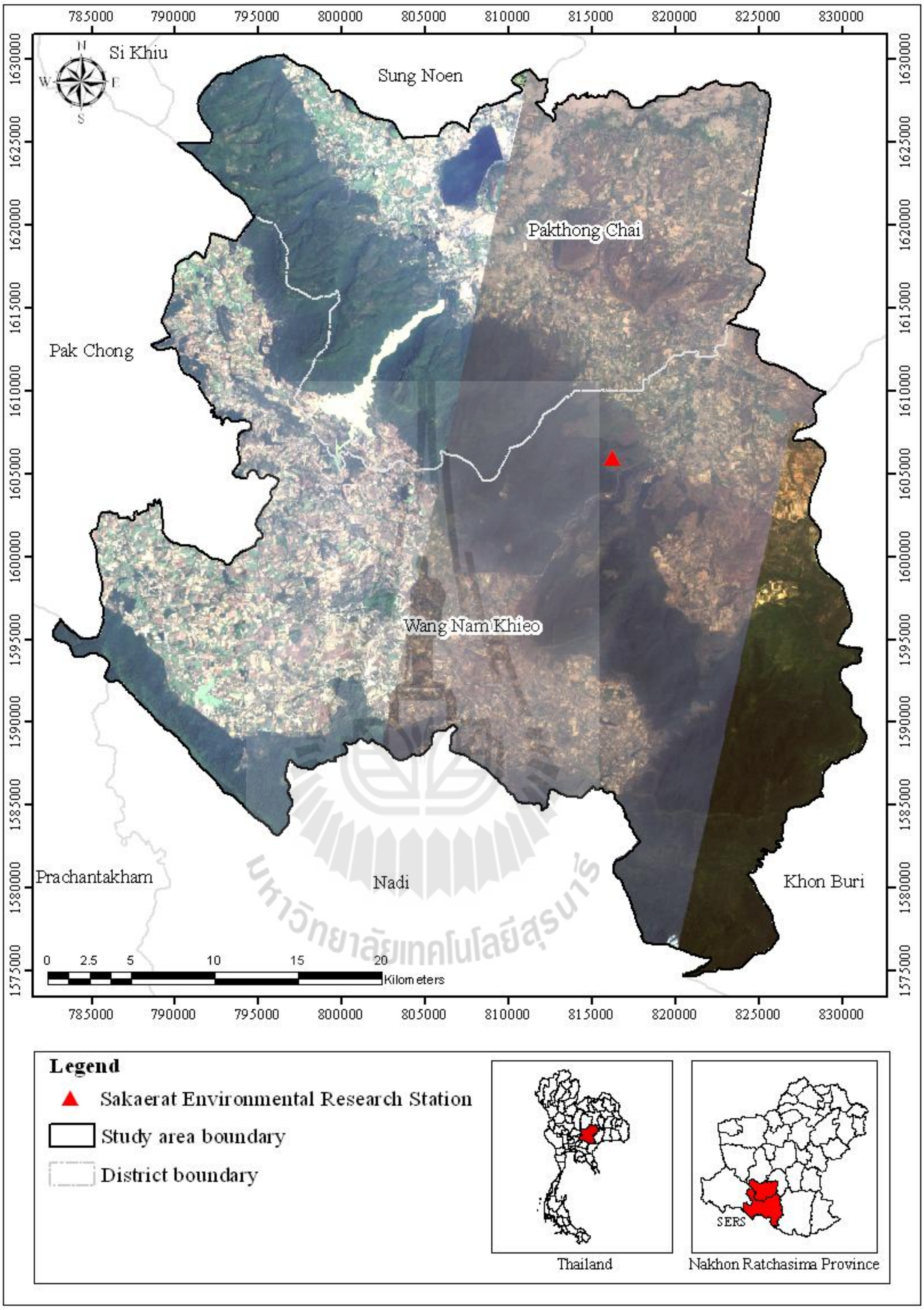


Figure 4.3 THEOS images of SBR in 2010.

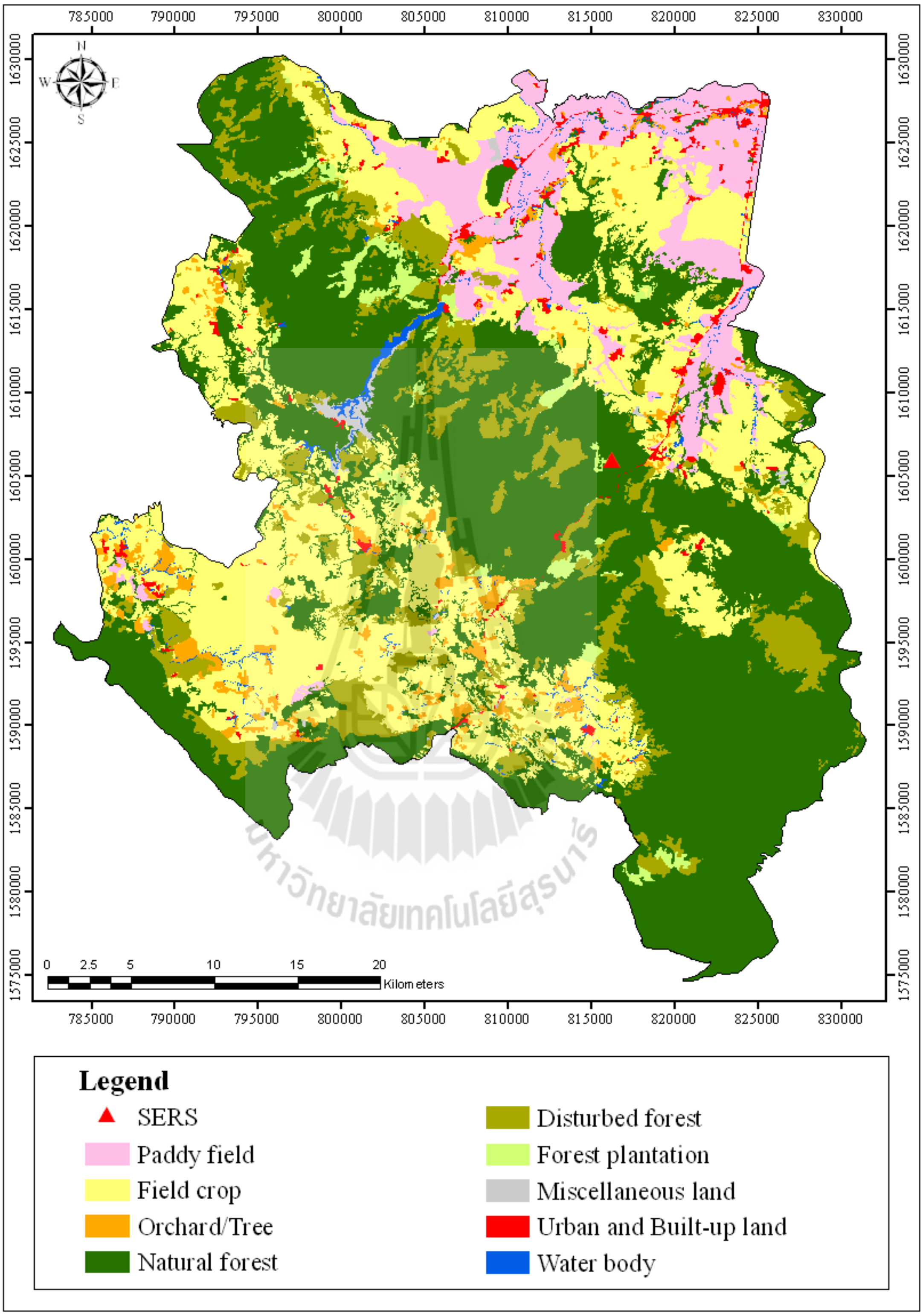


Figure 4.4 LULC Classification of SBR in 1980.

Table 4.1 Area and percentage of land use and land cover in 1980.

LULC	1980	
	Area (sq. km)	**%**
Paddy field	144.27	8.84
Field crop	453.64	27.79
Orchard/Tree	43.56	2.67
Natural forest	754.63	46.23
Disturbed forest	166.81	10.22
Forest plantation	26.23	1.61
Miscellaneous land	7.64	0.47
Urban/Built-up land	22.16	1.36
Water body	13.53	0.83
Total	**1,632.48**	**100.00**

4.1.2 LULC classification assessment of SBR in 2002

In 2002, LULC of SBR was classified on digital color orthophotomaps which resulted in the distribution of LULC of the top most 44.38 % (724.53 sq. km) of natural forest, followed by 27.83% (454.24 sq. km) of field crop and 7.40% (120.78 sq. km) of paddy filed. Some other classes, including orchard/tree, disturbed forest, and forest plantation were among of 5.84% (95.32 sq. km), 4.68% (76.34 sq. km), and 4.14% (67.62 sq. km), respectively, adding up with 2.34% (38.14 sq. km) of urban and built-up area, 2.44% (39.84 sq. km) of water body, and 0.96% (15.67 sq. km) of miscellaneous area. The details of all classification were shown in Figure 4.5 and. Table 4.2.

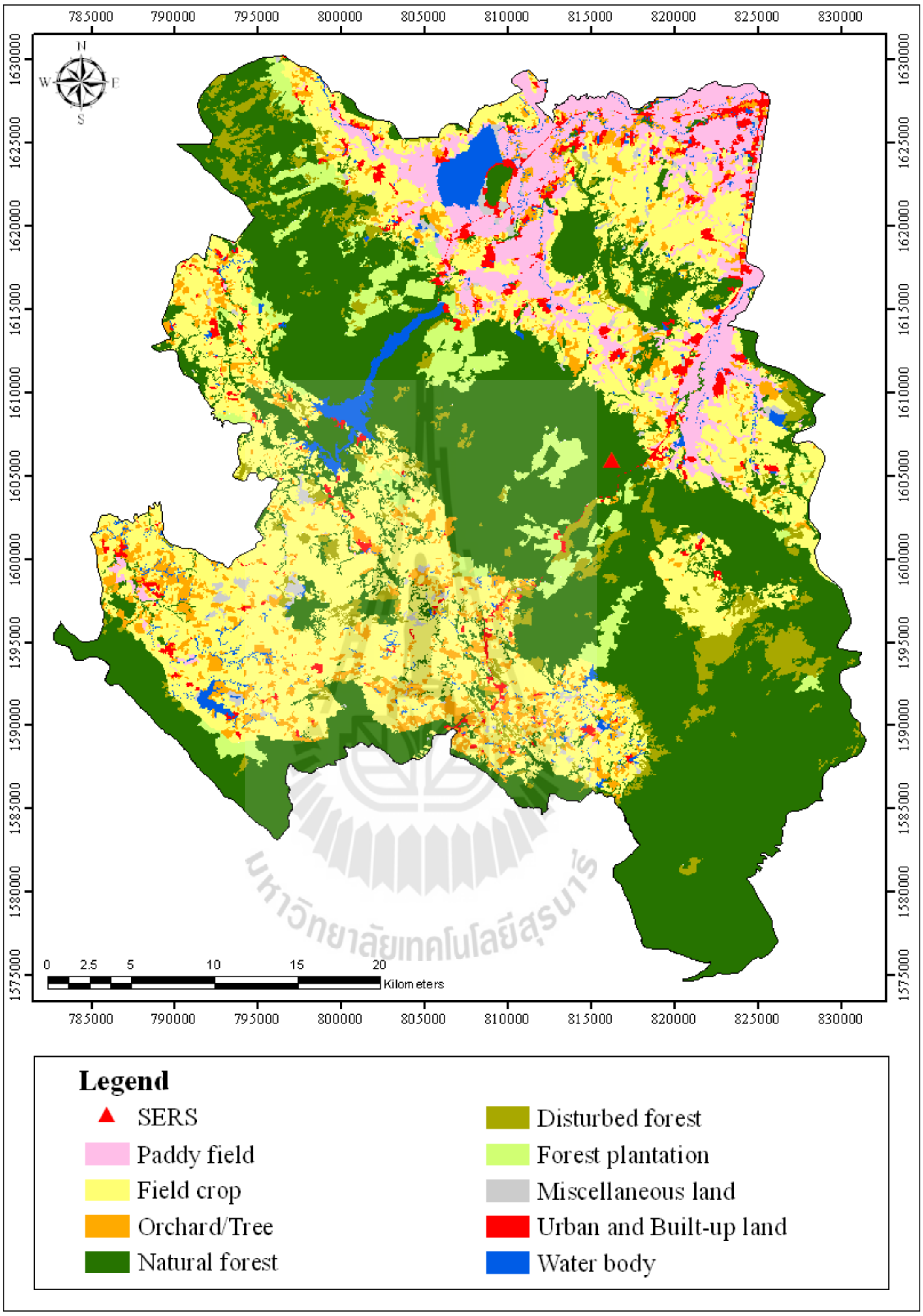


Figure 4.5 LULC Classification of SBR in 2002.

Table 4.2 Area and percentage of land use and land cover in 2002.

LULC	2002	
	Area (sq. km)	**%**
Paddy field	120.78	7.40
Field crop	454.24	27.83
Orchard/Tree	95.32	5.84
Natural forest	724.53	44.38
Disturbed forest	76.34	4.68
Forest plantation	67.62	4.14
Miscellaneous land	15.67	0.96
Urban/Built-up land	38.14	2.34
Water body	39.84	2.44
Total	**1,632.48**	**100.00**

4.1.3 LULC classification assessment of SBR in 2010

In 2010, LULC of SBR was classified on THEOS pansharpened imagery data resulted in the distribution of natural forest, field crop, paddy field, and orchard/tree at 44.40% (724.78 sq. km), 27.68% (450.60 sq. km), 7.35% (120.04 sq. km), and 6.33% (102.34 sq. km), respectively. Follow by the second group of disturbed forest, forest plantation, urban and built-up area, and water body were among of 3.99% (65.10 sq. km), 3.70% (60.59 sq. km), 2.98% (48.58 sq. km), and 2.74% (44.76 sq. km) of the total area. All of classification results were shown in Figure 4.6 and. Table 4.3.

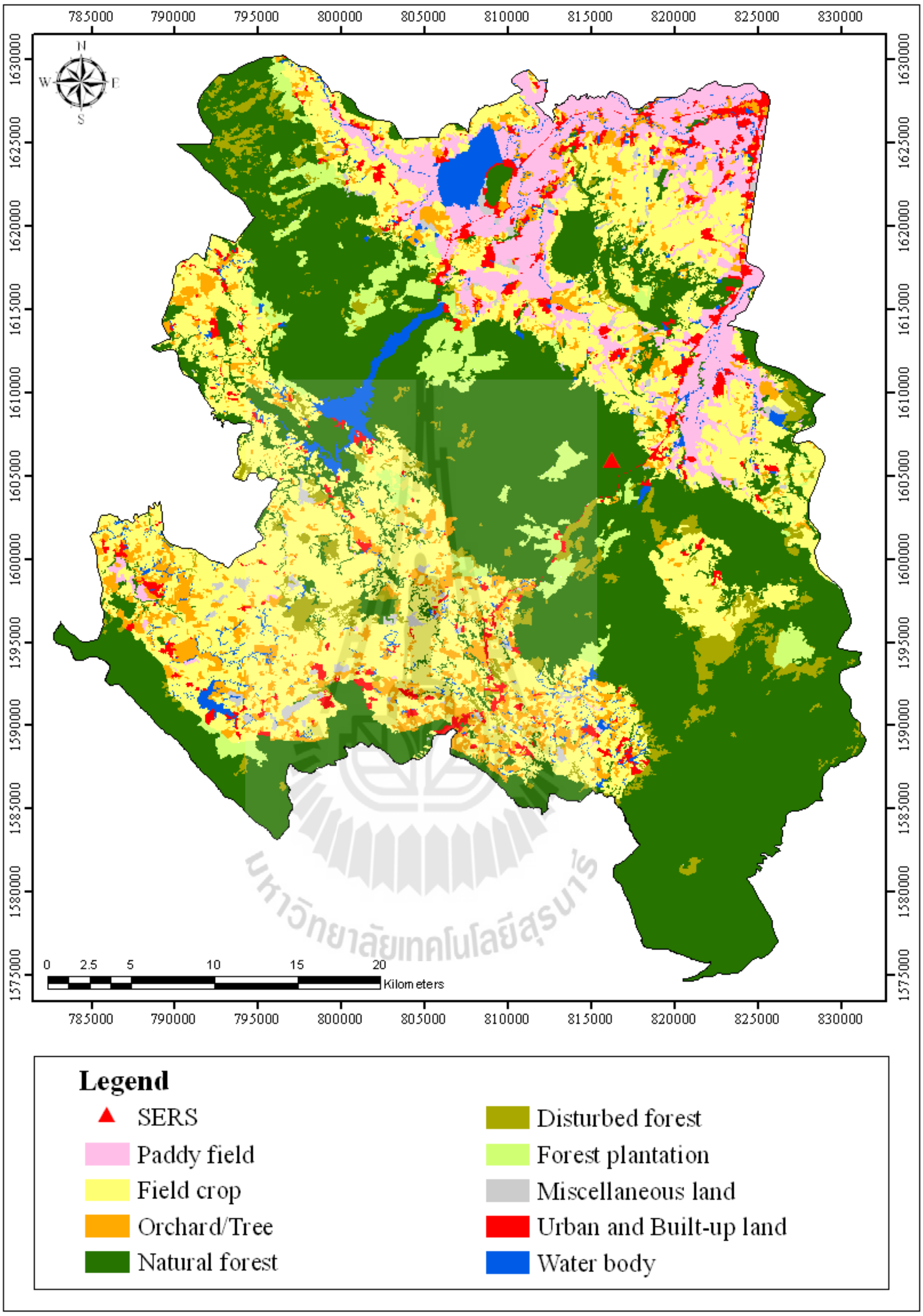


Figure 4.6 LULC Classification of SBR in 2010.

Table 4.3 Area and percentage of land use and land cover in 2010.

LULC	2010	
	Area (sq. km)	**%**
Paddy field	120.04	7.35
Field crop	450.60	27.60
Orchard/Tree	103.34	6.33
Natural forest	724.78	44.40
Disturbed forest	65.10	3.99
Forest plantation	60.59	3.71
Miscellaneous land	14.67	0.90
Urban/Built-up land	48.58	2.98
Water body	44.76	2.74
Total	**1,632.48**	**100.00**

Comparing three dates of LULC classification of SBR were summarized in Table 4.4. The overall result showed dynamic of change within forest classes at the most which were decreasing of natural forest from 1980 to 2002 and became somewhat constant in 2010. On the other hand, disturbed forest showed tendency of positive decreasing from 1980 to 2010, additionally forest plantation showed also increasing at some degree along the year 1980 to 2010.

Other two fluctuation classes were urban and built-up area and water body. These two classes showed distinctively increasing from 1980 up to 2010. However, it can be considered as the cause and effect of land development, management policy, and etc. which make urban and built-up area expanding from the past decade to serve more population growth in the present years. At the same time, increasing of water bodies which were reservoirs, wells, and irrigation canals for agricultural area and population daily usage could not avoid. As a result, urban and built-up area, and water body classes occurred to continue increasing.

For agricultural classes, paddy field was decreased from 1980 to 2002, and remained the same in 2010. Concurrently, field crop area showed little degree of change in average; by contrast, orchard/tree showed significantly increasing from the past up to year 2010. These tendencies revealed that the suitable areas of agricultural types, for example, rice (paddy field), corn and cassava (crop field) remained stable and the area might suitable for these specific crop types only, except for orchard/tree had dynamic of changed from the past up to the present that might due to economic incentive or market price induce.

Table 4.4 Summary of land use and land cover in 1980, 2002 and 2010.

LULC	**1980**		**2002**		**2010**	
	sq. km	**%**	**sq. km**	**%**	**sq. km**	**%**
Paddy field	144.27	8.84	120.78	7.40	120.04	7.35
Field crop	453.64	27.79	454.24	27.83	450.60	27.60
Orchard/Tree	43.56	2.67	95.32	5.84	103.34	6.33
Natural forest	754.63	46.23	724.53	44.38	724.78	44.40
Disturbed forest	166.81	10.22	76.34	4.68	65.10	3.99
Forest plantation	26.23	1.61	67.62	4.14	60.59	3.71
Miscellaneous land	7.64	0.47	15.67	0.96	14.67	0.90
Urban/Built-up land	22.16	1.36	38.14	2.34	48.58	2.98
Water body	13.53	0.83	39.84	2.44	44.76	2.74
Total	**1,632.48**	**100.00**	**1,632.48**	**100.00**	**1,632.48**	**100.00**

4.1.4 Accuracy assessment LULC of SBR in 2010

To evaluate the accuracy of the LULC map, reference sampling locations were randomly chosen to cover a full variety of LULC classes across the entire study area. Since, this study encompassed a relatively large area of approximately 1,632.48 Sq. km. which included a variety of physical environment conditions. In total, around 298 sample sites were extracted based on the stratified random sampling and the proportions of each classes were occupied. These sampling locations were assigned to visited, statistically, all 298 sites should have been visited, but the study area is quite large and some areas are inaccessible so that some sample sites had to be ignored and substitute with more accessible locations.

Finally, an error matrix was generated comparing LULC classification map and the ground-truth references. The extents to which these two classifications agreed were defined as the map accuracy according to the procedure of Congalton (1991). It should be noted that the field references data were collected after the time of the THEOS imagery data were acquired about 2 years. In some questionable LULC locations, to address the issue of LULC changes that may had occurred over this time, local farmers were interviewed in order to get more information about how land use changes from the time of image acquisition up to the time of ground truth were visited. The results showed that the overall map accuracy was 87.92%, and the Kappa hat coefficient of agreement was 0.84. According to Landis and Koch (1977) kappa hat coefficient of agreement value more than 0.80 represents strong agreement or accuracy between the classification map and the ground reference information. Details of producer's accuracy and user's accuracy were summarized in Table 4.5.

Table 4.5 Error matrixes and accuracy assessment of LULC of SBR year 2010.

2010	Reference											
	A1	**A2**	**A3**	**F1**	**F2**	**F3**	**M**	**U**	**W**	**Total**	**UA (%)**	**CE (%)**
A1	17	1	0	0	0	0	0	0	0	18	**94.44**	**5.56**
A2	2	84	2	0	1	1	1	3	1	95	**88.42**	**11.58**
A3	0	2	14	1	0	1	0	1	0	19	**73.68**	**26.32**
F1	0	7	1	87	2	0	0	1	0	98	**88.78**	**11.22**
F2	0	0	0	1	11	0	0	1	0	13	**84.62**	**15.38**
F3	0	0	0	3	0	7	0	0	0	10	**70.00**	**30**
M	0	0	0	0	0	0	8	0	0	8	**100.00**	**0**
U	2	0	0	0	0	0	0	18	0	20	**90.00**	**10**
W	0	1	0	0	0	0	0	0	16	17	**94.12**	**5.88**
Total	**21**	**95**	**17**	**92**	**14**	**9**	**9**	**24**	**17**	**298**		
PA (%)	**80.95**	**88.42**	**82.35**	**94.57**	**78.57**	**77.78**	**88.89**	**75.00**	**94.12**			
OE (%)	**19.05**	**11.58**	**17.65**	**5.43**	**21.43**	**22.22**	**11.11**	**25**	**5.88**			
Overall accuracy = 87.92%												
Kappa hat coefficient = 0.84												

Note: A1 = Paddy field, A2 = Field crop, A3 = Orchard/Tree, F1 = Natural forest, F2 = Disturbed forest, F3 = Forest plantation, M = Miscellaneous land, U = Urban and built-up area, and W = Water body.

According to Table 4.5, producer's accuracy of LULC varied from 75.00% to 94.57%. While user's accuracy varied from 70.00% to 100.00%. In contrary, omission error which represents errors of exclusion from corrected categories varied between 5.43% and 25% while commission error which demonstrated error of inclusion to wrong categories varied from 0% to 30%. For omission error, urban and built-up area leads misclassified while natural forest indicates the highest correct classified. Meanwhile, orchard and tree provided the highest commission error which inclusion of field crop, natural forest, forest plantation and urban and built-up area.

4.1.5 LULC change assessment of SBR between 1980 and 2002

LULC change assessment method was applied post classification comparison algorithm to both intervals: 1980-2002, and 2002-2010. The result of LULC change of SBR between year 1980 and 2002 were presented in Table 4.6 and Figure 4.7. The results showed that the major changed occurred in disturbed forest orchard/tree, forest plantation, water body, and urban-built up areas. For example, natural forest decreased from 754.63 sq. km in 1980 to 724.53 sq. km in 2002, by losing the area to filed crop (25.85 sq. km), paddy field (2.47 sq. km) and orchard/tree (5.89 sq. km); and also the main changes contributed to disturbed forest (28.03 sq. km) and forest plantation (19.62 sq. km). The same as disturbed forest mainly changed to filed crop (26.10 sq. km), forest plantation (34.09 sq. km), and natural forest area (43.47 sq. km). Meanwhile water body and urban and built-up had expanded by gaining more areas from mostly filed crop and paddy field.

Table 4.6 Change matrix of land use and land cover between 1980 and 200.

1980	**2002**									
	A1	**A2**	**A3**	**F1**	**F2**	**F3**	**M**	**U**	**W**	**Total**
Paddy field (A1)	100.45	21.01	7.64	0.00	0.00	0.00	1.95	4.16	9.06	144.27
Field crop (A2)	13.33	369.08	44.98	0.00	0.00	0.00	9.61	8.61	8.02	453.64
Orchard/Tree (A3)	0.55	11.42	30.48	0.00	0.00	0.00	0.10	0.70	0.31	43.56
Natural forest (F1)	2.47	25.85	5.89	668.74	28.03	19.62	1.33	1.03	1.65	754.63
Disturbed forest (F2)	3.91	26.10	6.22	43.47	48.30	34.09	1.76	1.46	1.51	166.81
Forest plantation (F3)	0.00	0.00	0.00	12.32	0.00	13.91	0.00	0.00	0.00	26.23
Miscellaneous land (M)	0.08	0.78	0.11	0.00	0.00	0.00	0.91	0.01	5.75	7.64
Urban/Built-up land (U)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.16	0.00	22.16
Water body (W)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.53	13.53
Total	**120.78**	**454.24**	**95.32**	**724.53**	**76.34**	**67.62**	**15.67**	**38.14**	**39.84**	**1,632.48**
Area of change (sq. km.)	**-23.49**	**0.60**	**51.75**	**-30.09**	**-90.48**	**41.39**	**8.03**	**15.98**	**26.31**	
Percentage of study area (%)	**-1.44**	**0.04**	**3.17**	**-1.84**	**-5.54**	**2.54**	**0.49**	**0.98**	**1.61**	
Area per annum (sq. km.)	**-1.07**	**0.03**	**2.35**	**-1.37**	**-4.11**	**1.88**	**0.36**	**0.73**	**1.20**	

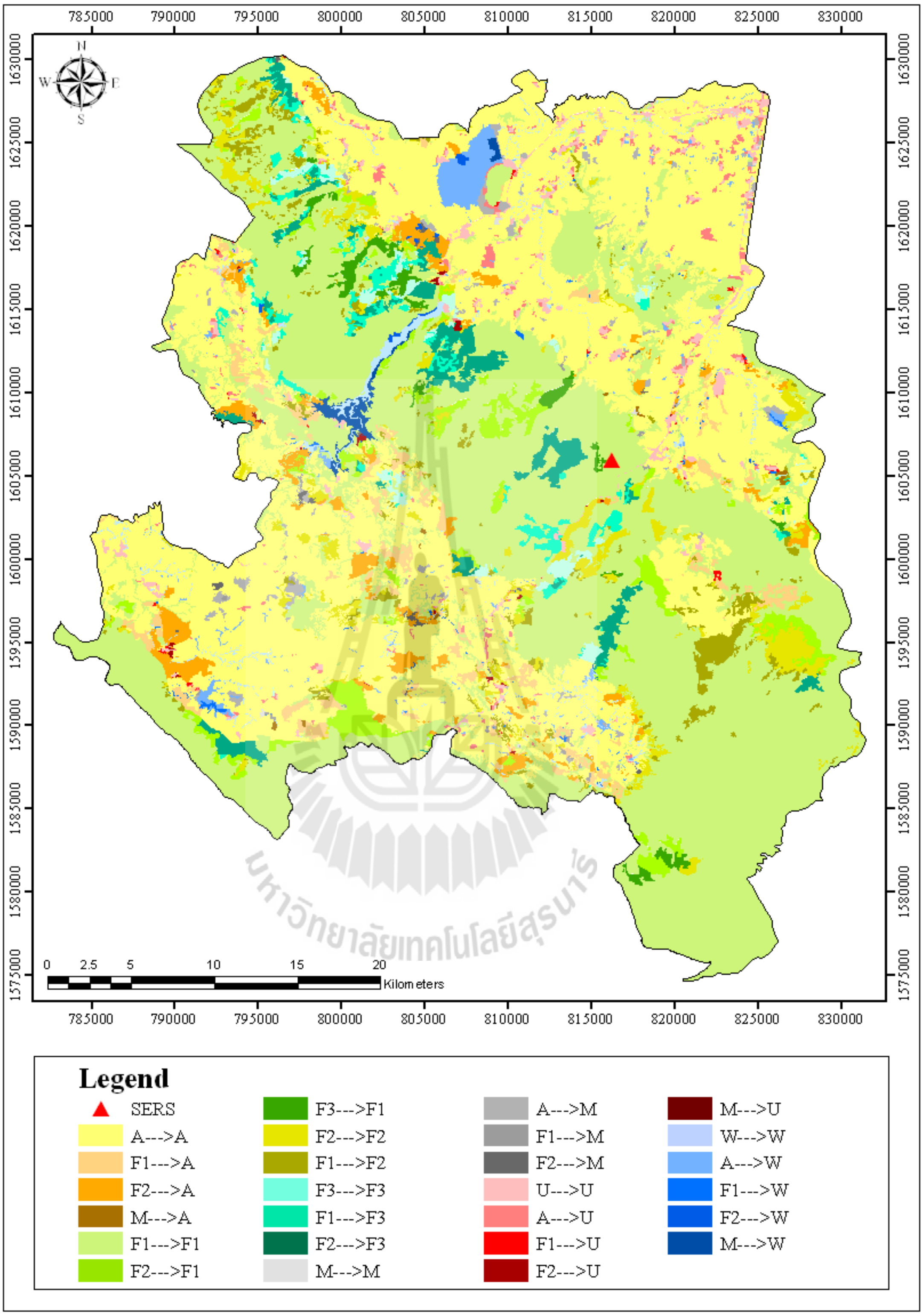


Figure 4.7 LULC change assessment of SBR between 1980 and 2002.

4.1.6 LULC change assessment of SBR between 2002 and 2010

This section was reported the post classification comparison change on the LULC of SBR between 2002 and 2010. The results presented in Table 4.7 and Figure 4.8**.** The results showed slightly changes in almost LULC classes compared to the previous year (1980-2002), as it was longer period of time interval the changes showed more obvious evidences. However, in this time period (2002-2010) the major changes were occurred in disturbed forest, urban and built-up, orchard/tree and forest plantation. Besides, natural forest maintains itself at the top most dominant in the area. Urban and built-up areas showed continue to growth since 1980 up to 2010. Comparison of all LULC areas change per annum during 1980 to 2002, and 2002 to 2010 were illustrated in Figure 4.9.

Table 4.7 Change matrix of land use and land cover between 2002 and 2010**.**

1980	**2002**									
	A1	**A2**	**A3**	**F1**	**F2**	**F3**	**M**	**U**	**W**	**Total**
Paddy field (A1)	115.76	1.28	2.26	0.00	0.00	0.00	0.01	1.13	0.34	120.78
Field crop (A2)	1.15	429.57	14.25	0.00	0.00	0.00	3.77	4.04	1.47	454.24
Orchard/Tree (A3)	1.76	8.86	81.95	0.00	0.00	0.00	0.50	2.02	0.23	95.32
Natural forest (F1)	0.25	4.63	2.31	705.37	6.04	0.38	1.07	1.85	2.63	724.53
Disturbed forest (F2)	0.08	2.84	1.01	6.13	59.06	5.87	0.52	0.66	0.16	76.34
Forest plantation (F3)	0.00	0.00	0.00	13.28	0.00	54.34	0.00	0.00	0.00	67.62
Miscellaneous land (M)	1.06	3.43	1.56	0.00	0.00	0.00	8.79	0.74	0.09	15.67
Urban/Built-up land (U)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.14	0.00	38.14
Water body (W)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	39.84	39.84
Total	**120.04**	**450.60**	**103.34**	**724.78**	**65.10**	**60.59**	**14.67**	**48.58**	**44.76**	**1,632.48**
Area of change (sq. km.)	**-0.74**	**-3.63**	**8.03**	**0.25**	**-11.23**	**-7.03**	**-1.00**	**10.44**	**4.92**	
Percentage of study area (%)	**-0.05**	**-0.22**	**0.49**	**0.02**	**-0.69**	**-0.43**	**-0.06**	**0.64**	**0.30**	
Area per annum (sq. km.)	**-0.09**	**-0.45**	**1.00**	**0.03**	**-1.40**	**-0.88**	**-0.13**	**1.31**	**0.61**	

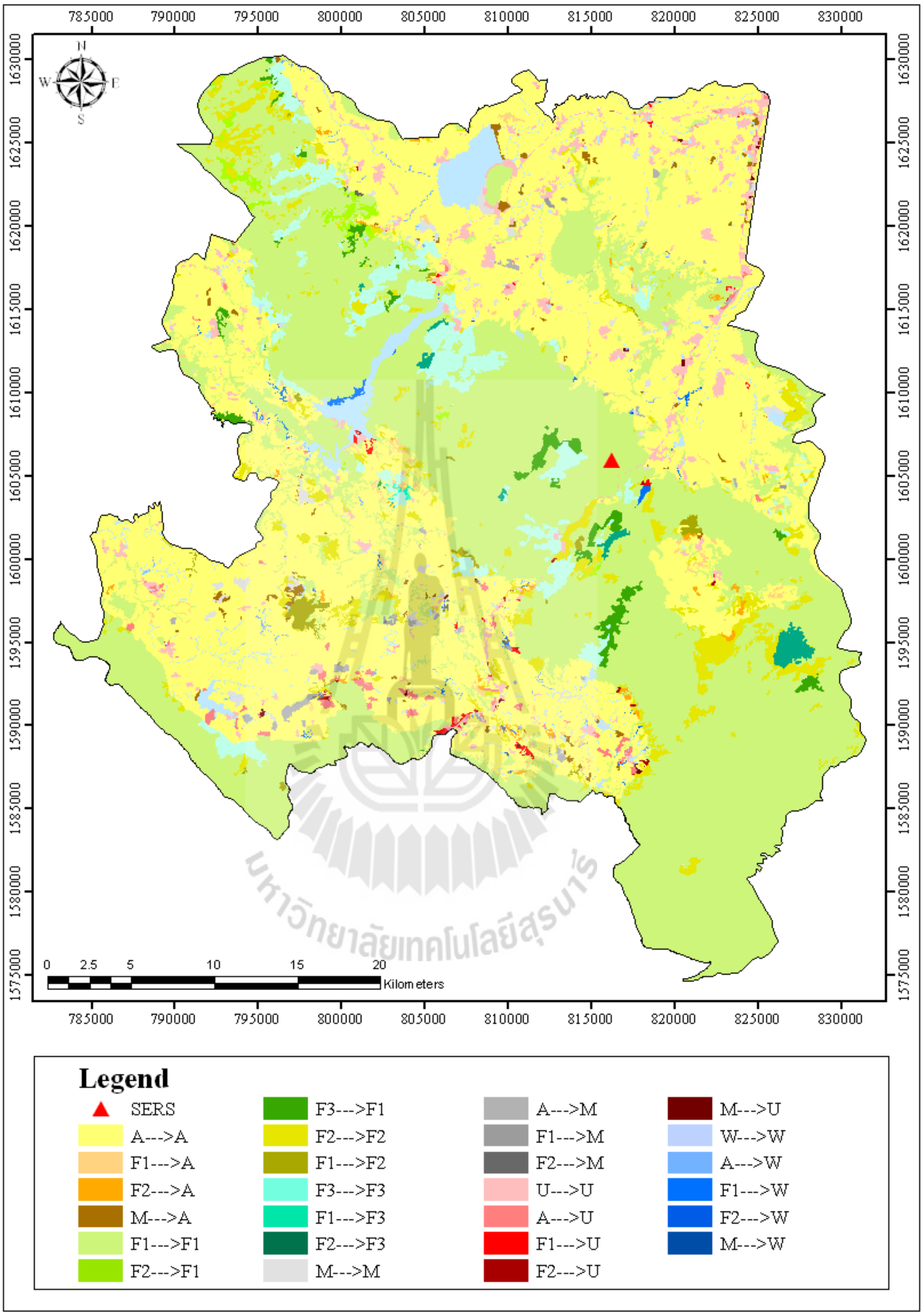


Figure 4.8 LULC change assessment of SBR between 2002 and 2010.

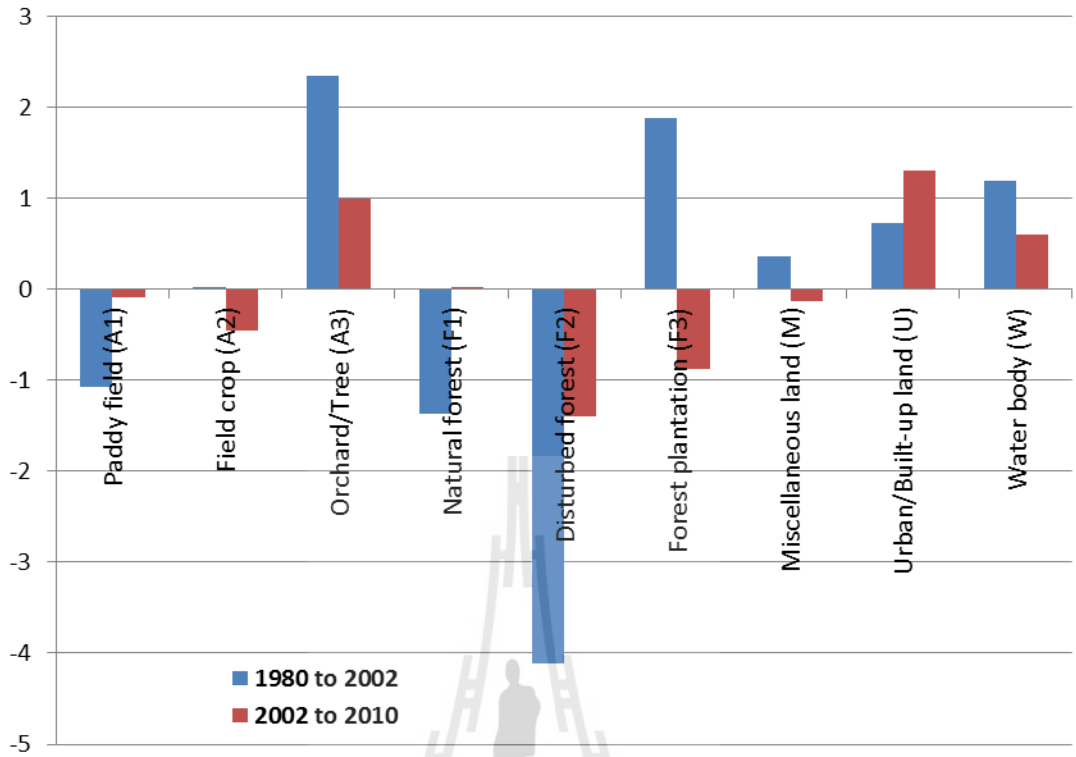


Figure 4.9 Comparison of LULC changes per annum of SBR during 1980 to 2002 and 2002 to 2010.

Refer to Figure 4.9, the dominant class according to positive change during two periods was orchard and tree with annual increase rate decreasing. This pattern of change was comparable to water body but contrasted to urban and built-up area. In opposite, negative change during two periods was disturbed forest and was the dominant class with annual decrease rate was decreasing. This pattern of change was similar to paddy field.

4.1.7 Status of LULC in SBR management zones

Since SBR was established into three management zones which were core, buffer, and transition zone, during 1980 to 2010, the land use and land cover were classified and results reported in Table 4.8.

In core zone which was securely protected sites for conserving biological diversity and minimally disturbed, natural forest occupied the area of 93.52% (53.52 sq. km), 96.37% (55.10 sq. km), and 97.20% (55.62 sq. km) in 1980, 2002, and 2010, respectively. Additionally, forest plantation appeared to increase from 1.54% (0.88 sq. km) in 1980, 2.86% (1.64 sq. km) in 2002, and 1.86% (1.06 sq. km) in 2010. On the other hand, disturbed forest revealed decreased trend of 4.94% (2.83 sq. km) in 1980, 0.77% (0.44 sq. km) in 2002, and 0.955% (0.54 sq. km) in 2010. The results showed good trend of changes in all forest areas which served well with the functional of core area.

In buffer zone, the results showed that forest areas which were natural forest, forest plantation and disturbed forest still appeared dominant over the whole area. The natural forest occupied the area of 68.96% (77.41 sq. km) in 1980, 72.79% (81.71 sq. km) in 2002, and 74.30% (83.41 sq. km) in 2010, followed by forest plantation and disturbed forest. Meanwhile, other classes such as paddy field, field crop, orchard/tree, urban and built-up area, water body and miscellaneous were contributed small parts of the area. This indicated well management activities in buffer zone of the biosphere.

In transition zone, the area may contain variety of land use and land cover and other human activities. Since, this zone concept was designed to be flexible and be implemented in a variety of ways in order to address local needs and conditions. The results showed significant change in urban and built-up area with highly increasing change from 1980, 2002, to 2010 at 1.51% (22.61 sq. km), 2.59% (37.96 sq. km), and 3.31% (48.81 sq. km), respectively. It was evidenced that urban had dramatically growth during this 30 years period. Concurrently, water body had increasing change in the same manner from 0.92% (13.52 sq. km) in 1980, to 2.71% (39.67 sq. km) in 2002, and to 3.04% (44.49 sq. km) in 2010. This due to during 1980 to 2002 there were large reservoirs built up in the area and also numerous of small wells were built during the year 2002 to 2010.

Meanwhile, agricultural areas composed of paddy field, field crop, and orchard/tree were among increasing change from 43.63 % in 1980 to 45.32 % in 2002 and relatively stable in 2010 at a rate of 45.55% of the total area. On the other hand, natural forest showed slightly decreased from 42.63% (623.70 sq. km) in 1980 to 40.17% (587.72 sq. km) in 2002, and to 40.04% (585.70 sq. km) in 2010. By contrast, disturbed forest that showed significantly decreased from 9.42% (137.75 sq. km) in 1980 to 4.97% (72.72 sq. km) in 2002, and to 4.25% (62.22 sq. km) in 2010. These figures expressed trend of disturbance in forest area. Furthermore, forest plantation showed its increasing change from 1.54% (22.54 sq. km) in 1980 to 3.18% (46.55 sq. km) in 2002, and to 2.83% (41.43 sq. km) in 2010. It was evident that forest plantation were gained more areas in transition zone. Comparison of LULC component in SBR management zones in 1980, 2002, and 2010 was illustrated in Figure 4.10.

Table 4.8 LULC of SBR in core, buffer, and transition zone in 1980, 2002, 2010.

Area of core zone

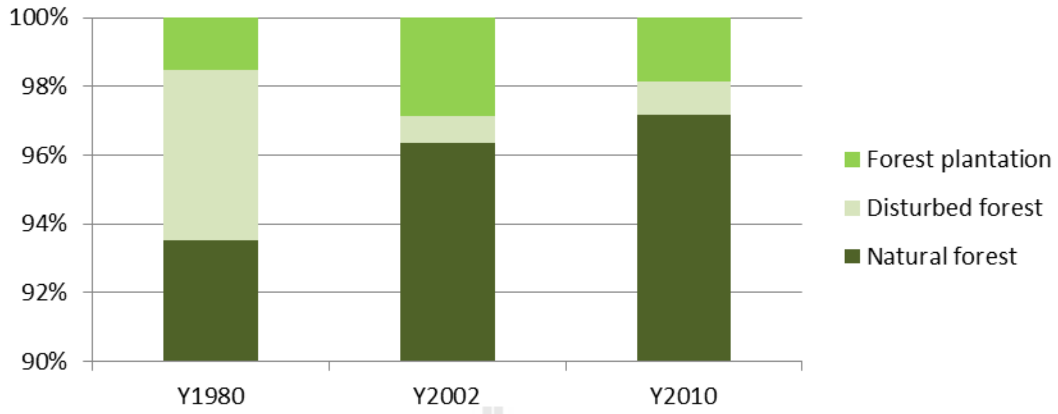
LULC	1980		2002		2010	
	Area	**%**	**Area**	**%**	**Area**	**%**
Natural forest	53.52	93.52	55.15	96.37	55.62	97.20
Disturbed forest	2.83	4.94	0.44	0.77	0.54	0.95
Forest plantation	0.88	1.54	1.64	2.86	1.06	1.86
Total	**57.23**	**100.00**	**57.23**	**100.00**	**57.23**	**100.00**

Area of buffer zone

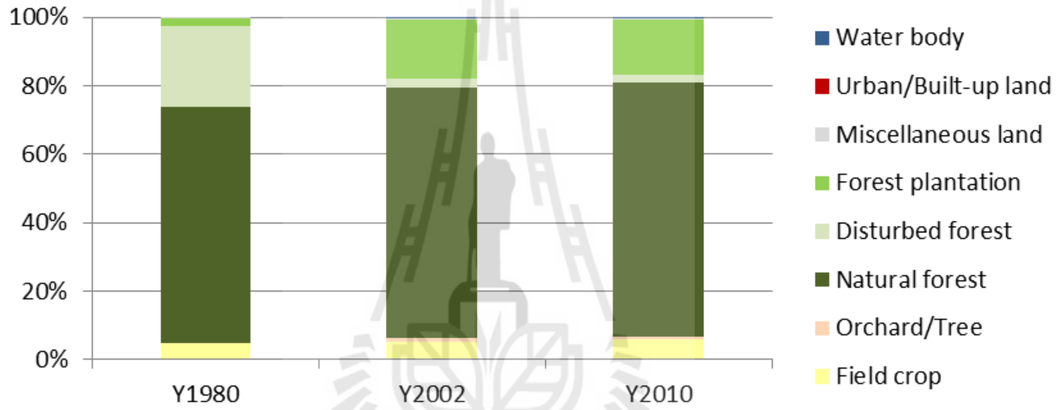
LULC	1980		2002		2010	
	Area	**%**	**Area**	**%**	**Area**	**%**
Paddy field	0.29	0.26	0.14	0.12	0.10	0.09
Field crop	5.01	4.46	5.94	5.29	6.44	5.73
Orchard/Tree	0.32	0.28	1.24	1.11	1.08	0.97
Natural forest	77.41	68.96	81.71	72.79	83.41	74.30
Disturbed forest	26.24	23.37	3.18	2.83	2.35	2.09
Forest plantation	2.79	2.48	19.43	17.31	18.10	16.13
Miscellaneous land	0.19	0.17	0.26	0.23	0.33	0.29
Urban/Built-up land	0.00	0.00	0.18	0.16	0.18	0.16
Water body	0.01	0.01	0.17	0.15	0.27	0.24
Total	**112.25**	**100.00**	**112.25**	**100.00**	**112.25**	**100.00**

Area of transition zone

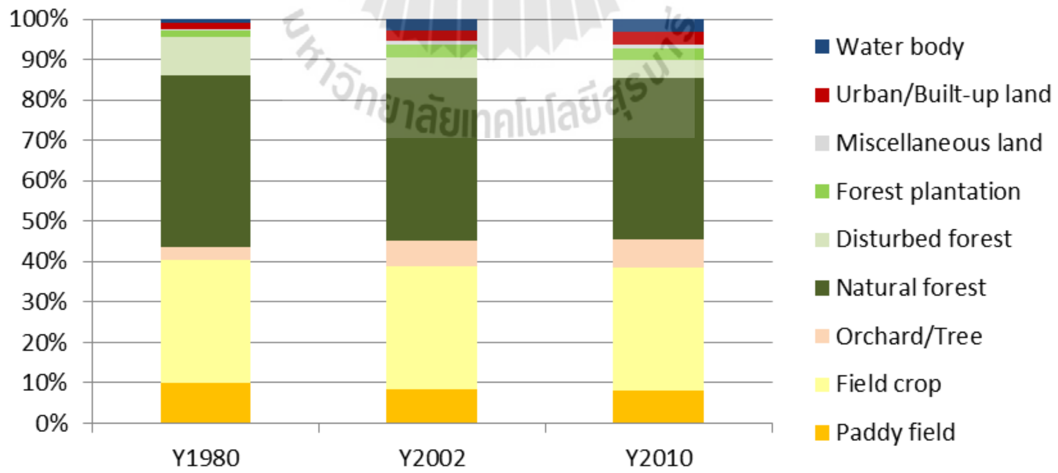
LULC	1980		2002		2010	
	Area	**%**	**Area**	**%**	**Area**	**%**
Paddy field	143.98	9.84	120.65	8.25	119.95	8.20
Field crop	448.63	30.66	448.30	30.64	444.17	30.36
Orchard/Tree	43.25	2.96	94.03	6.43	102.22	6.99
Natural forest	623.70	42.63	587.72	40.17	585.79	40.04
Disturbed forest	137.75	9.42	72.72	4.97	62.22	4.25
Forest plantation	22.56	1.54	46.55	3.18	41.43	2.83
Miscellaneous land	7.45	0.51	15.41	1.05	14.34	0.98
Urban/Built-up land	22.16	1.51	37.96	2.59	48.41	3.31
Water body	13.52	0.92	39.67	2.71	44.49	3.04
Total	**1,463.00**	**100.00**	**1,463.00**	**100.00**	**1,463.00**	**100.00**



(a) LULC component of Core Zone



(b) LULC component of Buffer Zone



(c) LULC component of Transition Zone

Figure 4.10 Component of LULC in SBR management zones in 1980, 2002, and 2010: (a) Core zone, (b) buffer zone, and (c) transition zone.

4.2 Results of landscape pattern analysis and assessment in SBR

This section presented the results of SBR landscape pattern analysis and assessment of pattern changes using selected landscape indices. Based on LULC classification in 1980, 2002, and 2010; SBR landscape was characterized into six landscape types which were agricultural landscape, natural forest landscape, disturbed forest landscape, forest plantation landscape, urban and built-up landscape, and miscellaneous landscape. Area and percentage of SBR landscape types in 1980, 2002, and 2010 were reported in Table 4.9. While distribution of SBR landscape types in 1980, 2002, and 2010 were presented in Figure 4.11 to Figure 4.13, respectively.

Table 4.9 Area and percentage of 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	1,632.48	100	1,632.48	100	1,632.48	100

Refer to Table 4.9, the most dominate landscape type of SBR was natural forest landscape occupied the area of 46.23% in 1980 and slightly decreasing to 44.38% and 44.40% in 2002 and 2010, respectively. Meanwhile, the moderate dominant landscape type was agriculture. On the contrary, the least dominant landscape type was miscellaneous landscape covered the area of 1.29% in 1980 and slightly increasing to 3.4% and to 3.64% in 2002 and 2010, respectively.

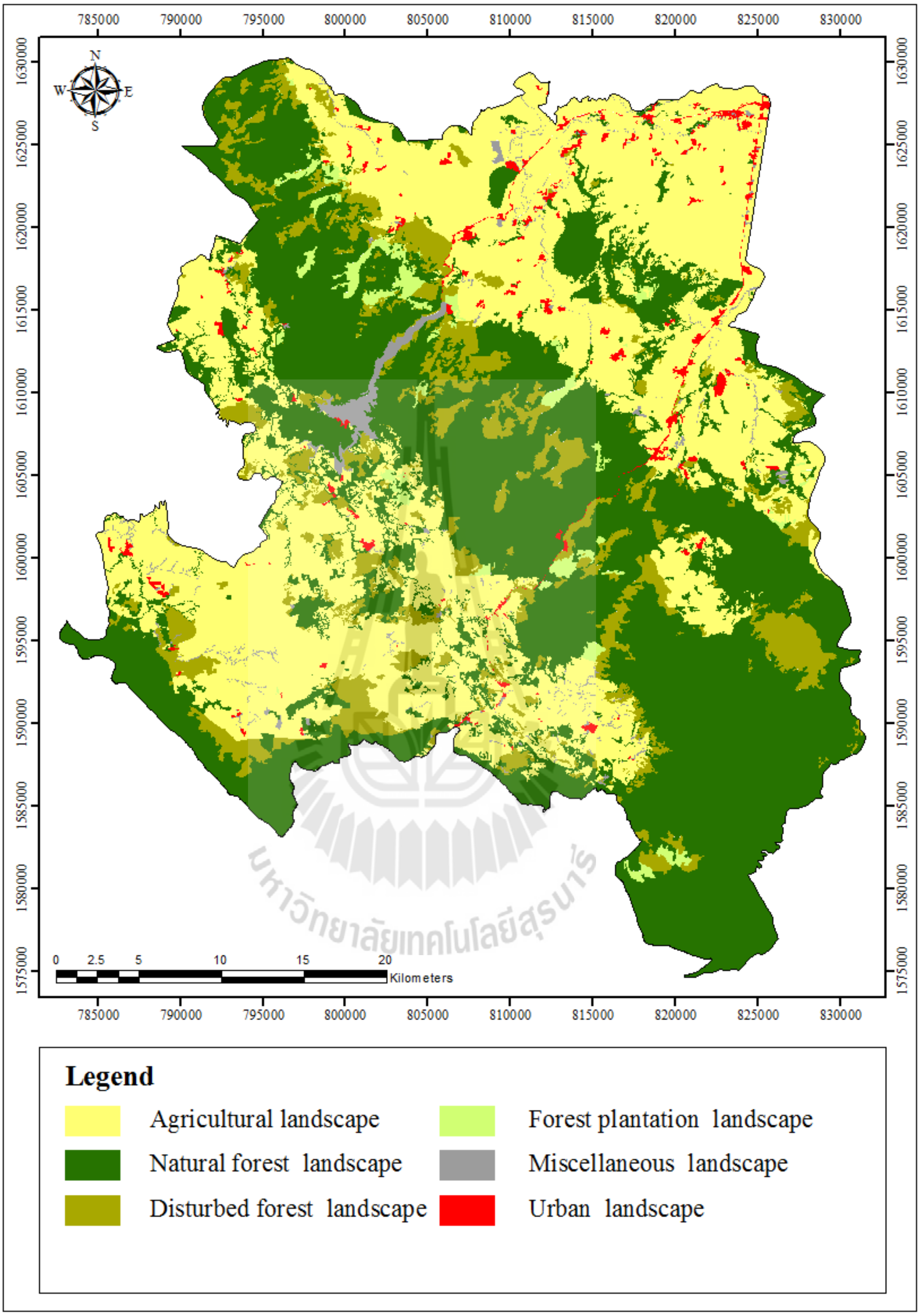


Figure 4.11 Distribution of SBR landscape types in 1980.

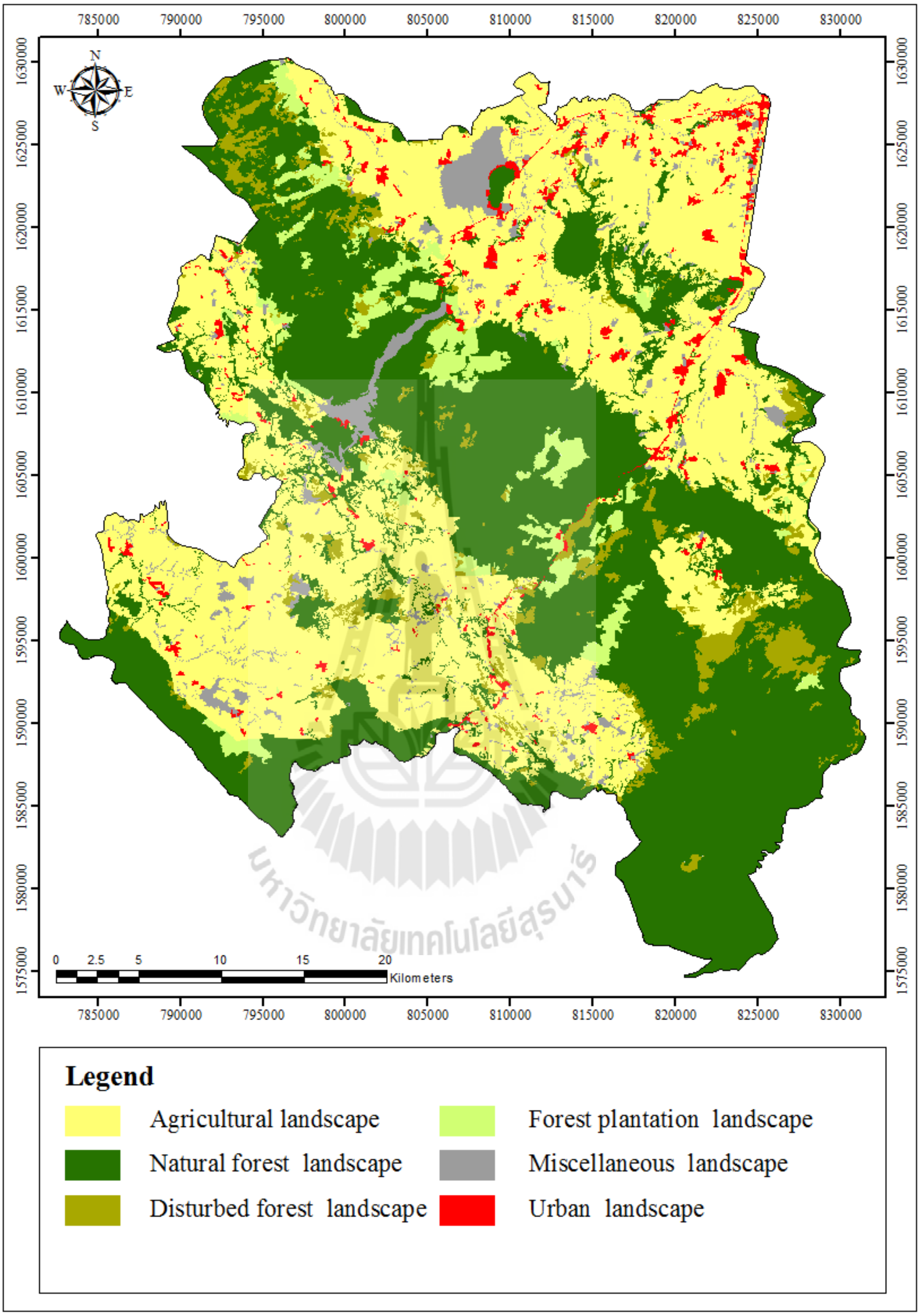


Figure 4.12 Distribution of SBR landscape types in 2002.

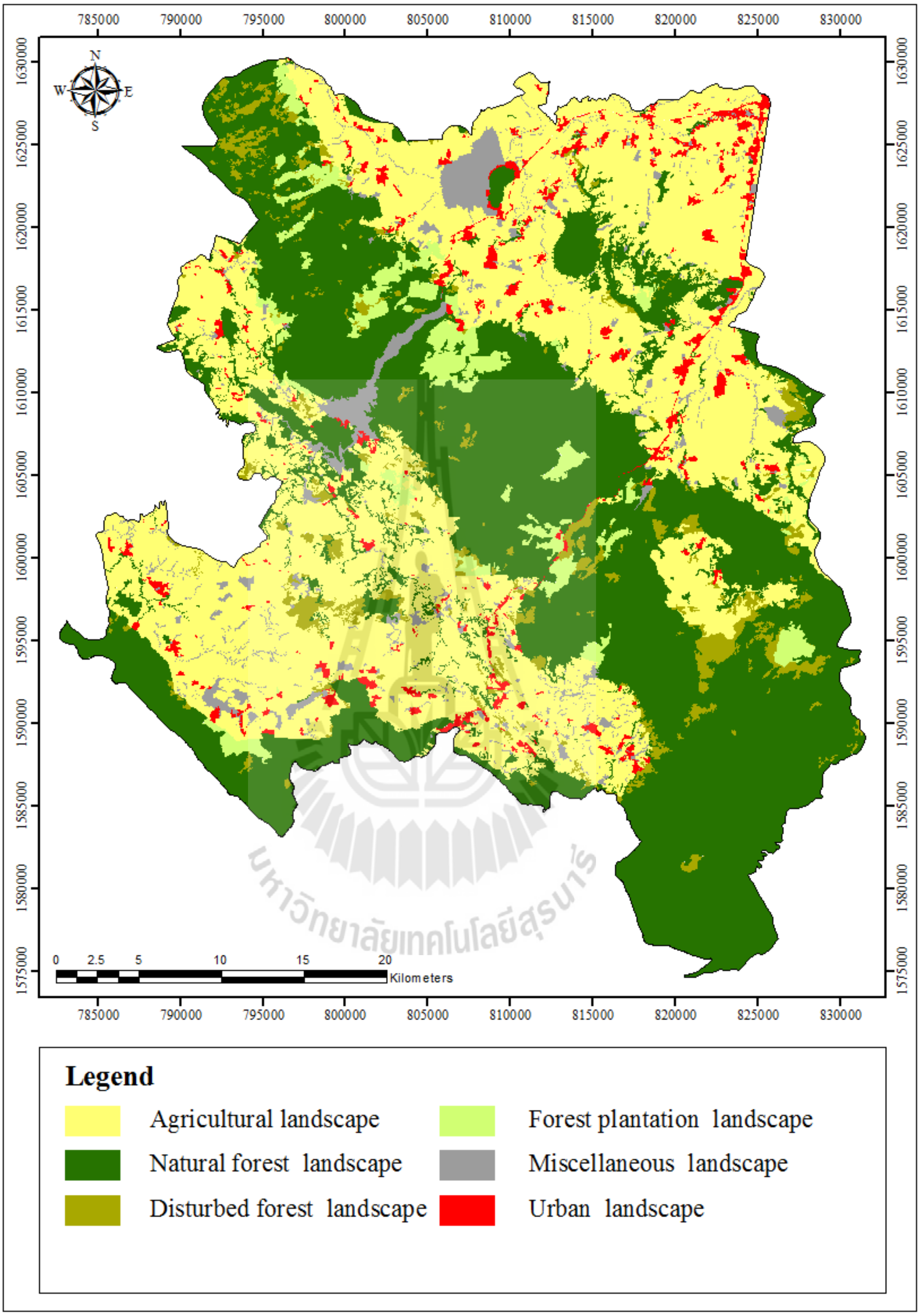


Figure 4.13 Distribution of SBR landscape types in 2010.

For analyze and assess landscape pattern of SBR, two levels of ecological landscape measurements including landscape and class levels were here conducted using landscape metrics. The selected landscape metrics at landscape level were included:

(1) Area/density/edge metrics measurement.
   (1) Number of Patch (NP);
   (2) Total Edge (TE); and
   (3) Edge density (ED).

(2) Shape metrics measurement.
   (1) Mean Shape Index (MSI); and
   (2) Mean Patch Fractal Dimension (MPFD).

(3) Core Area metrics measurement.
   (1) Total Core Area (TCA);
   (2) Mean Core Area (MCA);
   (3) Total Core Area Index (TCAI); and
   (4) Core Area Density (CAD).

(4) Diversity/interspersion/isolation metrics measurement.
   (1) Shannon's Diversity Index (SDI);
   (2) Shannon's Evenness Index (SEI);
   (3) Interspersion Juxtaposition Index (IJI);
   (4) Mean Proximity Index (MPI); and
   (5) Mean Nearest Neighbor (MNN).

Meanwhile, the selected landscape metrics at class level were included:

(1) Area/density/edge metrics measurement.
   (1) Number of Patch (NP);
   (2) Total Edge (TE); and
   (3) Edge density (ED).

(2) Shape metrics measurement.
   (1) Mean Shape Index (MSI); and
   (2) Mean Patch Fractal Dimension (MPFD).

(3) Core Area metrics measurement.

(1) Total Core Area (TCA);

(2) Mean Core Area (MCA);

(3) Total Core Area Index (TCAI); and

(4) Core Area Density (CAD).

(4) Interspersion/isolation metrics measurement.

(1) Interspersion Juxtaposition Index (IJI);

(2) Mean Proximity Index (MPI); and

(3) Mean Nearest Neighbor (MNN).

Results of SBR landscape metrics analysis in year 1980, 2002, and 2010 at landscape and class levels were here separately reported in the following sections.

4.2.1 Landscape pattern analysis of SBR at landscape level

At landscape level, landscape patterns were analyzed to fulfill four aspects of landscape ecology included: (1) area/density/edge, (2) shape, (3) core area, and (4) diversity/interspersion/isolation. The results of 14 indices in four aspects in 1980, 2002, and 2010 were summarized as shown in Table 4.10. Qualitative and quantitative comparisons of landscape ecological measurement of SBR were described separately in four aspects of landscape ecology.

(1) Area/density/edge metrics measurement. It was found that number of patch (NP) showed trend of increasing from 1980, 2002, to 2010 at the number of 2,064 patches, 2239 patches, and 2293 patches, respectively. Meanwhile, total edge (TE) and edge density (ED) had changed in the same manner which were increased from 1980 to 2002, and were slightly decreased in 2010. All the indices in this aspect were implied that the whole SBR landscapes had tendency of change to be fragmented from 1980 to 2002, and became slightly fragmented from 2002 to 2010.

(2) Shape metrics measurement. The results showed that mean shape index (MSI) has shown gradually changed to high value from 1980 to 2002, and relatively unchanged in 2010 at the value of 2.14, 2.23, and 2.21, respectively. It revealed increased with increasing patch shape irregularity in the landscape. Concurrently, mean patch fractal dimension (MPFD) has changed in the same way at the value of 1.12, 1.13, and 1.13 in 1980, 2002, and 2010, respectively. These two indices notified that shape complexity of the landscape had slightly changed to less complexity and become to be simpler.

(3) Core area metrics measurement. It was found that total core area (TCA) which was the absolute value had high decrease changed from 1980 to 2002, and backward to increase from 2002 to 2010. At the same time, total core area index (TCAI) and mean core area (MCA) had changed in the same manner from 1980 to 2010. Besides, cores area density (CAD) showed trend of positive slightly increasing from 1980 to 2002, in the value of 3.16 and 3.79, and little change to decrease to the value of 3.74 in 2010. This set of indices revealed that core area of the landscape had decreased during 1980 to 2002; it meant that the study area loss its interior habitat and then had little increased from 2002 to 2010. Thus, we gain core area after the year 2002, even though it was small part of the area.

(4) Diversity /Interspersion/Isolation metrics measurement. The results appeared that diversity index; Shannon's diversity index (SDI) had increased from 1980 to 2002 at 1.14 and 1.2, and remained constant at 1.2 in 2010. It implied that the landscape had become more divert with different types in the area. On the other hand, Shannon's evenness index (SEI) which measure distribution and abundance showed that the distribution of patch types in the landscape became more even, since the

index value were 0.64, 0.60, and 0.67 and they were approaching to 1 and remaining relatively the same during 1980 to 2010. For the last set of indices, interspersion juxtaposition index (IJI) and mean proximity index (MPI), indicated the aggregation of the patches in the landscape were increased during 1980 to 2010, and the degree of isolation of patches in the landscape were decreased from 1980 to 2010. It was implied that ecological status of the landscape from the past up to the recent year had become in a good health.

Table 4.10 Assessment of landscape metrics change of SBR at landscape level.

Ecological Aspects	**Landscape metrics (Unit)**	**Year**			**Change**	
		1980	**2002**	**2010**	**1980-2002**	**2002-2010**
Area/Density/ Edge	NP	2064	2239	2293	175	54
	TE (Meters)	5,840,520	6,462,435	6,248,820	621,915	-213,615
	ED (m/m²)	35.78	39.59	38.28	3.81	-1.31
Shape	MSI	2.14	2.23	2.21	0.09	-0.02
	MPFD	1.12	1.13	1.13	0.01	0.00
Core Area	TCA (hectares)	151,454.4	150,175.7	150,631.4	-1,279	456
	MCA (hectares)	29.33	24.27	24.66	-5.06	0.39
	TCAI	92.78	91.99	92.27	-0.79	0.28
	CAD (hectares)	3.16	3.79	3.74	0.63	-0.05
Diversity/ Interspersion/ Isolation	SDI	1.14	1.20	1.20	0.06	0.00
	SEI	0.64	0.60	0.67	-0.04	0.07
	IJI	68.45	72.69	73.49	4.24	0.80
	MPI	58,336.39	45,962.26	42,751.84	-12374	-3210
	MNN (meters)	190.4	207.8	200.8	17.40	-7.00

4.2.2 Landscape pattern analysis of SBR at class level

At class level, landscape patterns were analyzed to fulfill 4 aspects of landscape ecology included: (1) area/density/edge, (2) shape, (3) core area, and (4) interspersion/isolation. The results of 12 indices of four aspects in 1980, 2002, and 2010 were summarized as shown in Table 4.11 to Table 4.13, respectively. Qualitative and quantitative comparisons of landscape types ecological measurement of SBR were briefly separate described in four aspects of landscape ecology.

(1) Area/density/edge metrics measurement. It was found that number of patch in urban landscape had significantly changed in number of patches in the landscape. It had 434 patches in year 1980 then dramatically increasing to 739 patches in 2002 and 795 patches in 2010. Follow by group of natural forest, disturbed forest, forest plantation, and agricultural landscape which appeared to change in the same manner during the period of year 1980 to 2010, that were decreasing in number of patches from year 1980 to 2010.

Contrast to miscellaneous landscape had increasing change from 1980 to 2010. Total edge (TE) and edge density (ED) of all landscape types in the study area revealed change in the same pattern from 1980 to 2010, which can be grouped into two landscape groups. Firstly, natural forest and disturbed landscape had the same trends of decreasing from 1980 up to 2010. Secondly, agriculture, forest plantation, urban, and miscellaneous had the same trends of increasing from the 1980 up to 2010. These implied less fragmentation in natural forest landscape and re-habitability might occur in some parts of disturbed forest landscape. By contrast, other landscape types appeared to be more fragmented.

(2) Shape metrics measurement. It was found that mean shape index (MSI) and mean patch fractal dimension (MPED) had shown gradually increasing change from 1980 to 2010 in agriculture, nature forest, disturbed forest, forest plantation, and miscellaneous landscapes. Meanwhile, urban landscape was the only one that showed increasing of change. It was clearly that urban landscape show less complexity than other landscape types in the whole landscape.

(3) Core area metrics measurement. It was found that total core area (TCA) in agriculture, forest plantation, urban and miscellaneous landscape have the same trend of increasing from 1980 to 2010. On the other hand, natural forest and disturbed forest showed the same way of decreasing from 1980 to 2010. This indicated that landscape type's loss amount of their core habitat or interior area in which might affect their ecological function. Besides, total core area index (TCAI) of disturbed forest had also decreased from 1980 to 2002, after that trend to be the same as year 2010. Some other landscape types, such as forest plantation, urban and miscellaneous landscape showed tendency of increasing, especially urban landscape revealed high extent of increasing from 1980 to 2002, and level down of change from 2002 to 2010. Moreover, agriculture and natural forest landscape appeared to remain stable from 1980 to 2010. Mean core area (MCA) of agriculture, natural forest, forest plantation, and disturbed forest landscape demonstrated dominant status over other types such as urban and miscellaneous landscapes. Agriculture and forest plantation landscapes had increased their mean core areas; especially show significant increasing their mean core area from 1980 to 2002 but little increase after 2002 up to 2010. Disturbed forest had lost mean core area dramatically from 1980, 2002, and 2010. Core area density (CAD) of natural forest, urban, agriculture landscape occupied most

of the landscape area and urban landscape had increased their core area density from 1980 to 2010. Exceptionally, natural forest landscape had more fluctuation of change by increasing from year 1980 to 2002 and then decreasing after 2002 to 2010. Moreover, agriculture, disturbed forest, and forest plantation landscapes had little changed. This indicated that during 1980 to 2010, urban landscape had expanded their areas compare to some other types in the landscape.

(4) Interspersion/isolation metrics measurement. For interspersion juxtaposition index (IJI) it was found that in agriculture and natural forest had tendency of increasing from 1980 to 2010. This indicated that aggregation of the patches in the natural forest and agriculture landscapes were increased. At the same time, disturbed forest, forest plantation, and miscellaneous landscapes were among at the same level and showed low degree of changes from 1980 to 2010. Mean proximity index (MPI); agriculture and forest landscapes showed dominance in the landscape and had high value indices indicated that this two types of landscape had high isolate patches from some other landscape types. On the other hand, mean nearest neighbor (MNN) in forest plantation showed significantly high from 1980 to 2010 and had higher value indices compared to some other landscape types. This implied that forest plantation patches were sparsely from each other in the landscape as same as miscellaneous landscape. Urban and natural forest landscapes nearly had the same pattern of constant status from 1980 to 2010. Meanwhile, agriculture landscape showed little changed and had low indices values; it meant that agriculture landscape had their aggregation. Comparison of 12 indices value in 1980, 2002, and 2010 were presented in Figure 4.14 to Figure 4.25.

Table 4.11 Landscape metrics analysis of SBR at class level in 1980.

1980	Landscape type					
Landscape Metrics (Unit)	**Agriculture landscape**	**Natural forest landscape**	**Disturbed forest landscape**	**Forest plantation landscape**	**Urban landscape**	**Miscellaneous landscape**
NP	413	384	447	115	434	271
TE (meters)	3,952,170	3,802,140	1,815,690	324,780	869,340	575,340
ED (m/m²)	24.21	23.29	11.12	1.99	5.33	3.52
MSI	1.92	2.44	1.99	1.74	2.53	1.84
MPFD	1.10	1.13	1.11	1.09	1.15	1.10
TCA (hectares)	59,950.82	71,490.49	14,786.80	2,274.73	1,329.66	1,621.91
MCA (hectares)	65.74	38.05	20.83	18.96	1.27	3.26
TCAI	93.45	94.74	88.63	86.80	62.81	73.15
CAD (hectares)	0.56	1.15	0.43	0.07	0.64	0.30
IJI	74.98	63.10	61.55	60.74	53.41	56.73
MPI	19,2456.83	104,924.9 3	690.56	576.30	314.67	438.94
MNN (meters)	52.73	135.74	207.63	582.57	171.79	312.44

Table 4.12 Landscape metrics analysis of SBR at class level in 2002.

2002	Landscape type					
Landscape metrics (Unit)	**Agriculture landscape**	**Natural forest landscape**	**Disturbed forest landscape**	**Forest plantation landscape**	**Urban landscape**	**Miscellaneous landscape**
NP	292	357	395	94	739	362
TE (meters)	4,579,380	3,672,600	1,348,230	594,810	1,506,450	881,820
ED (m/m²)	28.05	22.50	8.26	3.64	9.23	5.40
MSI	2.16	2.67	2.11	2.00	2.29	1.90
MPFD	1.11	1.14	1.12	1.10	1.14	1.11
TCA (hectares)	62,159.54	68,636.21	6,245.73	6,127.56	4,118.87	2,887.76
MCA (hectares)	69.76	33.45	8.25	47.14	2.42	4.38
TCAI	92.73	94.74	81.77	90.64	74.21	75.69
CAD (hectares)	0.55	1.26	0.46	0.08	1.04	0.40
IJI	81.12	69.98	63.03	60.21	43.90	53.84
MPI	280,830.55	56,314.71	470.44	534.29	452.88	640.59
MNN (meters)	43.67	148.20	297.67	555.65	182.87	261.43

Table 4.13 Landscape metrics analysis of SBR at class level in 2010.

2010	**Landscape type**					
Landscape metrics (Unit)	**Agriculture landscape**	**Natural forest landscape**	**Disturbed forest landscape**	**Forest plantation landscape**	**Urban landscape**	**Miscellaneous landscape**
NP	279	353	377	91	795	398
TE (meters)	4,507,710	3,238,800	1,208,880	512,010	1,666,830	1,021,830
ED (m/m^2)	27.61	19.84	7.41	3.14	10.21	6.26
MSI	2.13	2.61	2.10	1.89	2.33	1.89
MPFD	1.11	1.14	1.12	1.09	1.14	1.11
TCA (hectares)	62,595.20	69,110.42	5,272.24	5,513.29	4,358.50	3,781.78
MCA (hectares)	75.69	39.31	7.44	47.94	2.18	5.36
TCAI	92.87	95.36	80.91	91.00	73.37	77.82
CAD (hectares)	0.51	1.08	0.43	0.07	1.22	0.43
IJI	83.26	71.49	63.60	62.13	42.90	52.97
MPI	281,149.30	52,704.93	478.58	481.64	582.12	747.31
MNN (meters)	44.11	136.30	323.93	560.59	167.82	234.64

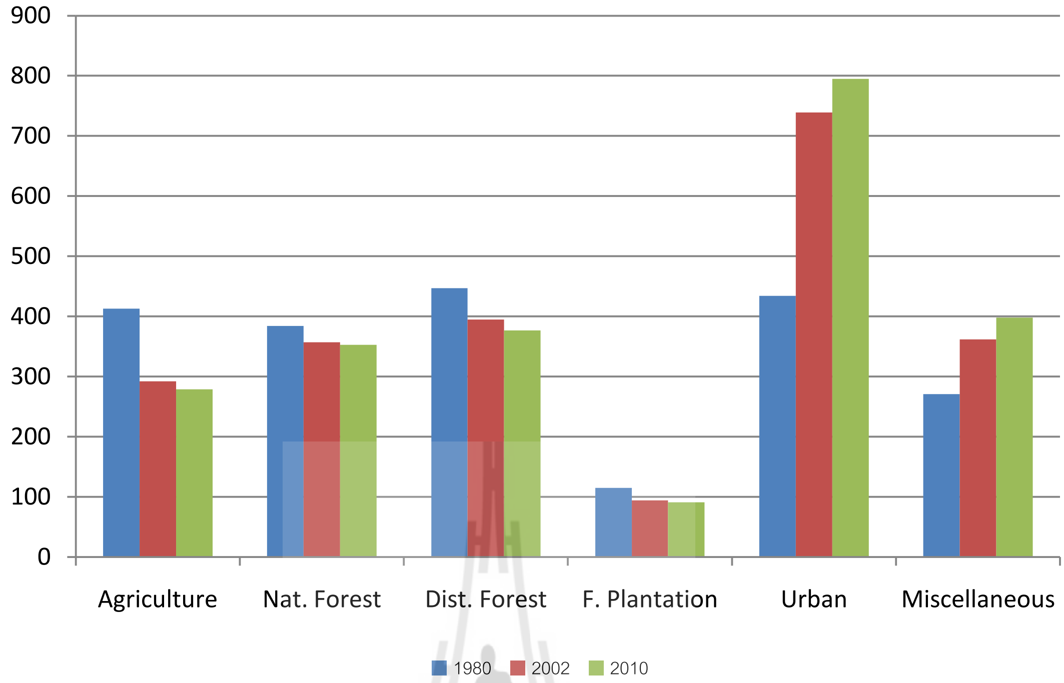


Figure 4.14 Comparison of Number of Patch (NP) in 1980, 2002, and 2010.

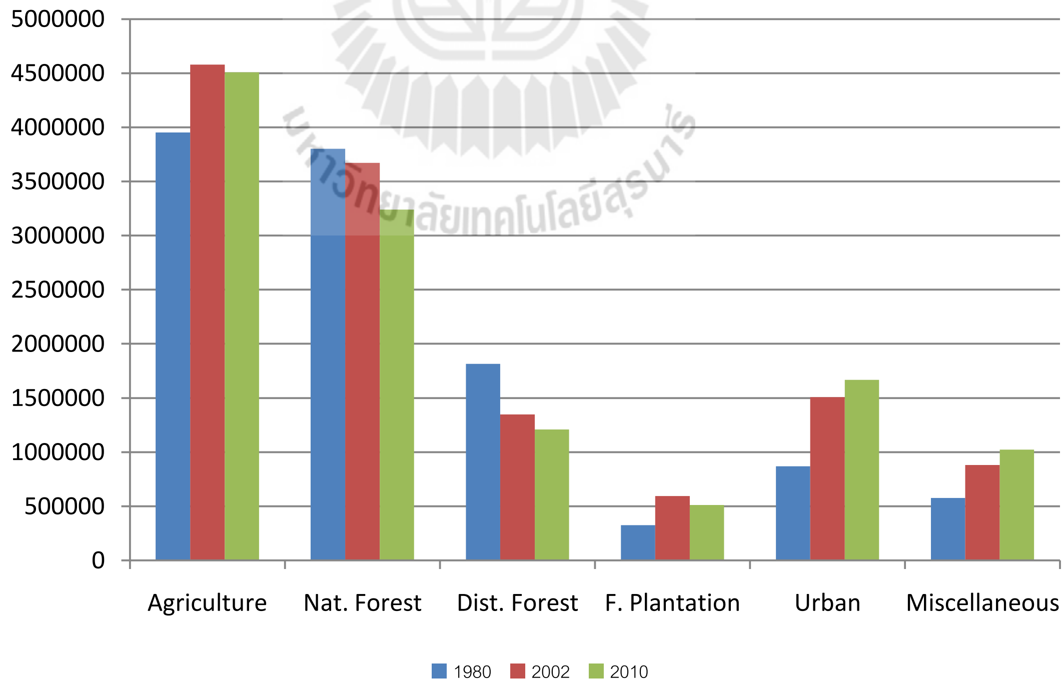


Figure 4.15 Comparison of Total Edge (TE) in 1980, 2002, and 2010.

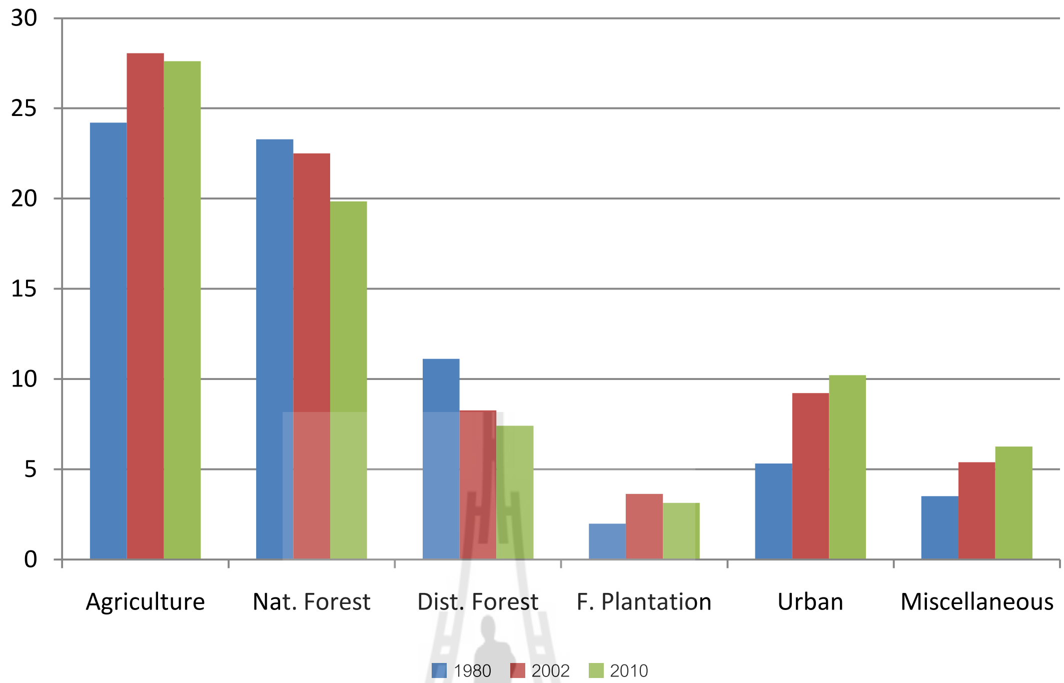


Figure 4.16 Comparison of Edge Density (ED) in 1980, 2002, and 2010.

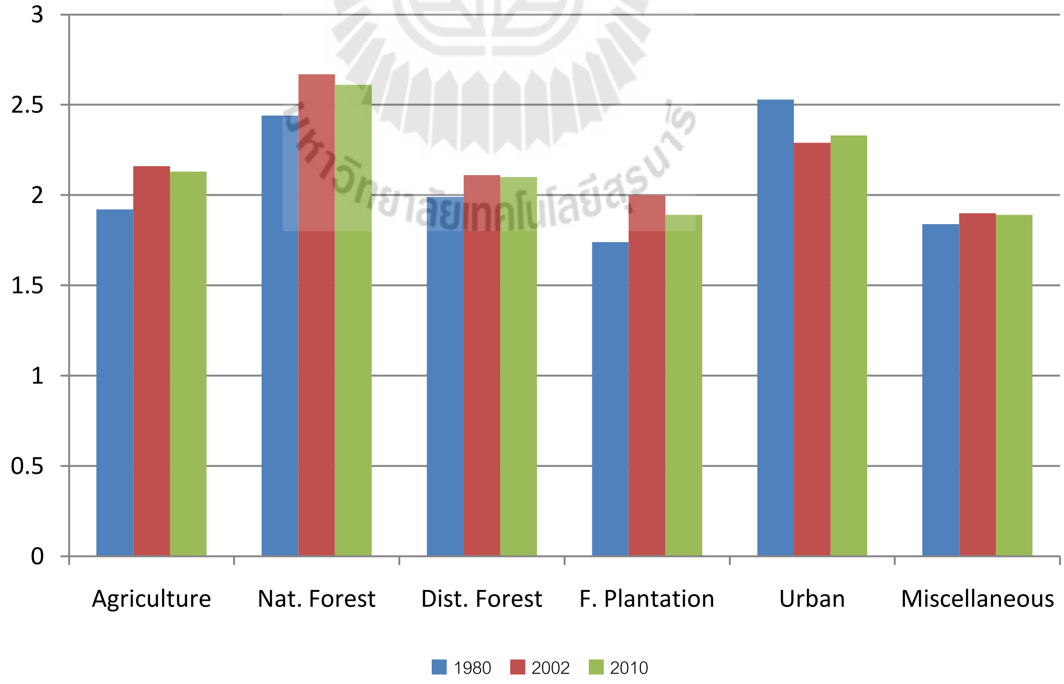


Figure 4.17 Comparison of Mean Shape Index (MSI) in 1980, 2002, and 2010.

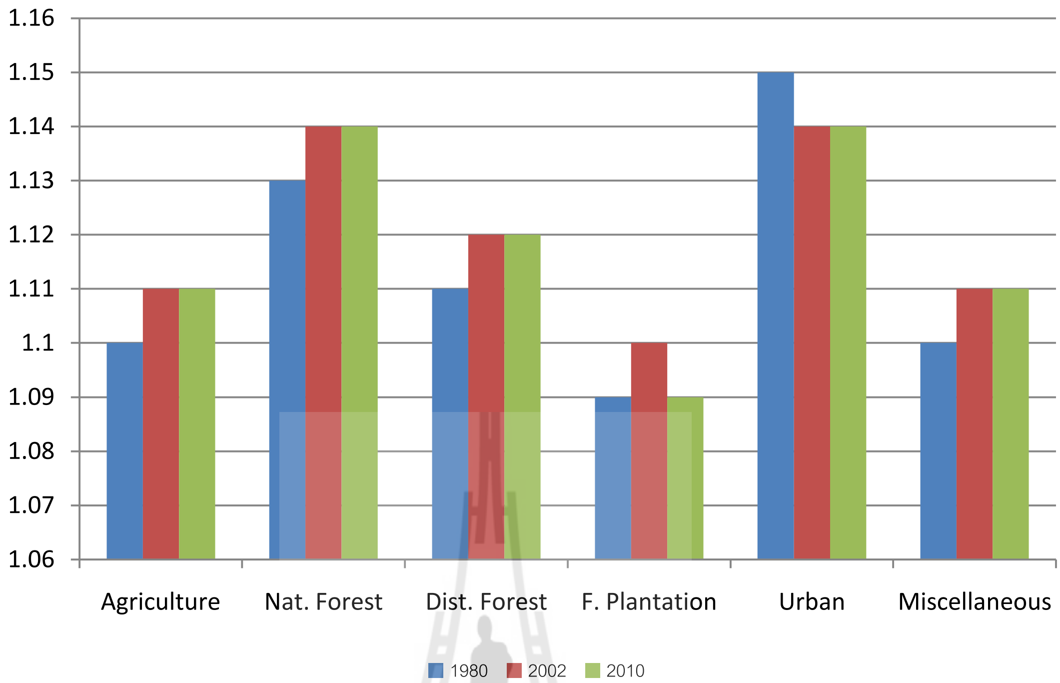


Figure 4.18 Comparison of Mean Patch Fractal Dimension (MPFD) in 1980, 2002, and 2010.

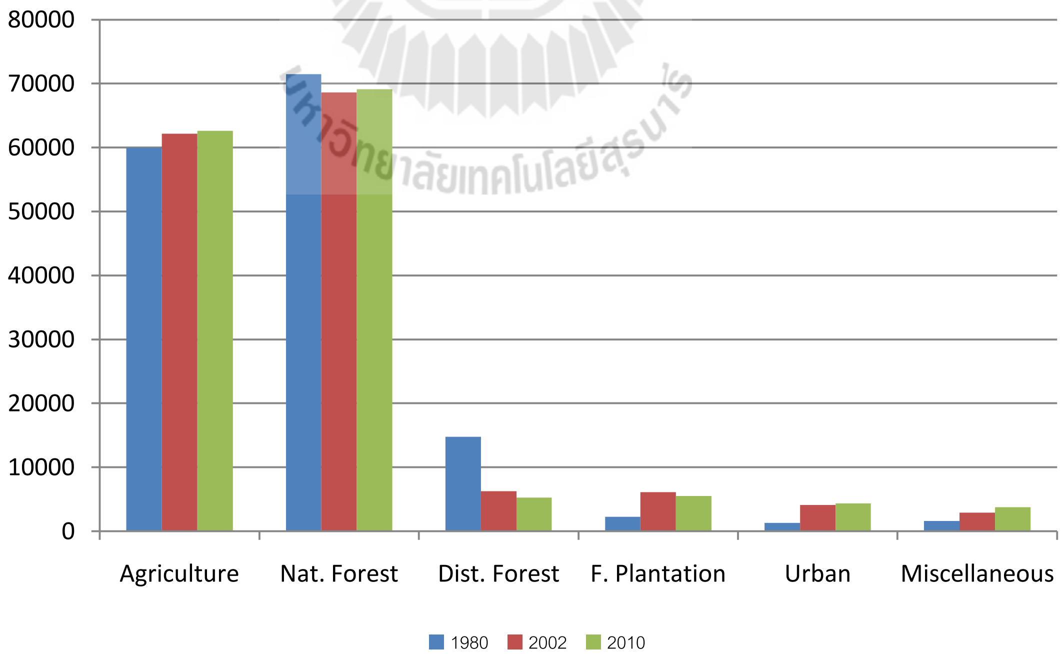


Figure 4.19 Comparison of Total Core Area (TCA) in 1980, 2002, and 2010.

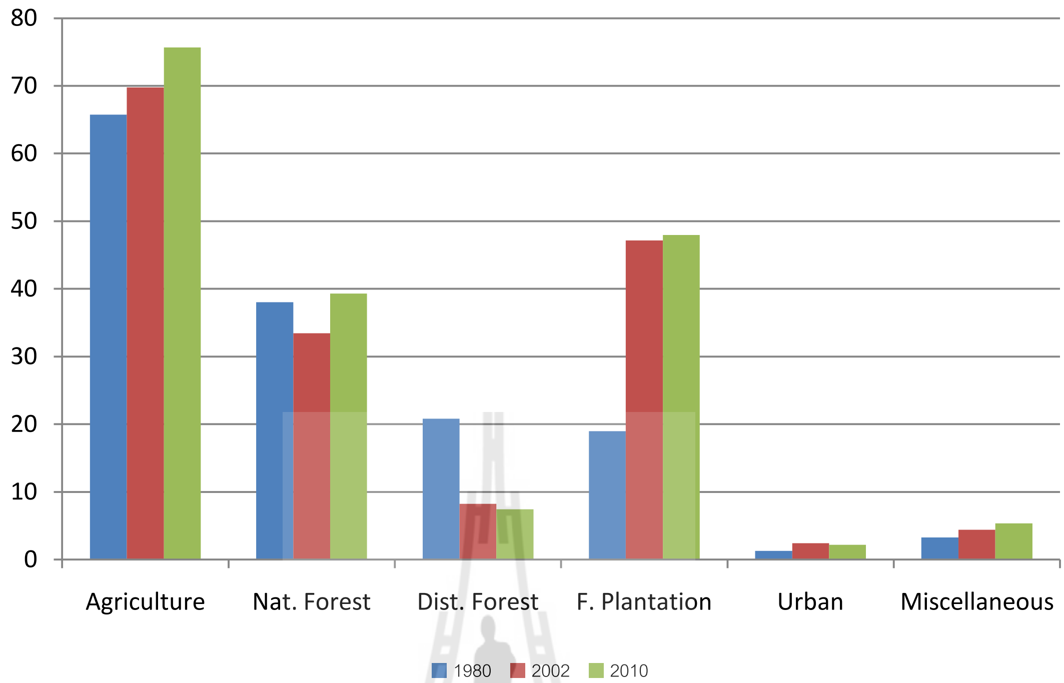


Figure 4.20 Comparison of Mean Core Area (MCA) in 1980, 2002, and 2010.

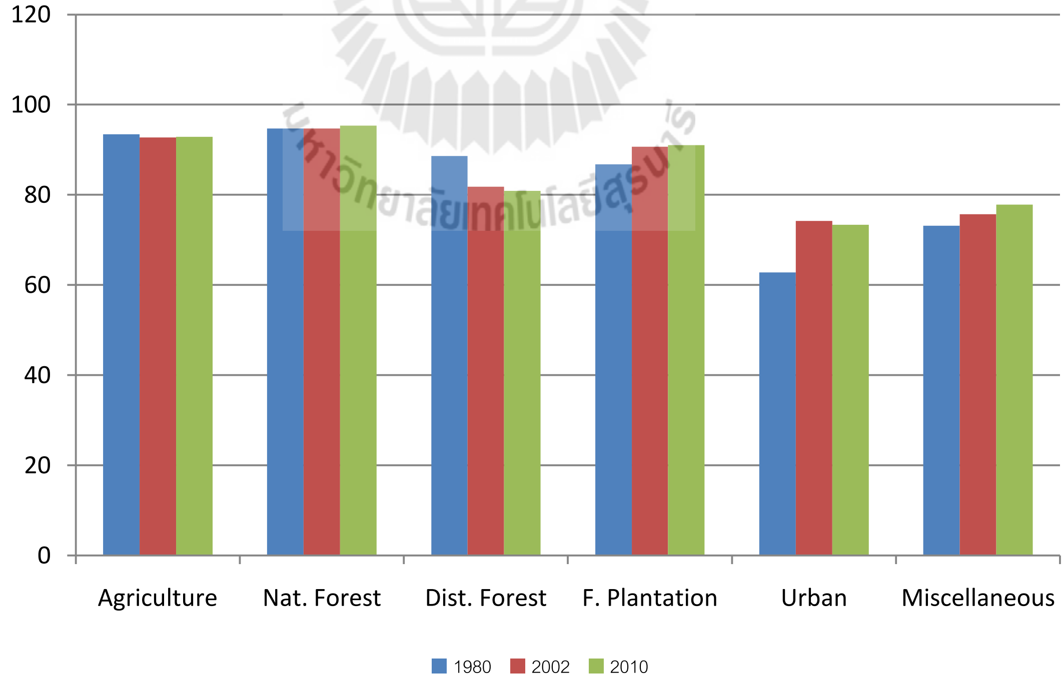


Figure 4.21 Comparison of Total Core Area Index (TCAI) in 1980, 2002, and 2010.

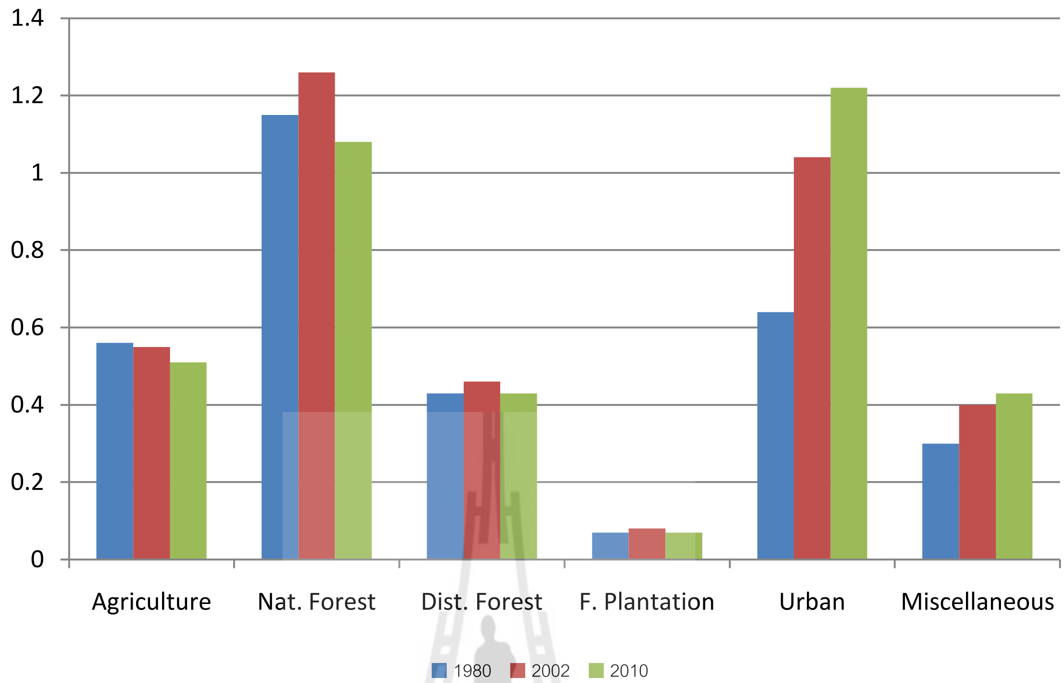


Figure 4.22 Comparison of Core Area Density (CAD) in 1980, 2002, and 2010.

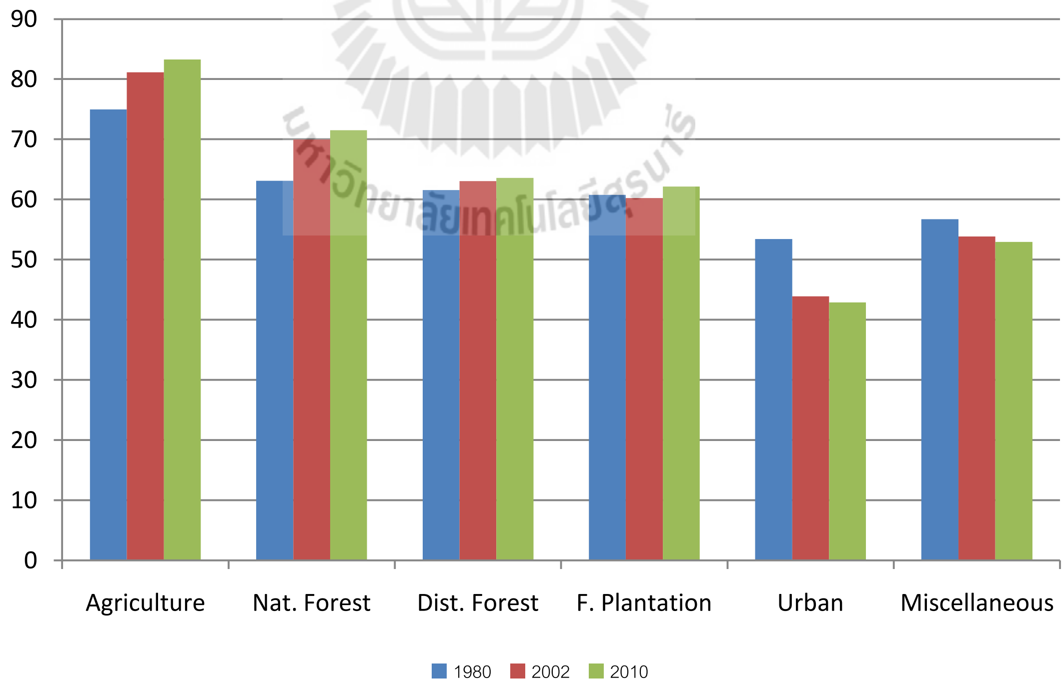


Figure 4.23 Comparison of Interspersion Juxtaposition Index (IJI) in 1980, 2002, and 2010.

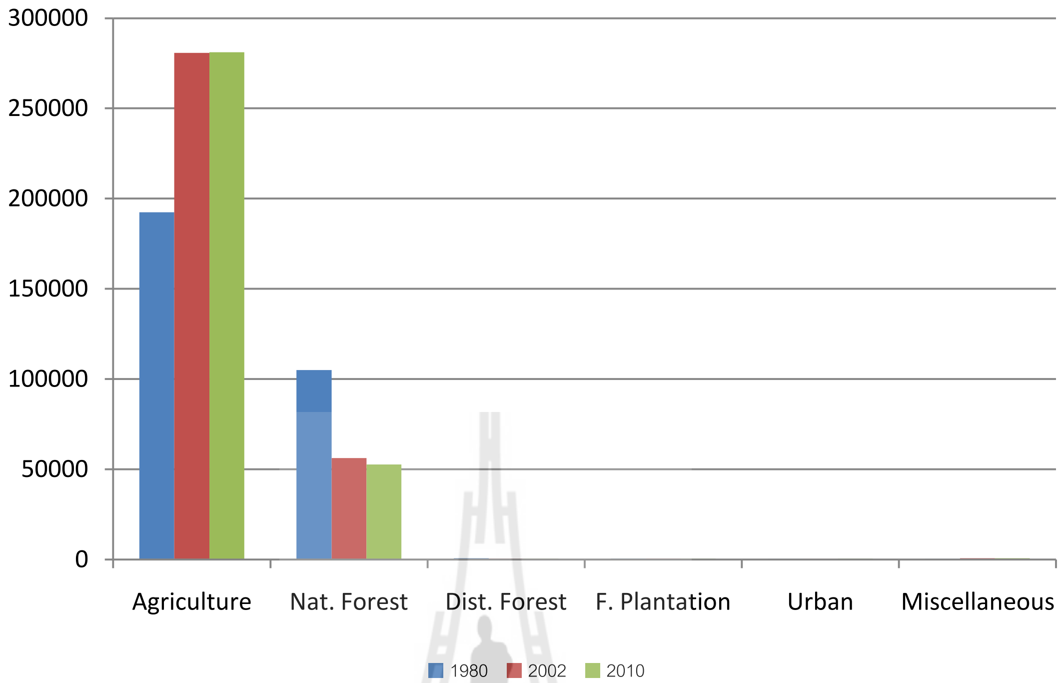


Figure 4.24 Comparison of Mean Proximity Index (MPI) in 1980, 2002, and 2010.

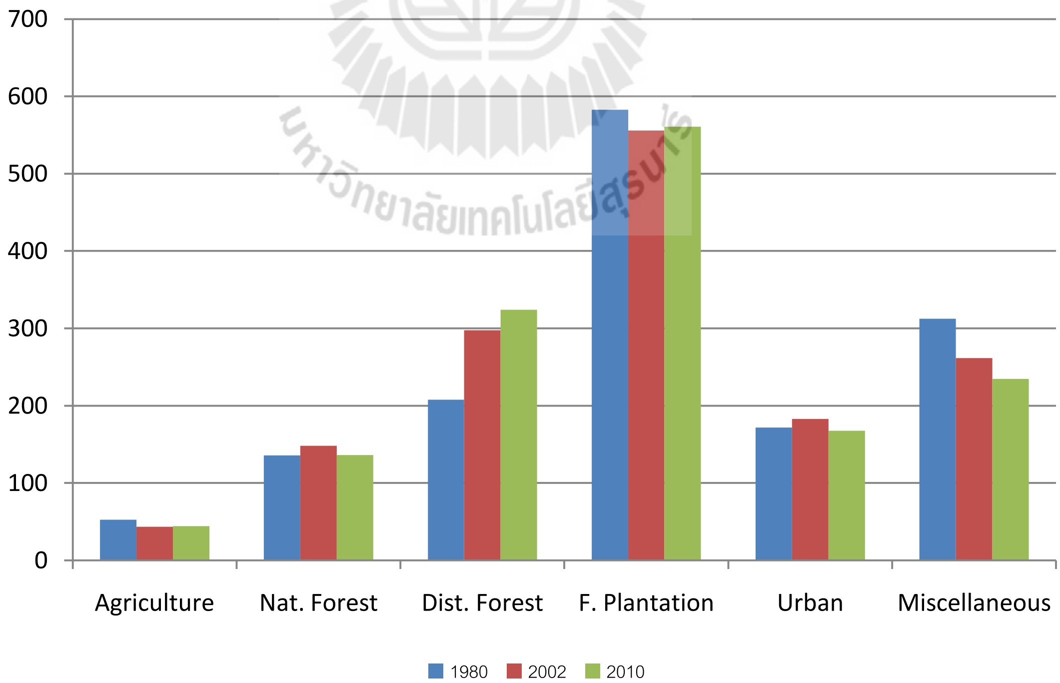


Figure 4.25 Comparison of Mean Nearest Neighbor (MNN) in 1980, 2002, and 2010.

4.3 Results of forest landscape pattern analysis and assessment in SBR management zones

In this section the SBR forest landscape including natural forest, disturbed forest and forest plantation were measured, analyzed and assessed in each management zones based on LULC classification in 1980, 2002, and 2010. The measures of forest landscape pattern using groups of indices were shown as the following:

(1) Area/density/edge metrics measurement

(1) Number of Patch (NP);

(2) Total Edge (TE); and

(3) Edge density (ED).

(2) Shape metrics measurement

(1) Mean Shape Index (MSI); and

(2) Mean Patch Fractal Dimension (MPFD).

(3) Core Area metrics measurement

(1) Total Core Area (TCA);

(2) Mean Core Area (MCA);

(3) Total Core Area Index (TCAI); and

(4) Core Area Density (CAD).

(4) Interspersion/Isolation metrics measurement

(1) Interspersion Juxtaposition Index (IJI);

(2) Mean Proximity Index (MPI); and

(3) Mean Nearest Neighbor (MNN).

Distribution of forest landscapes in each management zones in 1980, 2002, and 2010 were presented in Figure 4.26 to Figure 4.28, respectively. Whereas, areas and percentages of forest landscape types in SBR and in each management zones during 1980 to 2010 were reported in Table 4.14 and Table 4.15.

The main component of forest landscapes during 1980 to 2010 was natural forest which covered areas of 754.63 sq. km, 724.53 sq. km, and 742.78 sq. km or 46.23%, 44.38%, and 44.40% of SBR in 1980, 2002, and 2010, respectively. In the meantime, the second most dominant was disturbed forest which covered area of 166.81 sq. km, 76.34 sq. km, and 65.10 sq. km, or 10.22%, 4.68%, and 3.99% of SBR in 1980, 2002, and 2010, respectively. The third dominant was forest plantation which covered area of 26.23 sq. km, 67.62 sq. km, and 60.59 sq. km, or 1.61%, 4.14%, and 3.71% of SBR in 1980, 2002, and 2010, respectively. As a result, it was found that areas of natural forest landscape in three different years were rather stabled but dominated over other forest landscape types. Meanwhile, disturbed forest landscape was dramatically decreased from 1980 to 2010, but forest plantation landscape was sharply increased from 1980 to 2010.

Under SBR management zones, including core, buffer, and transition zones; the main component of forest landscapes during 1980 to 2010 was natural forest landscape. Natural forest landscape covered areas in the core zone at 93.52%, 96.37%, and 97.20 % in 1980, 2002, and 2010, respectively, while disturbed forest and forest plantation landscape covered areas in the core zone at 4.94%, 0.77%, and 0.95%; and 1.54%, 2.87% , and 1.86%, respectively. For the buffer zone, natural forest landscape covered areas of 72.73%, 78.32%, and 80.31% in 1980, 2002, and 2010, respectively; whereas disturbed forest covered areas in the buffer zone of

24.65%, 3.05%, and 2.26%, and forest plantation landscape covered the areas of 2.62%, 18.63%, and 17.43%, respectively. In addition, natural forest covered area in the transition zone at 79.55%, 83.42%, and 84.97% in 1980, 2002, and 2010, respectively, while disturbed forest and forest plantation covered area in the transition zone at 17.57%, 8.79%, and 9.02%; and 2.88%, 7.79%, and 6.01%, respectively.

The composition of forest landscapes in each management zones in 1980, 2002, and 2010 were compared as shown in Figure 4.29. Herewith, in all management zones included the core, buffer, and transition zones were dominated by natural forest landscape with increasing trend from 1980 to 2010. Additionally, forest plantation landscape exhibited trend of increasing in the same manner with natural forest in the core, buffer, and transition zones. On the other hand, disturbed forest landscape showed reverse trend to decrease in all management zones from 1980 to 2010. Besides, in the buffer and transition zones showed sharply decreasing in its areas.

In addition, forest landscapes pattern assessment with selected landscape metrics including (1) Number of Patch (NP), (2) Total Edge (TE), (3) Edge density (ED), (4) Mean Shape Index (MSI), (5) Mean Patch Fractal Dimension (MPFD), (6) Total Core Area (TCA), (7) Mean Core Area (MCA), (8) Total Core Area Index (TCAI), (9) Core Area Density (CAD), (10) Interspersion Juxtaposition Index (IJI), (11) Mean Proximity Index (MPI), and (12) Mean Nearest Neighbor (MNN) were analyzed for recommendations on forest restoration and management plans in SBR. Detail of each landscape metrics characters in each forest landscapes in management zones were described separately in the following sections; (1) Natural forest landscape pattern analysis of SBR, (2) Disturbed forest landscape pattern analysis of SBR, and (3) Forest plantation landscape pattern analysis of SBR.

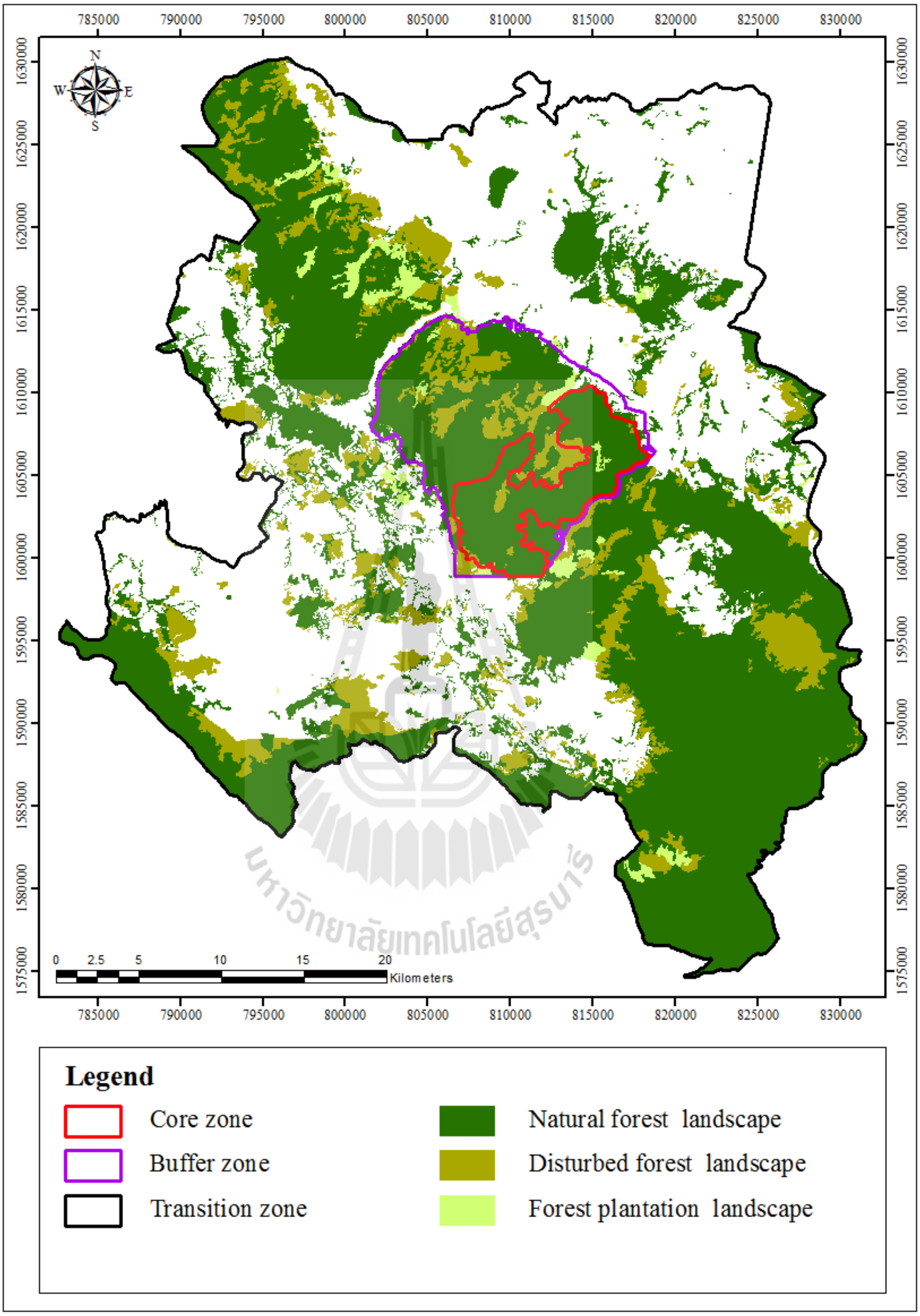


Figure 4.26 Distribution of forest landscapes in SBR management zones in 1980.

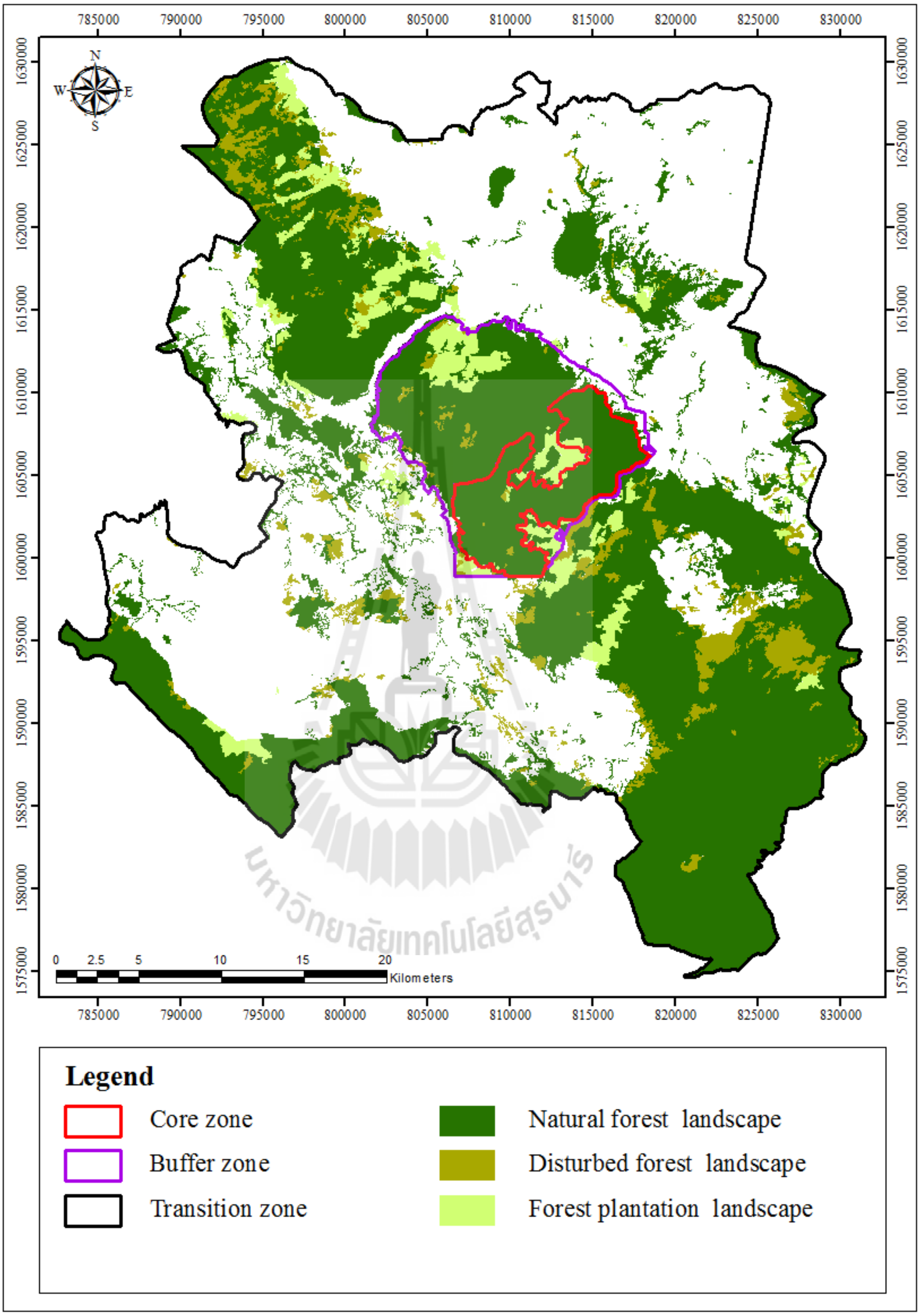


Figure 4.27 Distribution of forest landscapes in SBR management zones in 2002.

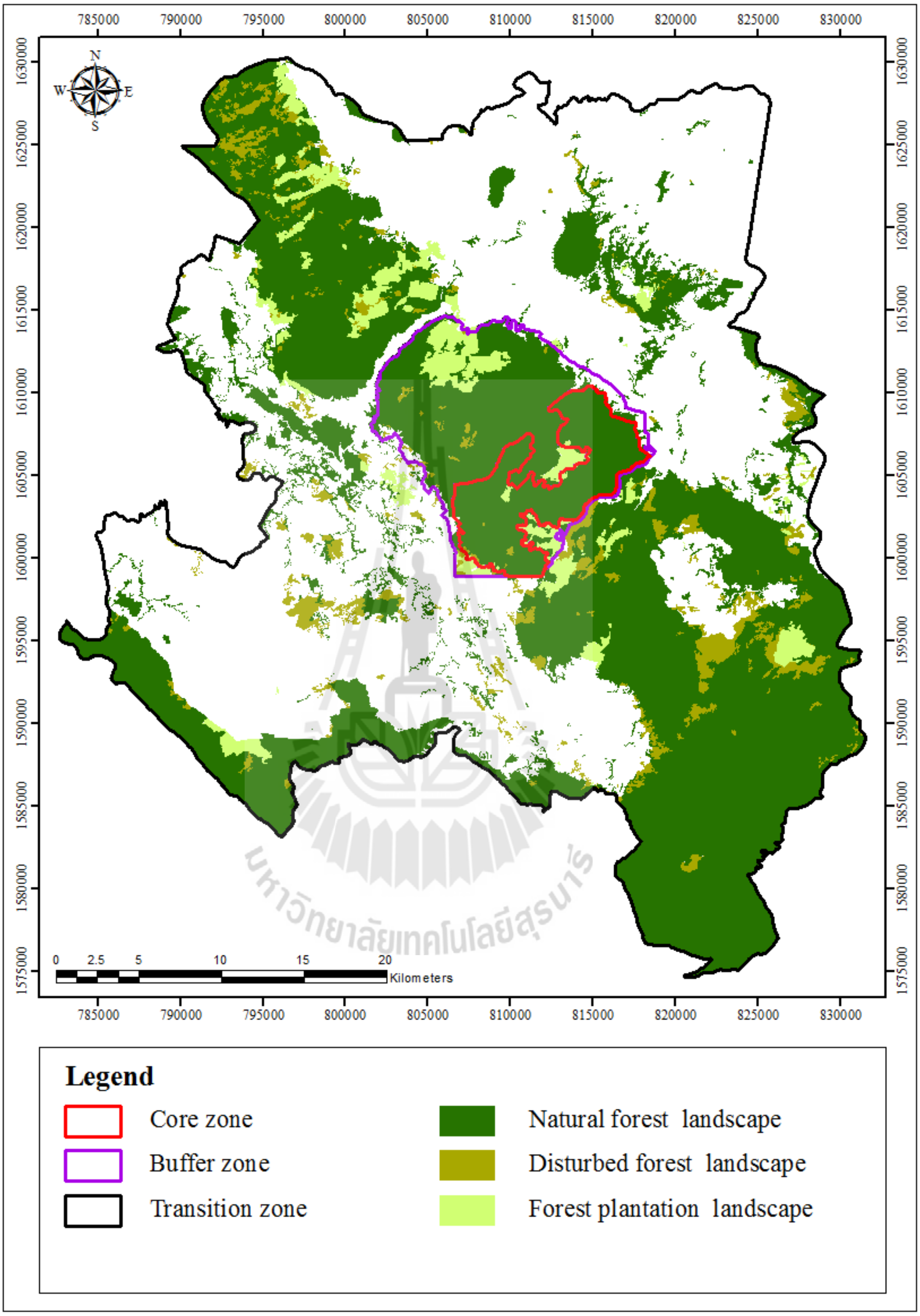


Figure 4.28 Distribution of forest landscapes in SBR management zones in 2010.

Table 4.14 Summary of forest landscape area and percentage in 1980, 2002, and 2010.

Landscape	1980		2002		2010	
	sq. km	**%**	**sq. km**	**%**	**sq. km**	**%**
Natural forest	754.63	46.23	724.53	44.38	724.78	44.40
Disturbed forest	166.81	10.22	76.34	4.68	65.10	3.99
Forest plantation	26.23	1.61	67.62	4.14	60.59	3.71
Others landscape	684.81	41.94	763.99	46.80	782.01	47.90
Total	**1,632.48**	**100.00**	**1,632.48**	**100.00**	**1,632.48**	**100.00**

Table 4.15 Area and percentage of forest landscape types in SBR management zones during 1980 to 2010.

1980	Core zone		Buffer zone		Transition zone	
	Area (sq. km)	**%**	**Area (sq. km)**	**%**	**Area (sq. km)**	**%**
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 (sq. km)	**%**	**Area (sq. km)**	**%**	**Area (sq. km)**	**%**
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**	**868.49**	**100.00**
2010	**Core zone**		**Buffer zone**		**Transition zone**	
	Area (sq. km)	**%**	**Area (sq. km)**	**%**	**Area (sq. km)**	**%**
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**

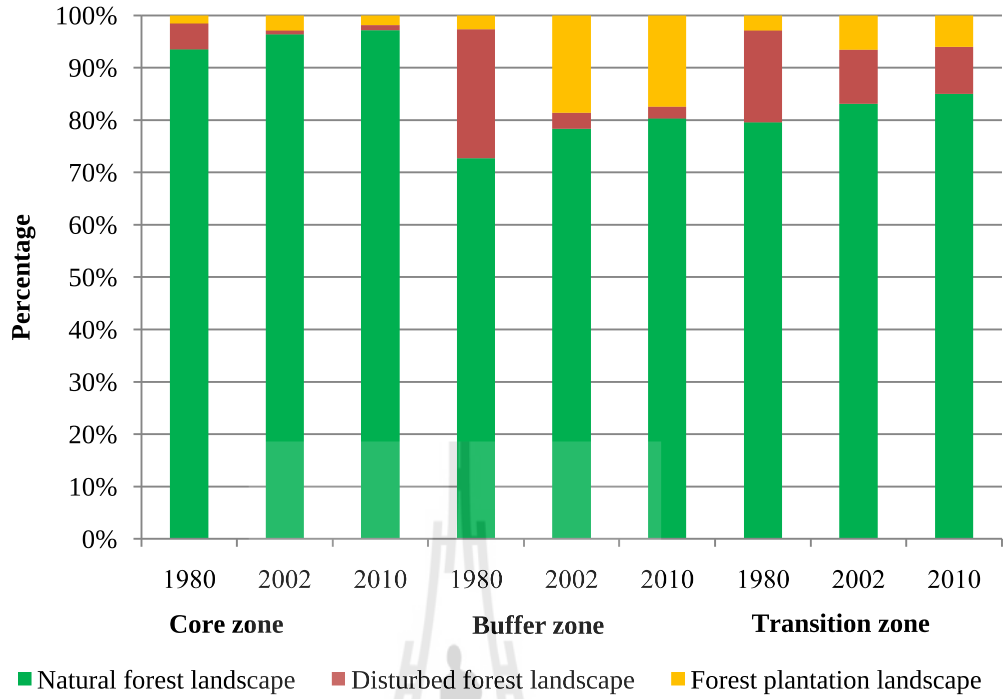


Figure 4.29 Composition of forest landscapes in each management zones in 1980, 2002, and 2010.

4.3.1 Natural forest landscape pattern analysis in SBR

At class level, natural forest landscape patterns in each SBR management zones were analyzed to fulfill 4 aspects of landscape ecology included (1) area/density/edge (2) shape (3) core area, and (4) interspersion/isolation.

The results of 12 indices measurement of four aspects in 1980, 2002, and 2010 for natural forest landscape were summarized as an overview in Table 4.16 and in each management zones in Table 4.17 to Table 4.19. Qualitative and quantitative explanations for ecological measurement were described separately for each management zones.

Core Zone; For area, density and edge ecological measurement, it was found that number of patch, total edge and edge density of natural forest were slightly changed. These implied that less fragmentation in natural forest landscape. At the same time, for shape complexity measurement, it revealed that shape of natural forest was rather stable; value of Mean Patch Fractal Dimension (MPFD) was rather stable in 1980, 2002, and 2010. However, value of Mean Shape Index (MSI) had some changed between 1980 and 2002. Meanwhile, value of core area indices (TCA, MCA, TCAI and CAD) had very slightly changed in three different years. These implied that core area of natural forest landscape was stable. Similarly, for interspersion and isolation measurement, natural forest landscape was rather aggregated to each other. However, the value of MPI and MNN had shown the trend of increasing from 1980 to 2010.

Buffer Zone; For area, density and edge ecological measurement, it was found that number of patch, total edge and edge density of natural forest landscape were moderately increasing. These implied that some fragmentation in natural forest landscape occurring in buffer zone. At the same time, for shape complexity measurement (MSI and MPFD), it revealed that shape of natural forest landscape in buffer zone was rather stable. Meanwhile, value of core area indices (TCA, MCA, TCAI and CAD) had slightly changed in three different years. These implied that core area of natural forest landscape in buffer zone was rather stable. In contrast to core area measurement, for interspersion and isolation measurement, natural forest in buffer zone was dispersed from each other. However, the value of MPI had shown the trend of increasing from 1980 to 2010.

Transition Zone; For area, density and edge ecological measurement, it was found that number of patch, total edge and edge density of natural forest landscape were fluctuated in transition zone during 1980 to 2010. These implied some fragmentation and compactness in natural forest landscape due to human activities (i.e., forest disturbance or forest enrichment). Concurrently, for shape complexity measurement (MSI and MPFD), it revealed that shape of natural forest in transition zone was rather stable. Similarly, values of core area indices (TCA, MCA, TCAI and CAD) had slightly changed in three different years. These implied that core area of natural forest in transition zone was stable. Meanwhile, the value of interspersion and isolation measurement (IJI, MPI and MNN) showed the trend of dispersion for natural forest in transition zone, especially MPI value.

Table 4.16 Assessment of natural forest landscapes metrics change in SBR during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	2002	2010	1980-2002	2002-2010
NP	384.00	357.00	353.00	-27.00	-4.00
TE (meters)	3,802,140.00	3,672,600.00	3,238,800.00	-129,540.00	-433,800.00
ED (m/m²)	23.29	22.50	19.84	-0.79	-2.66
MSI	2.44	2.67	2.61	0.23	-0.06
MPFD	1.13	1.14	1.14	0.01	0.00
TCA (hectares)	71,490.49	68,636.21	69,110.42	-2,854.28	474.21
MCA (hectares)	38.05	33.45	39.31	-4.60	5.86
TCAI	94.74	94.74	95.36	0.00	0.62
CAD (hectares)	1.15	1.26	1.08	0.11	-0.18
IJI	63.10	69.98	71.49	6.88	1.51
MPI	104,924.93	56,314.71	52,704.93	-48,610.22	-3,609.78
MNN (meters)	135.74	148.20	136.30	12.46	-11.90

Table 4.17 Assessment of natural forest landscape metrics in SBR core zone during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	2002	2010	1980-2002	2002-2010
NP	2.00	6.00	4.00	4.00	-2.00
TE (meters)	111,000.00	97,890.00	97,920.00	-13,110.00	30.00
ED (m/m²)	19.40	17.12	17.13	-2.28	0.01
MSI	2.47	1.70	1.78	-0.77	0.08
MPFD	1.10	1.10	1.09	0.00	-0.01
TCA (hectares)	5,231.36	5,404.97	5,452.29	173.61	47.32
MCA (hectares)	1,743.79	1,801.66	1,817.43	57.87	15.77
TCAI	97.76	98.09	98.11	0.33	0.02
CAD (hectares)	0.05	0.05	0.05	0.00	0.00
IJI	93.17	86.87	95.92	-6.30	9.05
MPI	59,459.50	72,469.39	93,474.44	13,009.89	21,005.05
MNN (meters)	21.21	26.28	31.92	5.07	5.64

Table 4.18 Assessment of natural forest landscape metrics in SBR buffer zone during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	**2002**	**2010**	**1980-2002**	**2002-2010**
NP	29.00	43.00	41.00	14.00	-2.00
TE (meters)	365,340.00	311,940.00	291,330.00	-53,400.00	-20,610.00
ED (m/m^2)	34.33	29.90	28.05	-4.43	-1.85
MSI	2.27	2.00	1.99	-0.27	-0.01
MPFD	1.11	1.11	1.11	0.00	0.00
TCA (hectares)	7,356.53	7,845.35	8,035.11	488.82	189.76
MCA (hectares)	113.18	92.30	111.60	-20.88	19.30
TCAI	95.03	96.01	96.34	0.98	0.33
CAD (hectares)	0.61	0.81	0.69	0.20	-0.12
IJI	42.68	92.38	88.16	49.70	-4.22
MPI	7,500.67	7,956.58	15,197.95	455.91	7,241.37
MNN (meters)	197.52	115.63	117.49	-81.89	1.86

Table 4.19 Assessment of natural forest landscape metrics in SBR transition zone during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	**2002**	**2010**	**1980-2002**	**2002-2010**
NP	425.00	484.00	463.00	59.00	-21.00
TE (meters)	3,499,800.00	3,375,840.00	2,970,840.00	-123,960.00	-405,000.00
ED (m/m^2)	44.64	47.75	43.09	3.11	-4.66
MSI	2.37	2.34	2.28	-0.03	-0.06
MPFD	1.13	1.12	1.12	-0.01	0.00
TCA (hectares)	58,722.23	54,234.80	54,584.16	-4,487.43	349.36
MCA (hectares)	31.22	29.27	34.27	-1.95	5.00
TCAI	94.16	92.28	93.18	-1.88	0.90
CAD (hectares)	2.40	2.62	2.31	0.22	-0.31
IJI	65.11	86.37	83.76	21.26	-2.61
MPI	57,592.04	32,075.95	29,819.80	-25,516.09	-2,256.15
MNN (meters)	143.13	120.45	123.30	-22.68	2.85

4.3.2 Disturbed forest landscape pattern analysis in SBR

The results of 12 indices for disturbed forest landscape pattern measurement in 1980, 2002 and 2010 were summarized as an overview in Table 4.20 and in each management zones in Table 4.21 to Table 4.23. Qualitative and quantitative explanations for ecological measurement were separately described for each management zones.

Core Zone; For area, density and edge ecological measurement, it was found that number of patch, total edge and edge density of disturbed forest had high decreasing changed. These implied that disturbed forest landscape became compactness and less fragmentation. At the same time, for shape complexity measurement, it revealed that shape of disturbed forest was rather stable; value of Mean Patch Fractal Dimension and Mean Shape Index were rather stable in 1980, 2002, and 2010. However, value of Mean Shape Index had some changed between 1980 and 2002. Meanwhile, value of core area indices (TCA, MCA, TCAI and CAD) had been decreasing changed in three different years. These implied that core area of disturbed forest was dramatically lost. Similar to interspersion and isolation measurement, disturbed forest had high fluctuated in indices value. However, the value of IJI and MNN had shown the trend of increasing from 1980 to 2010.

Buffer Zone; For area, density and edge ecological measurement, it was found that number of patch, total edge and edge density of disturbed forest were decreasing. These implied that less fragmentation in disturbed forest landscape occurring in buffer zone. At the same time, for shape complexity measurement, it revealed that shape complexity of disturbed forest in buffer zone was rather stable; value of MPFD was constant in 1980, 2002, and 2010. However, value of Mean

Shape Index had some changed between 1980 and 2002. Meanwhile, value of core area indices (TCA, MCA, TCAI and CAD) had highly decreasing in three different years. These implied that loss of core area of disturbed forest in buffer zone was highly changed. In contrast to core area measurement, for interspersion and isolation measurement, disturbed forest in buffer zone was dispersed from each other. However, the value of MPI had shown the trend of decreasing from 1980 to 2010.

Transition Zone; For area, density and edge ecological measurement, it was found that number of patch, total edge and edge density of disturbed forest were decreasing in transition zone during 1980 to 2010. These implied less fragmentation and compactness in disturbed forest landscape. At the same time, for shape complexity measurement, it revealed that shape complexity of disturbed forest in transition zone was rather stable, value of MSI and MPFD were rather stable in 1980, 2002, and 2010. On the other hand, values of core area indices (TCA, MCA, and TCAI) were decreasing in three different years. These implied that core area of disturbed forest in transition zone was decreased in its area. Meanwhile, the value of interspersion and isolation measurement (IJI, MPI and MNN) showed the trend for dispersion and isolation of disturbed forest in transition zone, especially MPI and MNN value.

Table 4.20 Assessment of disturbed forest landscapes metrics change in SBR during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	**2002**	**2010**	**1980-2002**	**2002-2010**
NP	447.00	395.00	377.00	-52.00	-18.00
TE (meters)	1,815,690.00	1,348,230.00	1,208,880.00	-467,460.00	-139,350.00
ED (m/m²)	11.12	8.26	7.41	-2.86	-0.85
MSI	1.99	2.11	2.10	0.12	-0.01
MPFD	1.11	1.12	1.12	0.01	0.00
TCA (hectares)	14,786.80	6,245.73	5,272.24	-8,541.07	-973.49
MCA (hectares)	20.83	8.25	7.44	-12.58	-0.81
TCAI	88.63	81.77	80.91	-6.86	-0.86
CAD (hectares)	0.43	0.46	0.43	0.03	-0.03
IJI	61.55	63.03	63.60	1.48	0.57
MPI	690.56	470.44	478.58	-220.12	8.14
MNN (meters)	207.63	297.67	323.93	90.04	26.26

Table 4.21 Assessment of disturbed forest landscape metrics in SBR core zone during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	**2002**	**2010**	**1980-2002**	**2002-2010**
NP	19.00	6.00	7.00	-13.00	1.00
TE (meters)	40,920.00	9,780.00	12,030.00	-31,140.00	2,250.00
ED (m/m²)	7.15	1.71	2.10	-5.44	0.39
MSI	1.64	1.67	1.68	0.03	0.01
MPFD	1.09	1.10	1.09	0.01	-0.01
TCA (hectares)	239.56	33.77	41.40	-205.79	7.63
MCA (hectares)	12.61	4.22	4.60	-8.39	0.38
TCAI	84.85	76.90	76.54	-7.95	-0.36
CAD (hectares)	0.33	0.14	0.16	-0.19	0.02
IJI	12.62	73.49	63.65	60.87	-9.84
MPI	10.42	3.81	14.58	-6.61	10.77
MNN (meters)	463.48	720.79	379.25	257.31	-341.54

Table 4.22 Assessment of disturbed forest landscape metrics in SBR buffer zone during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	**2002**	**2010**	**1980-2002**	**2002-2010**
NP	35.00	31.00	29.00	-4.00	-2.00
TE (meters)	222,690.00	66,630.00	54,150.00	-156,060.00	-12,480.00
ED (m/m²)	20.92	6.39	5.21	-14.53	-1.18
MSI	1.92	1.77	1.73	-0.15	-0.04
MPFD	1.10	1.10	1.10	0.00	0.00
TCA (hectares)	2,389.73	247.90	178.24	-2,141.83	-69.66
MCA (hectares)	66.38	6.36	5.40	-60.02	-0.96
TCAI	91.09	78.08	76.07	-13.01	-2.01
CAD (hectares)	0.34	0.37	0.32	0.03	-0.05
IJI	28.17	67.91	54.60	39.74	-13.31
MPI	704.85	34.24	31.54	-670.61	-2.70
MNN (meters)	339.25	703.09	755.98	363.84	52.89

Table 4.23 Assessment of disturbed forest landscape metrics in SBR transition zone during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	**2002**	**2010**	**1980-2002**	**2002-2010**
NP	430.00	389.00	380.00	-41.00	-9.00
TE (meters)	1,590,060.00	1,255,080.00	1,131,560.00	-334,980.00	-123,520.00
ED (m/m²)	20.28	17.75	16.41	-2.53	-1.34
MSI	1.97	2.04	2.02	0.07	-0.02
MPFD	1.11	1.11	1.11	0.00	0.00
TCA (hectares)	12,118.48	5,586.20	4,711.28	-6,532.28	-874.92
MCA (hectares)	17.61	7.82	6.85	-9.79	-0.97
TCAI	87.96	76.79	75.68	-11.17	-1.11
CAD (hectares)	0.88	1.01	1.00	0.13	-0.01
IJI	32.59	41.77	40.40	9.18	-1.37
MPI	587.72	295.78	317.61	-291.94	21.83
MNN (meters)	214.33	282.50	294.54	68.17	12.04

4.3.3 Forest plantation landscape pattern analysis in SBR

The results of 12 indices interpretation for forest plantation landscape pattern measurement in 1980, 2002 and 2010 were summarized as an overview in Table 4.24 and in each management zones in Table 4.25 to Table 4.27. Qualitative and quantitative explanations for ecological measurement were separately described for each management zones.

Core Zone; For area, density and edge ecological measurement, it was found that number of patch, total edge and edge density of forest plantation were increasing during 1980 to 2010. In the case of forest plantation, it indicated that forest plantation landscape gain amount of its area. At the same time, for shape complexity measurement, it revealed that shape complexity of forest plantation was less complex, since the value of MSI was decreased from 1980 to 2010. However, value of MPFD was rather stable. Meanwhile, value of core area indices (TCA, MCA, TCAI and CAD) had very slightly changed in three different years. These implied that core area of forest plantation was rather increased and decreased during this 30 years period. At the same time, for interspersion and isolation measurement, forest plantation was rather aggregate to each other. However, the value of MPI and MNN had shown the fluctuation trend from year 1980 to 2010.

Buffer Zone; For area, density and edge ecological measurement, it was found that number of patch, total edge and edge density of forest plantation showed decreased in number of patch and increased in TE and ED. These implied that forest plantation became more aggregated in the buffer zone. Likewise, for shape complexity measurement (MPI and MPFD), it revealed that shape complexity of forest plantation in buffer zone was rather stable. This revealed man management in the forest plantation. Meanwhile, value of core area indices (TCA, MCA, TCAI and CAD) had slightly changed in three different years. These implied that core area of forest plantation in buffer zone was rather stable. In contrast, for interspersion and isolation measurement, forest plantation in buffer zone had some degree of dispersion. However, the value of MPI had shown the trend of increasing from 1980 to 2010.

Transition Zone; For area, density and edge ecological measurement, it was found that number of patch, total edge and edge density of forest plantation had some changed in transition zone during 1980 to 2010. Number of patch was decreased from 1980 to 2010. This implied that less fragmentation and compactness occurred in forest plantation landscape. At the same time, TE and ED had slightly increased from 1980 to 2010. For shape complexity measurement, it revealed that shape complexity of forest plantation in transition zone was rather stable, value of MSI and MPFD were rather stable from 1980 to 2010. Similarly, values of core area indices (TCA, MCA, TCAI and CAD) had slightly changed in three different years. These implied that core area of forest plantation in transition zone was rather stable. Meanwhile, the value of interspersion and isolation measurement (IJI, MPI and MNN) showed the trend in even distribution for forest plantation in transition zone, especially IJI value. Decreasing of MPI value from 1980 to 2010 was indicated isolation of forest plantation landscape.

Table 4.24 Assessment of forest plantation landscapes metrics change in SBR during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	2002	2010	1980-2002	2002-2010
NP	115.00	94.00	91.00	-21.00	-3.00
TE (meters)	324,780.00	594,810.00	512,010.00	270,030.00	-82,800.00
ED (m/m²)	1.99	3.64	3.14	1.65	-0.50
MSI	1.74	2.00	1.89	0.26	-0.11
MPFD	1.09	1.10	1.09	0.01	-0.01
TCA (hectares)	2,274.73	6,127.56	5,513.29	3,852.83	-614.27
MCA (hectares)	18.96	47.14	47.94	28.18	0.80
TCAI	86.80	90.64	91.00	3.84	0.36
CAD (hectares)	0.07	0.08	0.07	0.01	-0.01
IJI	60.74	60.21	62.13	-0.53	1.92
MPI	576.30	534.29	481.64	-42.01	-52.65
MNN (meters)	582.57	555.65	560.59	-26.92	4.94

Table 4.25 Assessment of forest plantation landscape metrics in SBR core zone during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	2002	2010	1980-2002	2002-2010
NP	4.00	14.00	11.00	10.00	-3.00
TE (meters)	18,360.00	29,880.00	20,820.00	11,520.00	-9,060.00
ED (m/m²)	3.21	5.23	3.64	2.02	-1.59
MSI	2.42	1.71	1.59	-0.71	-0.12
MPFD	1.14	1.09	1.08	-0.05	-0.01
TCA (hectares)	68.87	131.87	84.47	63.00	-47.40
MCA (hectares)	11.48	8.24	6.50	-3.24	-1.74
TCAI	77.95	80.59	79.48	2.64	-1.11
CAD (hectares)	0.10	0.28	0.23	0.18	-0.05
IJI	20.47	45.65	48.72	25.18	3.07
MPI	0.58	6.70	3.12	6.12	-3.58
MNN (meters)	172.45	202.98	450.65	30.53	247.67

Table 4.26 Assessment of forest plantation landscape metrics in SBR buffer zone during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	**2002**	**2010**	**1980-2002**	**2002-2010**
NP	16.00	14.00	10.00	-2.00	-4.00
TE (meters)	33,900.00	124,920.00	110,880.00	91,020.00	-14,040.00
ED (m/m^2)	3.19	11.97	10.68	8.78	-1.29
MSI	1.71	1.97	2.13	0.26	0.16
MPFD	1.10	1.09	1.10	-0.01	0.01
TCA (hectares)	243.63	1,810.30	1,691.01	1,566.67	-119.29
MCA (hectares)	20.30	120.69	130.08	100.39	9.39
TCAI	87.36	93.14	93.41	5.78	0.27
CAD (hectares)	0.11	0.14	0.13	0.03	-0.01
IJI	93.42	47.17	32.02	-46.25	-15.15
MPI	13.42	1,455.46	91.72	1,442.04	-1,363.74
MNN (meters)	405.21	131.51	383.05	-273.70	251.54

Table 4.27 Assessment of forest plantation landscape metrics in SBR transition zone during 1980 to 2010.

Landscape Metrics (unit)	Year			Change	
	1980	**2002**	**2010**	**1980-2002**	**2002-2010**
NP	100.00	85.00	85.00	-15.00	0.00
TE (meters)	279,840.00	461,120.00	393,160.00	181,280.00	-67,960.00
ED (m/m^2)	3.57	6.52	5.70	2.95	-0.82
MSI	1.72	1.94	1.83	0.22	-0.11
MPFD	1.09	1.10	1.09	0.01	-0.01
TCA (hectares)	1,955.84	4,008.28	3,592.96	2,052.44	-415.32
MCA (hectares)	18.28	32.59	33.27	14.31	0.68
TCAI	86.79	86.11	86.71	-0.68	0.60
CAD (hectares)	0.14	0.17	0.16	0.03	-0.01
IJI	79.52	69.52	70.88	-10.00	1.36
MPI	658.68	279.79	323.67	-378.89	43.88
MNN (meters)	608.09	654.78	627.40	46.69	-27.38

In addition, comparisons of 12 landscape metrics value in each management zone were presented in Figure 4.30 to Figure 4.41. The character of each landscape indices represents ecological meaning as detailed describe in previous section. For example, number of patch in core zone in three different years was stable when compare to buffer and transition zone as presented in Figure 4.30. This result implies that fragmentation of forest occurs in core zone less than buffer and transition zones.

Furthermore, trend of change (increase or decrease) in landscape indices for each SBR management zones in Table 4.17 to Table 4.19 (Natural forest landscape), Table 4.21 to Table 4.23 (Disturbed forest landscape), and Table 4.25 to Table 4.27 (Forest plantation landscape) were further used for forest restoration and management plan recommendation and were described in detail in the next section.

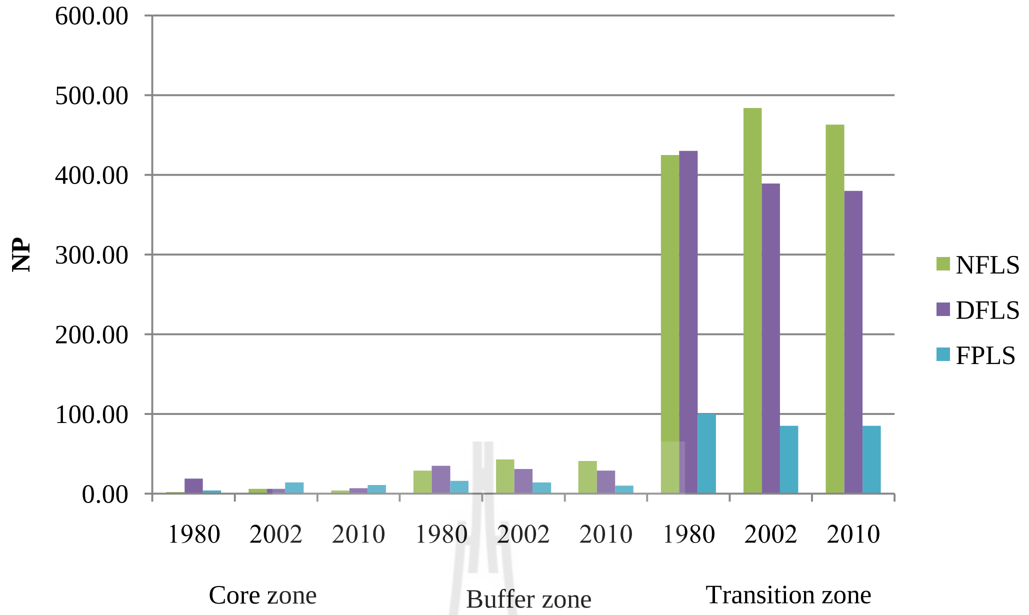


Figure 4.30 Comparison of Number of Patch (NP) of forest landscape types in SBR management zones in 1980, 2002, and 2010.

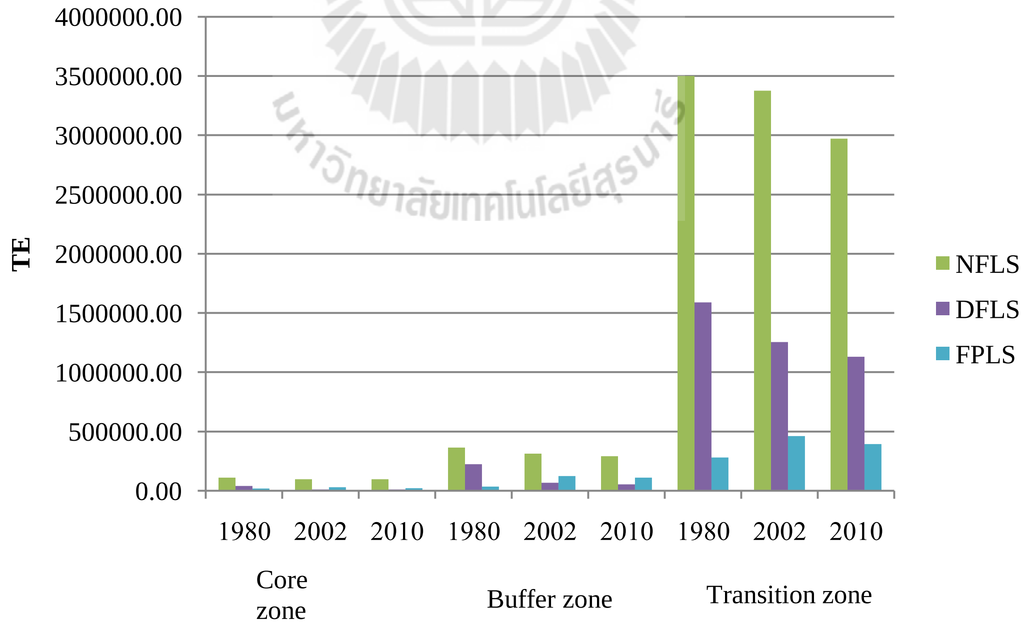


Figure 4.31 Comparison of Total Edge (TE) of forest landscape types in SBR management zones in 1980, 2002, and 2010.

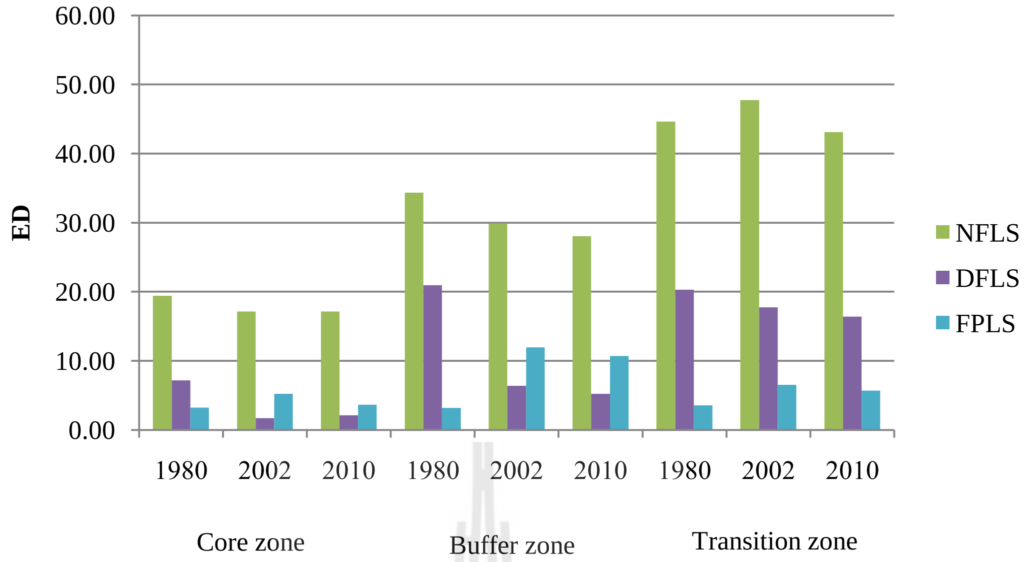


Figure 4.32 Comparison of Edge Density (ED) of forest landscape types in SBR management zones in 1980, 2002, and 2010.

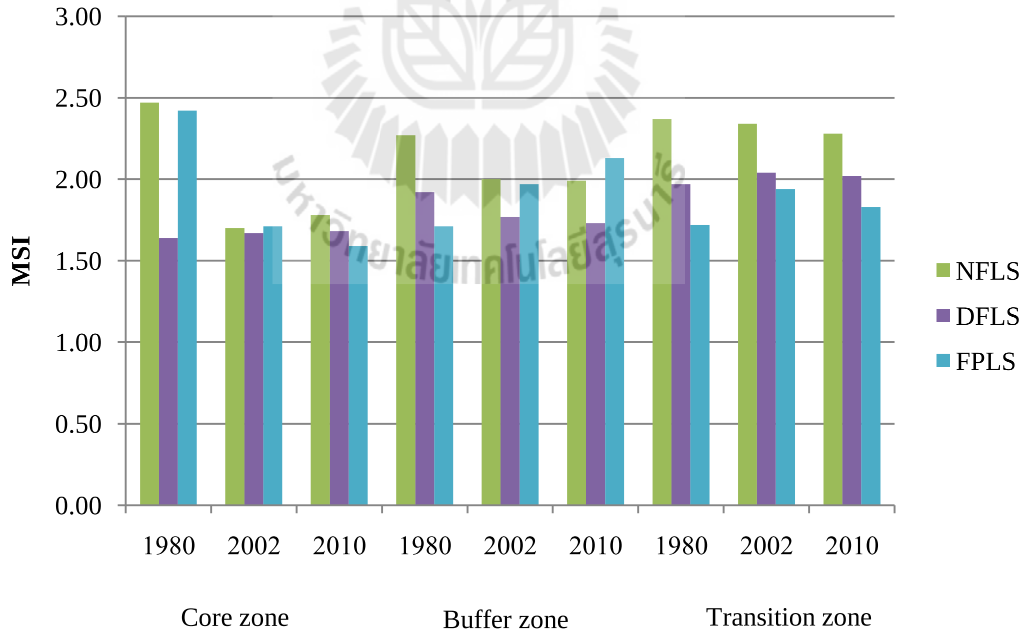


Figure 4.33 Comparison of Mean Shape Index (MSI) of forest landscape types in SBR management zones in 1980, 2002, and 2010.

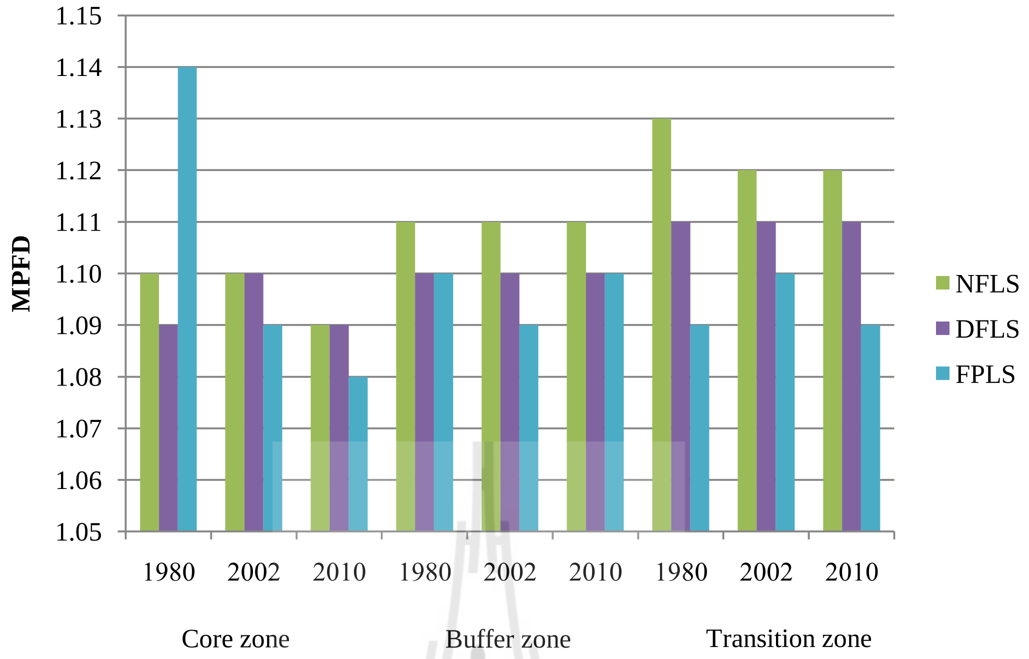


Figure 4.34 Comparison of Mean Patch Fractal Dimension (MPFD of forest landscape types in SBR management zones in 1980, 2002, and 2010.

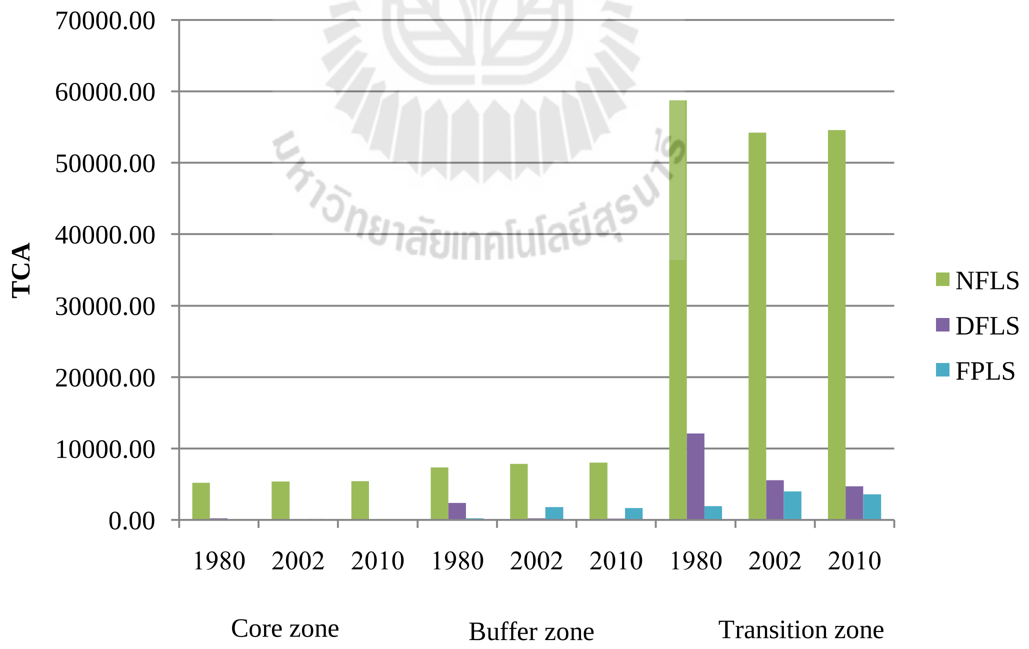


Figure 4.35 Comparison of Total Core Area (TCA) of forest landscape types in SBR management zones in 1980, 2002, and 2010.

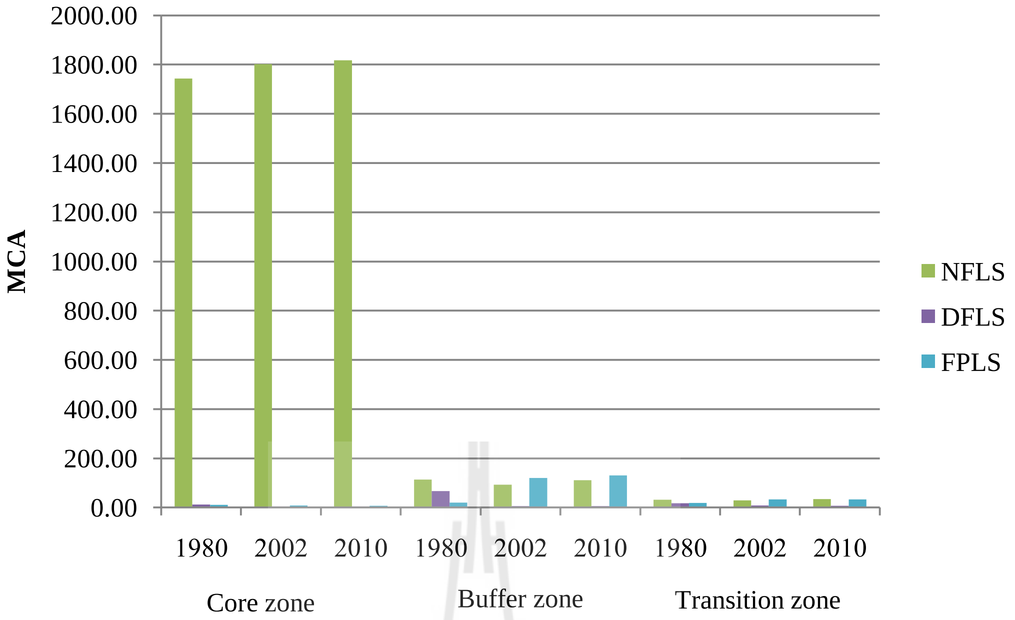


Figure 4.36 Comparison of Mean Core Area (MCA) of forest landscape types in SBR management zones in 1980, 2002, and 2010.

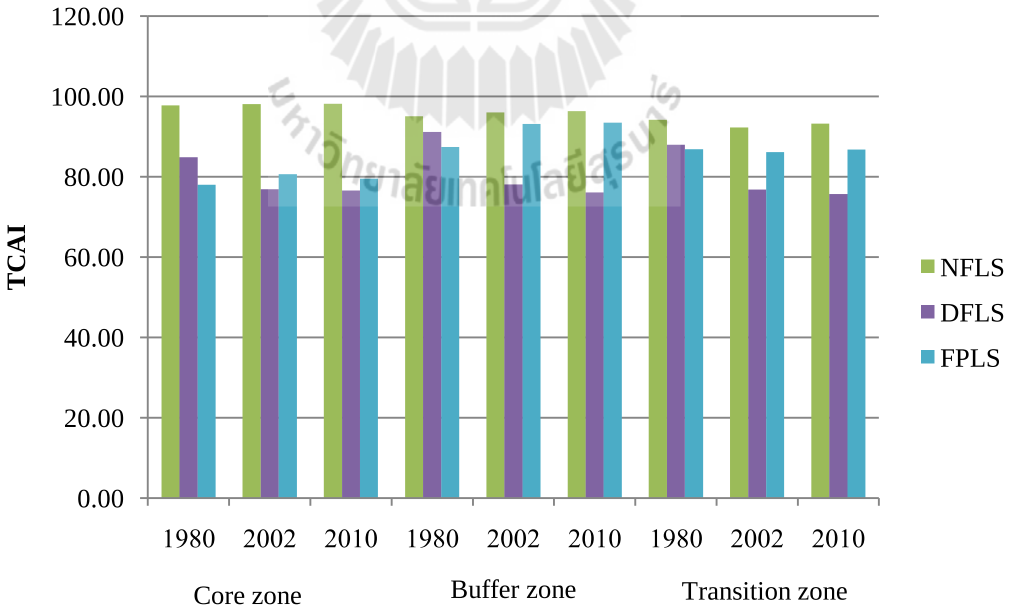


Figure 4.37 Comparison of Total Core Area Index (TCAI) of forest landscape types in SBR management zones in 1980, 2002, and 2010.

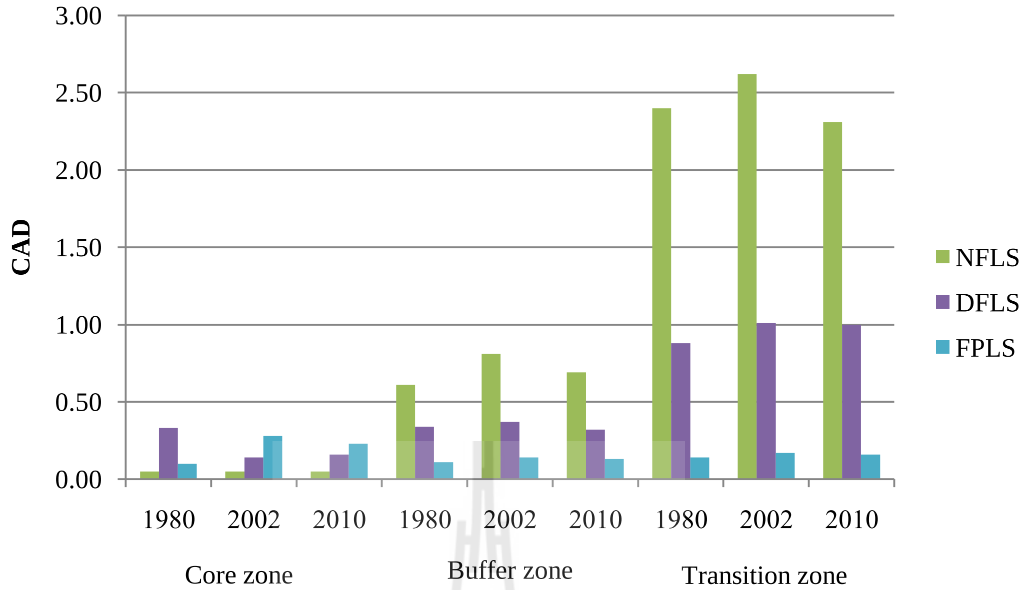


Figure 4.38 Comparison of Core Area Density (CAD) of forest landscape types in SBR management zones in 1980, 2002, and 2010.

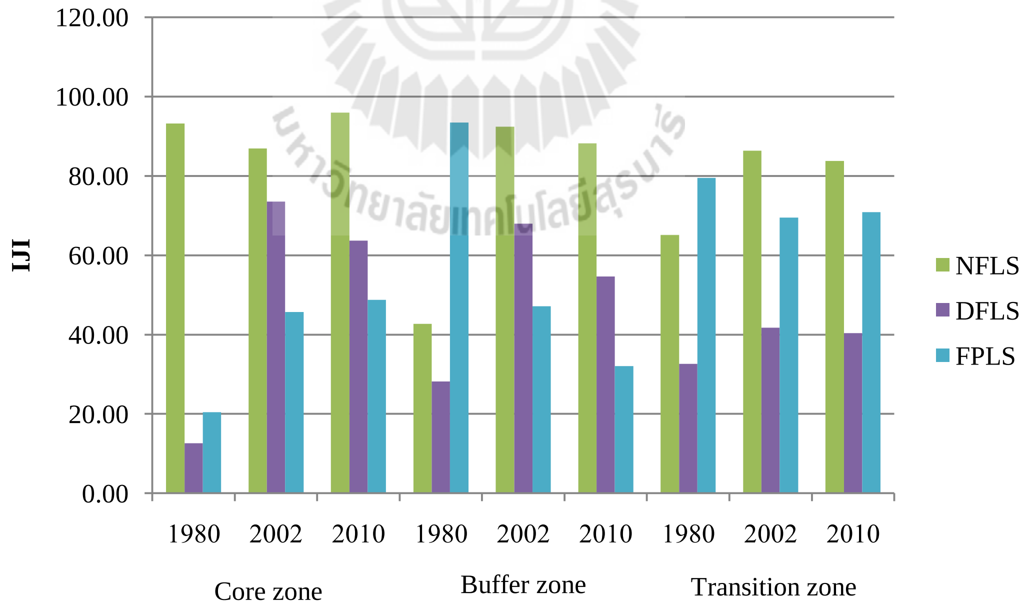


Figure 4.39 Comparison of Interspersion Juxtaposition Index (IJI) of forest landscape types in SBR management zones in 1980, 2002, and 2010.

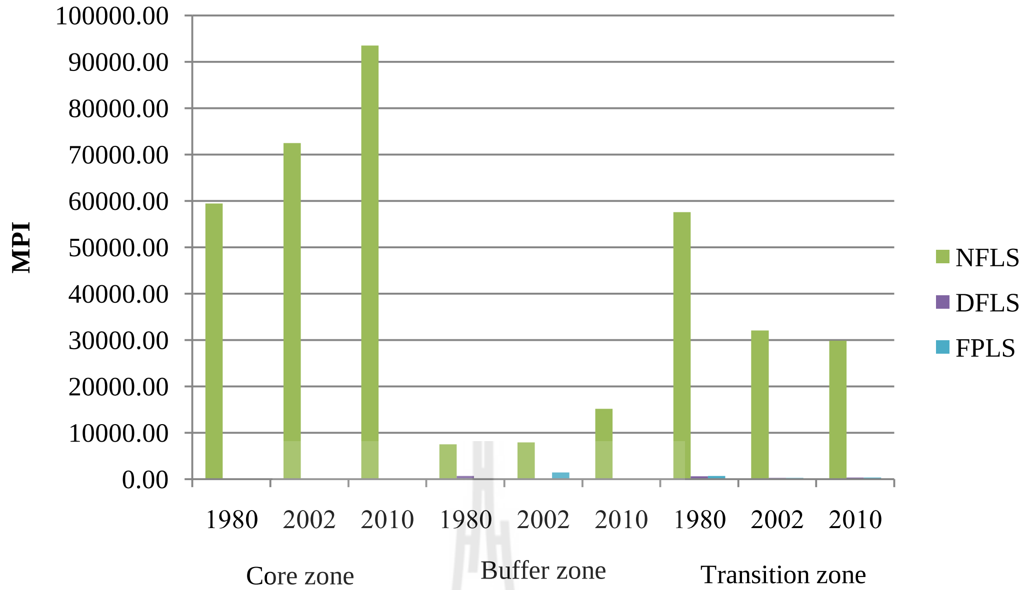


Figure 4.40 Comparison of Mean Proximity Index (MPI) of forest landscape types in SBR management zones in 1980, 2002, and 2010.

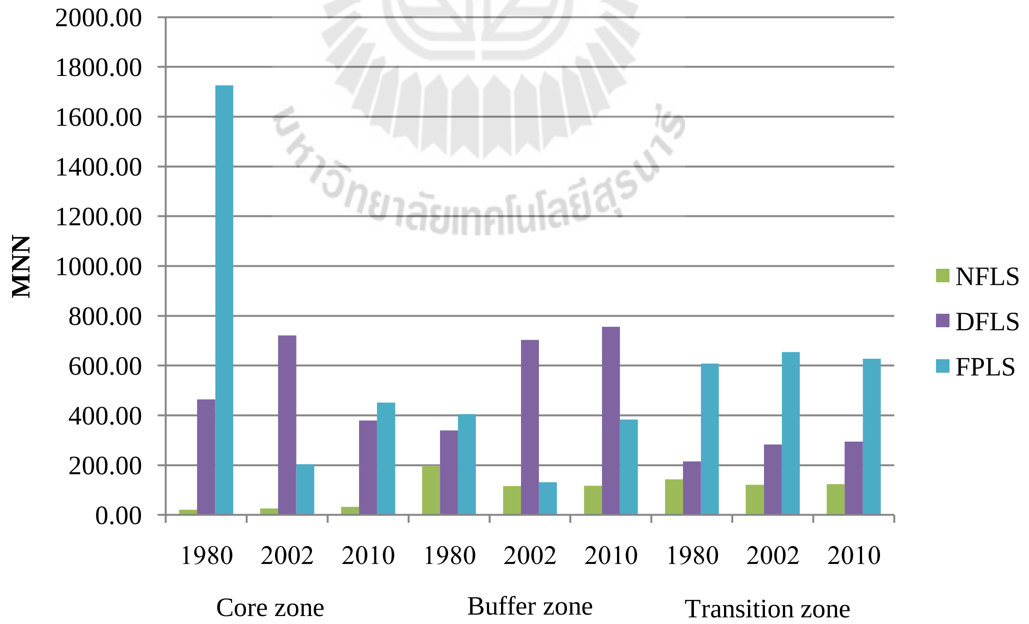


Figure 4.41 Comparison of Mean Nearest Neighbor (MNN) of forest landscape types in SBR management zones in 1980, 2002, and 2010.

4.4 Recommendation for forest restoration and management plan in SBR

Landscape ecology has been applied to many planning issues because of the relevance of the results to the planning process. As the remaining natural areas of our country continue to disappear, it is increasingly important to protect representative examples that have the capacity to retain their typical biological diversity in the long run. Diversity of landscapes that we observed today on the different regions has been developed and changed by many human activities and their environmental factors interactions. The negative impacts of diversity changed occur much more, thus the biological, ecological and cultural diversity of the total landscape must be protected, conserved and if necessary, to be restored in order to sustained the landscapes original integrity.

According to trend of change (increase or decrease) in landscape indices for each SBR management zones in Table 4.17 to Table 4.19 (Natural forest landscape), Table 4.21 to table 4.23 (Disturbed forest landscape), and Table 4.25 to Table 4.27 (Forest plantation landscape), gain and loss in forest ecology aspects were interpreted and set up the priority level for forest restoration and management plans as shown next in Table 4.28 to Table 4.36.

Table 4.28 Interpretation trend of change for priority set up of natural forest landscape in SBR core zone.

Landscape Metrics (unit)	Change		Forest ecology Aspect		Priority
	1980-2002	2002-2010	1980-2002	2002-2010	
NP	4	-2	Loss	Gain	**Moderate**
TE (meters)	-13,110	30	Gain	Loss	**High**
ED (m/m²)	-2.28	0.01	Gain	Loss	**High**
MSI	-0.77	0.08	Loss	Gain	**Moderate**
MPFD	0	-0.01	Gain	Loss	**High**
TCA (hectares)	173.61	47.32	Gain	Gain	**Low**
MCA (hectares)	57.87	15.77	Gain	Gain	**Low**
TCAI	0.33	0.02	Gain	Gain	**Low**
CAD (hectares)	0	0	Gain	Gain	**Low**
IJI	-6.3	9.05	Loss	Gain	**Moderate**
MPI	13,009.89	21,005.05	Loss	Loss	**Urgent**
MNN (meters)	5.07	5.64	Loss	Loss	**Urgent**

Table 4.29 Interpretation trend of change for priority set up of natural forest landscape in SBR buffer zone**.**

Landscape Metrics (unit)	Change		Forest ecology Aspect		Priority
	1980-2002	2002-2010	1980-2002	2002-2010	
NP	14	-2	Loss	Gain	**Moderate**
TE (meters)	-53,400	-20,610	Gain	Gain	**Low**
ED (m/m²)	-4.43	-1.85	Gain	Gain	**Low**
MSI	-0.27	-0.01	Loss	Loss	**Urgent**
MPFD	0	0	Gain	Gain	**Low**
TCA (hectares)	488.82	189.76	Gain	Gain	**Low**
MCA (hectares)	-20.88	19.3	Loss	Gain	**Moderate**
TCAI	0.98	0.33	Gain	Gain	**Low**
CAD (hectares)	0.2	-0.12	Gain	Loss	**High**
IJI	49.7	-4.22	Gain	Loss	**High**
MPI	455.91	7,241.37	Loss	Loss	**Urgent**
MNN (meters)	-81.89	1.86	Gain	Loss	**High**

Table 4.30 Interpretation trend of change for priority set up of natural forest landscape in SBR transition zone.

Landscape Metrics (unit)	Change		Forest ecology Aspect		Priority
	1980-2002	2002-2010	1980-2002	2002-2010	
NP	59	-21	Loss	Gain	**Moderate**
TE (meters)	-123,960	-405,000	Gain	Gain	**Low**
ED (m/m^2)	3.11	-4.66	Loss	Gain	**Moderate**
MSI	-0.03	-0.06	Loss	Loss	**Urgent**
MPFD	-0.01	0	Loss	Gain	**Moderate**
TCA (hectares)	-4,487.43	349.36	Loss	Gain	**Moderate**
MCA (hectares)	-1.95	5	Loss	Gain	**Moderate**
TCAI	-1.88	0.9	Loss	Gain	**Moderate**
CAD (hectares)	0.22	-0.31	Gain	Loss	**High**
IJI	21.26	-2.61	Gain	Loss	**High**
MPI	-25,516.1	-2,256.15	Gain	Gain	**Low**
MNN (meters)	-22.68	2.85	Gain	Loss	**High**

Table 4.31 Interpretation trend of change for priority set up of disturbed forest landscape in SBR core one.

Landscape Metrics (unit)	Change		Forest ecology Aspect		Priority
	1980-2002	2002-2010	1980-2002	2002-2010	
NP	-13	1	Gain	Loss	**High**
TE (meters)	-31,140	2,250	Gain	Loss	**High**
ED (m/m^2)	-5.44	0.39	Gain	Loss	**High**
MSI	0.03	0.01	Gain	Gain	**Low**
MPFD	0.01	-0.01	Gain	Loss	**High**
TCA (hectares)	-205.79	7.63	Loss	Gain	**Moderate**
MCA (hectares)	-8.39	0.38	Loss	Gain	**Moderate**
TCAI	-7.95	-0.36	Loss	Loss	**Urgent**
CAD (hectares)	-0.19	0.02	Loss	Gain	**Moderate**
IJI	60.87	-9.84	Gain	Loss	**High**
MPI	-6.61	10.77	Gain	Loss	**High**
MNN (meters)	257.31	-341.54	Loss	Gain	**Moderate**

Table 4.32 Interpretation trend of change for priority set up of disturbed forest landscape in SBR buffer zone.

Landscape Metrics (unit)	Change		Forest ecology Aspect		Priority
	1980-2002	2002-2010	1980-2002	2002-2010	
NP	-4	-2	Gain	Gain	**Low**
TE (meters)	-156,060	-12,480	Gain	Gain	**Low**
ED (m/m²)	-14.53	-1.18	Gain	Gain	**Low**
MSI	-0.15	-0.04	Loss	Loss	**Urgent**
MPFD	0	0	Gain	Gain	**Low**
TCA (hectares)	-2,141.83	-69.66	Loss	Loss	**Urgent**
MCA (hectares)	-60.02	-0.96	Loss	Loss	**Urgent**
TCAI	-13.01	-2.01	Loss	Loss	**Urgent**
CAD (hectares)	0.03	-0.05	Gain	Loss	**High**
IJI	39.74	-13.31	Gain	Loss	**High**
MPI	-670.61	-2.7	Gain	Gain	**Low**
MNN (meters)	363.84	52.89	Loss	Loss	**Urgent**

Table 4.33 Interpretation trend of change for priority set up of disturbed forest landscape in SBR transition zone.

Landscape Metrics (unit)	Change		Forest ecology Aspect		Priority
	1980-2002	2002-2010	1980-2002	2002-2010	
NP	-41	-9	Gain	Gain	**Low**
TE (meters)	-334,980	-123,520	Gain	Gain	**Low**
ED (m/m²)	-2.53	-1.34	Gain	Gain	**Low**
MSI	0.07	-0.02	Gain	Loss	**High**
MPFD	0	0	Gain	Gain	**Low**
TCA (hectares)	-6,532.28	-874.92	Loss	Loss	**Urgent**
MCA (hectares)	-9.79	-0.97	Loss	Loss	**Urgent**
TCAI	-11.17	-1.11	Loss	Loss	**Urgent**
CAD (hectares)	0.13	-0.01	Gain	Loss	**High**
IJI	9.18	-1.37	Gain	Loss	**High**
MPI	-291.94	21.83	Gain	Loss	**High**
MNN (meters)	68.17	12.04	Loss	Loss	**Urgent**

Table 4.34 Interpretation trend of change for priority set up of forest plantation landscape in SBR core zone.

Landscape Metrics (unit)	Change		Forest ecology Aspect		Priority
	1980-2002	2002-2010	1980-2002	2002-2010	
NP	10	-3	Loss	Gain	**Moderate**
TE (meters)	11,520	-9,060	Loss	Gain	**Moderate**
ED (m/m²)	2.02	-1.59	Loss	Gain	**Moderate**
MSI	-0.71	-0.12	Loss	Loss	**Urgent**
MPFD	-0.05	-0.01	Loss	Loss	**Urgent**
TCA (hectares)	63	-47.4	Gain	Loss	**High**
MCA (hectares)	-3.24	-1.74	Loss	Loss	**Urgent**
TCAI	2.64	-1.11	Gain	Loss	**High**
CAD (hectares)	0.18	-0.05	Gain	Loss	**High**
IJI	25.18	3.07	Gain	Gain	**Low**
MPI	6.12	-3.58	Loss	Gain	**Moderate**
MNN (meters)	30.53	247.67	Loss	Loss	**Urgent**

Table 4.35 Interpretation trend of change for priority set up of forest plantation landscape in SBR buffer zone.

Landscape Metrics (unit)	Change		Forest ecology Aspect		Priority
	1980-2002	2002-2010	1980-2002	2002-2010	
NP	-2	-4	Gain	Gain	**Low**
TE (meters)	91,020	-14,040	Loss	Gain	**Moderate**
ED (m/m²)	8.78	-1.29	Loss	Gain	**Moderate**
MSI	0.26	0.16	Gain	Gain	**Low**
MPFD	-0.01	0.01	Loss	Gain	**Moderate**
TCA (hectares)	1,566.67	-119.29	Gain	Loss	**High**
MCA (hectares)	100.39	9.39	Gain	Gain	**Low**
TCAI	5.78	0.27	Gain	Gain	**Low**
CAD (hectares)	0.03	-0.01	Gain	Loss	**High**
IJI	-46.25	-15.15	Loss	Loss	**Urgent**
MPI	1,442.04	-1,363.74	Loss	Gain	**Moderate**
MNN (meters)	-273.7	251.54	Gain	Loss	**High**

Table 4.36 Interpretation trend of change for priority set up of forest plantation landscape in SBR transition zone.

Landscape Metrics (unit)	**Change**		**Forest ecology Aspect**		**Priority**
	1980-2002	**2002-2010**	**1980-2002**	**2002-2010**	
NP	-15	0	Gain	Loss	**High**
TE (meters)	181,280	-67,960	Loss	Gain	**Moderate**
ED (m/m²)	2.95	-0.82	Loss	Gain	**Moderate**
MSI	0.22	-0.11	Gain	Loss	**High**
MPFD	0.01	-0.01	Gain	Loss	**High**
TCA (hectares)	2,052.44	-415.32	Gain	Loss	**High**
MCA (hectares)	14.31	0.68	Gain	Gain	**Low**
TCAI	-0.68	0.6	Loss	Gain	**Moderate**
CAD (hectares)	0.03	-0.01	Gain	Loss	**High**
IJI	-10	1.36	Loss	Gain	**Moderate**
MPI	-378.89	43.88	Gain	Loss	**High**
MNN (meters)	46.69	-27.38	Loss	Gain	**Moderate**

The possibility for gain and loss of ecological meaning for each selected landscape metric and theirs priority for forest restoration and management plan were shown in Table 3.6. In the study, the priority for forest restoration and management plan will be assigned to be score value as follows:

- Urgent priority equals to 7;
- High priority equals to 5;
- Moderate priority equals to 3;
- Low priority equals to 1.

The score value was then applied for each landscape metrics to identify the final priority level for forest restoration and management plan in each forest landscape types: natural forest (F1), disturbed forest (F2) and forest plantation (F3) by mean of scoring method. Herein, Simple Additive Weighting (SAW) method with equally weight was used for calculate overall score of priority class identification. Overall score (12 to 84) then be equally divided into 4 levels with equally level interval as follows:

(1) 12.0-30.0 Low priority for forest restoration and management plan;

(2) 30.0-48.0 Moderate priority for forest restoration and management plan;

(3) 48.0-66.0 High priority for forest restoration and management plan;

(4) 66.0-84.0 Urgent priority for forest restoration and management plan.

The derived priority level for forest restoration and management plan in each management zone were summarized in Table 4.37 to Table 4.39. Details of recommendation for forest restoration and management plan in each management zone were further explained as following.

Table 4.37 Priority level of natural forest landscape in each management zones.

Metrics	Natural Forest Landscape								
	Core Zone			Buffer Zone			Transition Zone		
	Priority	Score	Weight	Priority	Score	Weight	Priority	Score	Weight
NP	**Moderate**	3	1	**Moderate**	3	1	**Moderate**	3	1
TE	**High**	5	1	**Low**	1	1	**Low**	1	1
ED	**High**	5	1	**Low**	1	1	**Moderate**	3	1
MSI	**Moderate**	3	1	**Urgent**	7	1	**Urgent**	7	1
MPFD	**High**	5	1	**Low**	1	1	**Moderate**	3	1
TCA	**Low**	1	1	**Low**	1	1	**Moderate**	3	1
MCA	**Low**	1	1	**Moderate**	3	1	**Moderate**	3	1
TCAI	**Low**	1	1	**Low**	1	1	**Moderate**	3	1
CAD	**Low**	1	1	**High**	5	1	**High**	5	1
IJI	**Moderate**	3	1	**High**	5	1	**High**	5	1
MPI	**Urgent**	7	1	**Urgent**	7	1	**Low**	1	1
MNN	**Urgent**	7	1	**High**	5	1	**High**	5	1
Overall score	**42**			**40**			**42**		
Priority level	**Moderate**			**Moderate**			**Moderate**		

Table 4.38 Priority level of disturbed forest landscape in each management zones.

Metrics	Disturbed Forest Landscape								
	Core Zone			Buffer Zone			Transition Zone		
	Priority	Score	Weight	Priority	Score	Weight	Priority	Score	Weight
NP	**High**	5	1	**Low**	1	1	**Low**	1	1
TE	**High**	5	1	**Low**	1	1	**Low**	1	1
ED	**High**	5	1	**Low**	1	1	**Low**	1	1
MSI	**low**	1	1	**Urgent**	7	1	**High**	5	1
MPFD	**High**	5	1	**Low**	1	1	**Low**	1	1
TCA	**Moderate**	3	1	**Urgent**	7	1	**Urgent**	7	1
MCA	**Moderate**	3	1	**Urgent**	7	1	**Urgent**	7	1
TCAI	**Urgent**	7	1	**Urgent**	7	1	**Urgent**	7	1
CAD	**Moderate**	3	1	**High**	5	1	**High**	5	1
IJI	**High**	5	1	**High**	5	1	**High**	5	1
MPI	**High**	5	1	**Low**	1	1	**High**	5	1
MNN	**Moderate**	3	1	**Urgent**	7	1	**Urgent**	7	1
Overall score		**50**			**50**			**52**	
Priority level		**High**			**High**			**High**	

Table 4.39 Priority level of forest plantation landscape in each management zones.

Metrics	Forest Plantation Landscape								
	Core Zone			Buffer Zone			Transition Zone		
	Priority	Score	Weight	Priority	Score	Weight	Priority	Score	Weight
NP	**Moderate**	3	1	**Low**	1	1	**High**	5	1
TE	**Moderate**	3	1	**Moderate**	3	1	**Moderate**	3	1
ED	**Moderate**	3	1	**Moderate**	3	1	**Moderate**	3	1
MSI	**Urgent**	7	1	**Low**	1	1	**High**	5	1
MPFD	**Urgent**	7	1	**Moderate**	3	1	**High**	5	1
TCA	**High**	5	1	**High**	5	1	**High**	5	1
MCA	**Urgent**	7	1	**Low**	1	1	**Low**	1	1
TCAI	**High**	5	1	**Low**	1	1	**Moderate**	3	1
CAD	**High**	5	1	**High**	5	1	**High**	5	1
IJI	**Low**	1	1	**Urgent**	7	1	**Moderate**	3	1
MPI	**Moderate**	3	1	**Moderate**	3	1	**High**	5	1
MNN	**Urgent**	7	1	**High**	5	1	**Moderate**	3	1
Overall score		**56**			**38**			**46**	
Priority level		**High**		**Moderate**				**High**	

As SBR is a biosphere reserve area contains three different management zones, activities are limited by the purposes of biosphere reserve establishment. Therefore, action plans for restoration or management methods have to take those of the main purposes of the biosphere reserve into account seriously. Consequently, any implement action plans that would be accomplished in the area need carefully consideration and well decision making were presented in Table 4.40 to Table 4.42.

Table 4.40 Recommendation for restoration and management action plans for natural forest landscape.

Management Zone	Priority Level	Action Plan	
		Restoration Plan (10-20 Years)	**Management Plan (5-10 Years)**
Core zone	**Moderate**	- Minimal requirement for forest restoration /leave natural forest landscape maintain itself with natural succession - Regularly monitoring natural forest by patrolling	- Minimal requirement for forest management plan including forest patrolling and forest fire prevention programs - Regularly forest patrolling and forest fire prevention
Buffer zone	**Moderate**	- Moderate requirement for forest restoration by mean of rehabilitation - Regularly monitoring natural forest landscape by patrolling	- Moderate requirement for forest management plan including forest patrolling, forest fire prevention, rehabilitation and reforestation programs - Regularly forest patrolling and forest fire prevention
Transition zone	**Moderate**	- Moderate requirement for forest restoration in government land by reforestation - Regularly forest patrolling and forest fire prevention especially for large patch of natural forest landscape	- High requirement for forest management plan including forest patrolling, forest fire prevention and reforestation programs - Regularly forest patrolling and forest fire prevention especially for large patch of natural forest landscape

Table 4.41 Recommendation for restoration and management action plans for disturbed forest landscape.

Management Zone	Priority Level	Action Plan	
		Restoration Plan (10-20 Years)	**Management Plan (5-10 Years)**
Core zone	**High**	- Minimal requirement for restoration /leave disturbed forest landscape restoring by natural regeneration	- Minimal requirement for disturbed forest management plan including forest rehabilitation and forest fire controlling programs - Regularly forest fire controlling in disturbed forest landscape
Buffer zone	**High**	- Moderate requirement for disturbed forest restoration by mean of rehabilitation and reforestation - Regularly forest fire controlling in disturbed forest landscape	- High requirement for disturbed forest management plan including forest fire prevention, rehabilitation and reforestation programs - Regularly forest fire prevention in disturbed forest landscape
Transition zone	**High**	- Moderate requirement for disturbed forest restoration in government land by reforestation - Regularly forest fire controlling especially for large patch of disturbed forest landscape	- Moderate requirement for disturbed forest management plan including forest fire prevention and reforestation programs - Regularly forest fire prevention especially for large patch of disturbed forest landscape in government land

Table 4.42 Recommendation for restoration and management action plans for forest plantation landscape.

Management Zone	Priority Level	Action Plan	
		Restoration Plan (10-20 Years)	**Management Plan (5-10 Years)**
Core zone	**High**	- Minimal requirement for forest plantation restoration /leave forest plantation to grow naturally - Regularly monitoring forest plantation landscape by patrolling	- Minimal requirement for forest plantation management plan including forest patrolling and forest fire prevention programs - Regularly forest patrolling and forest fire prevention in forest plantation landscape
Buffer zone	**Moderate**	- Moderate requirement for forest plantation restoration by mean of tree enrichment - Regularly monitoring forest plantation landscape by patrolling	- Moderate requirement for forest plantation management plan including forest patrolling, forest fire prevention, tree enrichment programs - Regularly forest patrolling and forest fire prevention in forest plantation landscape
Transition zone	**High**	- High requirement for forest plantation restoration by reforestation in government land - Regularly forest patrolling and forest fire prevention especially for large patch of government's forest plantation landscape	- Moderate requirement for forest plantation management plan including forest patrolling, forest fire prevention and reforestation programs - Regularly forest patrolling and forest fire prevention especially for large patch of government's forest plantation landscape

According to need of forest landscape restoration and management recognized throughout the world regions as a component of sustainable forest management plan. Thus forest landscape restoration in SBR management zones will follow typical restoration and management concepts. As management means taking care and improving of what's already there and try to encourage the continued growth and enhancement of natural communities already in that site. Management can also be considered a form of restoration as well. Meanwhile, restoration represents a more intensive effort. It is a process of returning a degraded natural community to its original structure and species composition.

Additionally, more recently research has suggested that landscape pattern indices are effectively evaluate tools for planning and design. Botequilha Leitao and Ahern (2002) suggest recommendations for the use of landscape pattern indices in sustainable landscape planning, for example, using indices at several phases of planning and design, using the core set of indices that have been suggested through precious research, using indices for comparative purposes, relying upon more than one index from the core set of indices to clarify information about ecological processes and using indices to provide useful direction for planning and design. Concurrently, Corry and Nassauer (2005) also review that landscape pattern have two potentially attractive attributes for planners and designers that are firstly, they are relatively efficient tools that can be applied quickly to several different alternative plans and secondly, they are accessible tool, easily acquired, fully documented, and applicable to digital data representing alternative plans and designs.

Refer to recommendation for restoration and management plans for forest landscapes in each management zones of SBR, discussions were here in details.

4.4.1 Recommendation for restoration and management plans for natural forest landscape

For natural forest landscape in core, buffer and transition zone revealed moderate priority level in all management zones. Thus suggested recommendation for restoration and management plans should be;

(1) In core zone, in which greatly restrict to any impact activity and highly protected for conservation thus minimal requirement for forest restoration and management were recommended. In addition, natural forest can maintain itself by natural succession for the time being. At the same time, natural forest management including forest patrolling and forest fire prevention programs should be regularly operating in natural forest landscape core zone.

(2) In buffer zone, in which the area connected to core area and at the same time functional guarded to core area, it is also limited to only ecological friendly activities such as basic research study, nature education, recreation and ecotourism. Hence, recommendation for natural forest restoration is moderate requirement to restoration and management plan. For restoration plan, natural forest rehabilitation and regularly patrolling are recommended. For natural forest management plan, forest patrolling and forest fire prevention, rehabilitation and reforestation programs are recommended.

(3) In transition zone, the area in which contain many human activities and design to flexible for implementing variety of way to serve local need, therefore recommend restoration is moderate requirement for forest restoration in government land by reforestation and regularly forest patrolling and forest fire prevention especially for large patch of natural forest landscape. Whereas, high requirement for natural forest management plan, including forest patrolling, forest fire prevention and reforestation programs for large patch of natural forest are recommended.

4.4.2 Recommendation for restoration and management plans for disturbed forest landscape

For disturbed forest landscape; priority level in core, buffer and transition zone was high in all management zones. Thus suggested recommendation for restoration and management plans should be;

(1) In core area, minimal requirement for restoration and management plans were recommended. Restoration is leaving disturbed forest landscape restoring by natural regeneration. Concurrently, management plans were forest rehabilitation and operating regularly forest fire controlling in disturbed forest landscape.

(2) In buffer zone, recommend for moderate requirement for restoring disturbed forest by mean of rehabilitation and reforestation, and also regularly forest fire controlling. In addition, high requirement for disturbed forest management plan including forest fire prevention, rehabilitation and reforestation programs, and also operating regularly forest fire prevention were recommended in disturbed forest landscape.

(3) In transition zone, recommendation was moderate requirement for disturbed forest restoration in government land by reforestation and regularly forest fire controlling especially for large patch of disturbed forest landscape. At the same time, moderate requirement for management plan was recommended by operating forest fire prevention and reforestation programs, including regularly forest fire prevention especially for large patch of disturbed forest landscape in government land.

4.4.3 Recommendation for restoration and management plans for forest plantation landscape

For forest plantation landscape; priority level in core, buffer and transition zone was high, moderate, and high, respectively. Action plans that would recommend for restoration and management should be;

(1) In core area, since percentage of forest plantation in core area were small, then minimal requirement for forest plantation restoration are to leave forest plantation to grow naturally and regularly patrolling in forest plantation landscape. Similarly, minimal requirement for management plan which including forest patrolling and forest fire prevention were recommended in forest plantation landscape.

(2) In buffer zone, moderate requirement in restoration and management plan are recommended. For forest plantation restoration, by mean of tree enrichment and regularly patrolling in forest plantation landscape are suggested to operate. For forest plantation management plan including regularly forest patrolling, forest fire prevention, and tree enrichment programs are recommended.

(3) In transition zone, high requirement for forest plantation restoration by reforestation in government land, including regularly forest patrolling and forest fire prevention especially for large patch of government's forest plantation landscape are recommended. Whereas, moderate requirement for forest plantation management plan including reforestation programs, regularly forest patrolling, and forest fire prevention especially for large patch of government's forest plantation landscape are high recommended.

In addition, on top of obtaining recommendation for restoration and management plan in each SBR management zones, other geographical aspects of the area such as slope can be taken into account to identify hotspots or priority of attention to operate restoration and management activities. In this case, forest landscape data was superimposed over slope classes (0-35 degree and more than 35 degree), the areas with more than 35 degree slope can be highlighted as high priority area (Figure 4.42).

Refer to Figure 4.42, hotspots or high priority areas for operating recommend activities in core, buffer and transition zone can be located as shown in red. The areas that should play more attention were appeared distributing mostly along the mountain ridge. In the case of disturbed forest landscape, immediately replanting should applied to reduce soil erosion and produce more green areas.

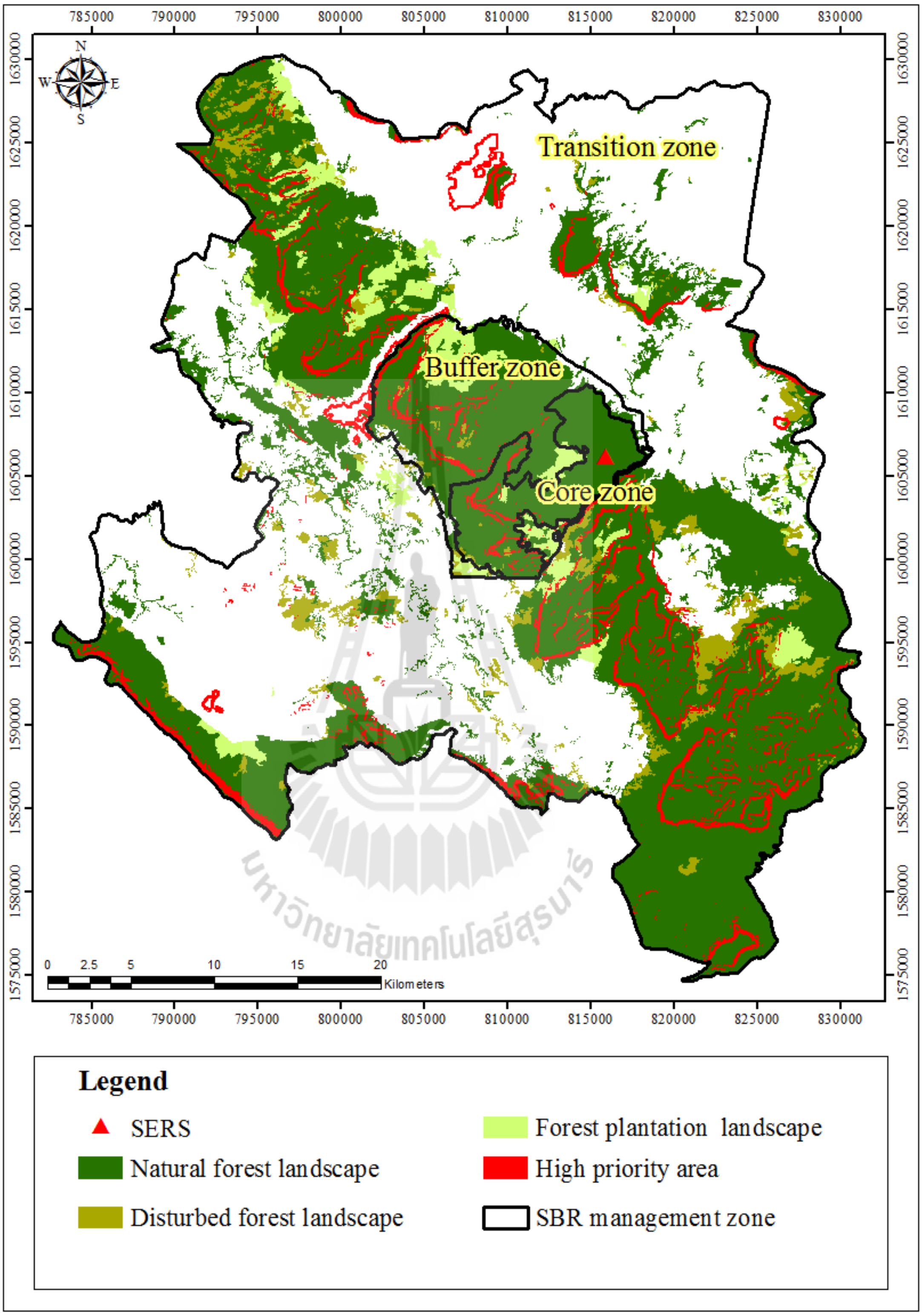


Figure 4.42 High priority areas (> 35 degree slope) for restoration and management activities in SBR management zones.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The results of the study responded to three main objectives as reported in detail in the previous chapter, including: (1) results of classification land use and land cover (LULC) of SBR and assessment of change, (2) results of landscape pattern analysis and assessment of SBR using selected landscape metrics, (3) results of forest landscape pattern analysis and assessment in SBR management zones (core, buffer ,and transition zones) using selected landscape metrics, and (4) recommendation for forest restoration and management plans in SBR.

5.1 Conclusions

5.1.1 Classification of land use and land cover (LULC) in SBR and assessment of change

During 1980 to 2010, classification of LULC in SBR showed that in 1980 natural forest, field crop, and paddy field were among the most dominant classes and occupied large areas of 46.23%, 27.79%, and 8.84% of the total area, respectively. Similarly, in 2002, the results showed that all those three classes still dominated over other classes but decreasing in their areas, by natural forest covered the area at 44.38%, and paddy field covered the area at 7.40% of the total area. Field crop was relatively stable and covered 27.83% of the area. In the year 2010, the distribution of LULC in SBR maintained the same pattern but had some degree of changed between 1980 and 2002; meanwhile, relatively change had occurred between 2002 and 2010. This fact may possibly due to the time interval of the first period was 22 years, but the second period was 8 years, so the difference between these time intervals could have affected the significance and distinctively change occurred more in the first longer time period. However, at these three different dates, the major classes that occupied the area were forest classes, including natural forest, disturbed forest, and forest plantation. Another major group was agriculture, comprised of paddy field, field crop, and orchard/tree; they were dynamic and had some change over the time period. As illustrated in the comparison of LULC change per annum between 1980 to 2002, and 2002 to 2010, the fluctuation of changes mostly occurred in forest, agriculture, and urban and built-up areas, in which natural forest maintained its stable status along the time period, meanwhile, disturbed forest exhibited to decline and reversed to forest plantation and some other land use classes. This demonstrated a good sign of gaining forest area.

Urban and built-up area was also revealed significant change from the first date, no surprisingly the more the land development the more urban and built-up expansion. This expansion occurs worldwide, the question ask is that how to control its acceleration and regulation of sprawling. Since, in this area urban expansion is one of the major problems that cause natural forest encroachments and also holding of disturbed forest area for shifting cultivation and private resort areas.

5.1.2 Analysis and assessment of landscape pattern in SBR

For analysis and assessment of SBR landscape pattern changes; SBR landscape was characterized into six landscape types, which were agricultural landscape, natural forest landscape, disturbed forest landscape, forest plantation landscape, urban and built-up landscape, and miscellaneous landscape. Distribution of SBR landscape types in 1980, 2002, and 2010 presented major changes in the disturbed forest landscape with decreasing from 10.22%, 4.69%, and 3.99% in 1980, 2002, and 2010, respectively. By contrast, forest plantation tended to increase from 1.61% to 4.14% from 1980 to 2002, and slightly drop off to 3.71% in 2010.

The urban and built-up and miscellaneous landscapes had been increasing since 1980 to 2010 with the percentages of 1.36%, 2.34%, and 2.98%; and 1.29%, 3.4%, and 3.64% in 1980, 2002, and 2010, respectively. Subsequently, natural forest and agriculture landscapes showed pattern changes during 1980 to 2002, in which forest landscape decreased but agriculture landscape increased; however, both landscapes remained nearly stable from 2002 to 2010.

Numerous landscape indices have been developed to quantify landscape structure with landscape composition and configuration. Since landscape structure information is important for managing landscape and meaningful in ecological aspects. It provides information about their arrangement, shape characteristic, distance, position, location, and so on. The collections of selected indices in which given this kind of information in this study are including:

(1) Area, density and edge metrics measurements: Number of Patch (NP), Total Edge (TE), and Edge density (ED);

(2) Shape metrics measurements: Mean Shape Index (MSI) and Mean Patch Fractal Dimension (MPFD);

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

(4) Diversity/Interspersion/Isolation metrics measurements: Shannon’s Diversity Index (SDI), Shannon’s Evenness Index (SEI), Interspersion Juxtaposition Index (IJI), Mean Proximity Index (MPI), and Mean Nearest Neighbor (MNN).

At the landscape level measurement, interpretation of indices values was concluded in four aspects.

(1) Area/density/edge metrics: interpretation of indices showed increasing of indices value tendency from 1980 to 2010, this indicated that the SBR landscape trend to be fragmented with increasing of number of patch, total edge and edge density.

(2) Shape metrics: interpretation of indices indicated that overall the shape complexity of the landscape had less complexity and become simpler than in the past.

(3) Core Area metrics: interpretation of indices showed loss of total core area from the past to 2002, after which it remained fairly stable up to 2010.

(4) Diversity/Interspersion/Isolation metrics: interpretation of indices revealed that diversity and evenness of the landscape had slightly changed. This indicated less heterogeneity of landscape, for example, agriculture landscape became monocultures in a larger proportion of the area. Additionally, in some areas of SBR, such as forest plantation landscape, it was man-made landscape so less diversity of plants species compared to the original natural forest. Besides, some disturbed forest landscapes, which may be in succession or secondary regrowth are still in younger state, moreover other environment factors may impact its seedling richness. The proximity and isolation indices showed that patches in the landscape become more isolated, but the distribution of adjacency among patch types in the landscape had

become more equally adjacent to all other patch types. This implied aggregation of some patches in the landscape.

5.1.3 Analysis and assessment of forest landscape pattern in SBR management zones (core, buffer, and transition zones)

The collections of selected indices used the same set as in SBR landscape, except for SDI and SEI. The results showed that three components of forest landscape, including natural forest, disturbed forest, and forest plantation landscapes. The distribution of these three landscapes, natural forest landscape dominated over other landscapes and maintained stable status in its area from 1980 to 2010. In contrast, disturbed forest landscape indicated significant change to increase from year 1980 to 2010, but forest plantation showed a sharp increase from 1980 to 2010.

Under the management zones of SBR, which were core, buffer, and transition zones, the major landscape type that occupied in these three zones was natural forest. The less dominant landscape in the core zone was disturbed forest. In the buffer and transition zones disturbed forest and forest plantation covered smaller areas and exhibited opposite trends of change. While disturbed forest decreased, forest plantation increased.

The interpretation of 12 indices of four aspects for each forest landscape in SBR management zones were given below,

(1) Natural forest landscape. Interpretation of indices showed that (1) in the core zone; number of patch, total edge, and edge density were slightly changed. These implied that less fragmentation occurred in the natural forest landscape. Shape complexity and core area indices showed the same trend in relatively stable condition;

(2) in the buffer zone; number of patch, total edge, and edge density were moderately increasing. These implied that some fragmentation had occurred in natural forest landscape. At the same time, shape complexity revealed rather stable; meanwhile, value of core area indices had slightly changed in three different years; and (3) in transition zone; number of patch, total edge, and edge density of natural forest were fluctuated. The shape complexity measurement revealed that the shape complexity of natural forest landscape in transition zone was rather stable, whereas the values of core area indices had slightly changed between the three different years.

(2) Disturbed forest landscape. Interpretation of indices showed that (1) in core zone; number of patch, total edge, and edge density indicated highly decreasing changes. These implied that the disturbed forest landscape became compactness and less fragmentation. Shape complexity indices were rather stable indicating no change. Core area indices had been decreasing changed in three different years implied that core area of disturbed forest landscape was dramatically lost, (2) in buffer zone; number of patch, total edge, and edge density of the disturbed forest landscape were decreasing, these implied less fragmentation. Meanwhile, the values of core area indices showed highly decreasing between the three different years. These implied that losing of core area in the disturbed forest landscape, and (3) in transition zone; number of patch, total edge, and edge density were decreasing, which implied less fragmentation and compactness. On the other hand, the values of core area indices were decreasing, which implied decreasing core area in the disturbed forest landscape.

(3) Forest plantation landscape. Interpretation of indices showed that (1) in core zone; number of patch, total edge, and edge density were increasing. In the case of forest plantation, it indicated that forest plantation landscape gained more area. The shape complexity of forest plantation landscape was less complex due to it manmade landscape. Meanwhile the value of core area indices had very slightly changed. These implied that core area of forest plantation landscape was rather increased and decreased during this period of 30 years, (2) in buffer zone; area, density, and edge indices values indicated that forest plantation landscape became more aggregated in the buffer. Shape complexity and core area indices values showed stable trend, and (3) in transition zone; interpretation of indices values indicated that forest plantation landscape had less fragmented and rather stable in core area and shape complexity. On the other hand, decreased of mean proximity index indicated isolation occurred in forest plantation landscape.

5.1.4 Recommendation for forest restoration and management plans in SBR

The objective of forest restoration and management programs in SBR is to ensure the long term health of forest ecosystems for the benefit of the local and global environments while enabling present and future generations to meet their needs. Since forest landscape provides a range of values and opportunities to the public, its management must be planned in a manner that recognizes the requirements and value of other uses. Therefore, results from the landscape metrics analysis have been used for forest restoration and management planning in SBR by which setting priority levels to urgent, high, moderate and low and identifying each SBR management zones priority level.

In relation to developing priority levels to implement restoration and management plans in SBR, the outcomes discussed previously can be concluded as:

(1) Natural forest landscape. The priority level for forest restoration and management plan in core, buffer, and transition zones of SBR was moderate. Therefore, in the core zone minimal requirements for forest restoration and management action plan are recommends. Natural forest restoring should be by natural succession and should have regular patrolling in the natural forest landscape. Meanwhile, management plans are forest patrolling and forest fire prevention. In the buffer zone, there is a moderate requirement for restoration and management plans are recommended by mean of rehabilitation, regular forest patrolling and forest fire prevention. In the transition zone, there is a moderate requirement for rehabilitation restoring and forest fire prevention. Whereas, a high requirement is seen for management plan, including reforestation program, forest patrolling and forest fire prevention.

(2) Disturbed forest landscape. The priority status for forest restoration and management plans in the core, buffer, and transition zones was high. Thus, recommendations in the core zone are a minimal requirement for restoration disturbed forest by natural regeneration and minimal requirement for management plan by forest rehabilitation and forest fire controlling. In the buffer zone, a moderate requirement is recommended for disturbed rehabilitation restoration and forest fire controlling. Whereas, high requirements for management plan by rehabilitation, reforestation programs and regular forest fire prevention in disturbed forest landscape are recommended. In the transition zone, moderate requirements are recommended for both restoration and management plans. Reforestation and forest fire control and prevention should be applied in the government’s disturbed forest landscape.

(3) Forest plantation landscape. The priority level for forest restoration and management plans in the core, buffer, and transition zones was high, moderate ,and high, respectively. Recommendations in the core zone are a minimal requirement for both restoration and management plans. Restoration is to leave forest plantation to grow naturally with regular patrolling. Whereas, forest patrolling and forest fire prevention are applied for the management plan. In the buffer zone, a moderate requirement for tree enrichment restoring and a moderate requirement for management plans, including forest patrolling and forest fire prevention are recommended. In the transition zone, a high requirement for reforestation restoring and forest fire prevention in large patches of the government's forest plantation landscape is recommended. At the same time, a moderate requirement for forest plantation plans, including reforestation, forest patrolling and forest fire prevention are recommend to apply in large patches of the government's forest plantation landscape.

5.2 Recommendations

Even though this study had been fulfilled the objectives of the study as presented, at some points it may not be so inclusive. To comprehend on top of this study some concerns from experiences that should be addressed in further research are listed below.

5.2.1 The results of the multi temporal LULC classification and landscape pattern changes show that changes can be traced and interpreted. However, detecting changes require a high quality standard of input data (temporal and spatial consistency) in order to avoid any data related distortion of the results.

5.2.2 The digitizing process is time consuming and is considered costly in large areas. If it must be processed, it should focus on a smaller area.

5.2.3 Regarding to change detection and interpretation of the selected landscape indices, it is important to take into account the quality of geo-referencing input data, because consistency in concepts of land use and land cover and acquisition dates of primary data determines the value of output products.

5.2.4 One single index could not describe all aspects of landscape structure. To avoid misinterpretations, multiple metrics should always be calculated and the interpretation of these indices should refer to each other.

5.2.5 Landscape metrics serve as a useful tool to describe the landscape structure in its various aspects (e.g., landscape diversity, fragmentation, and shape complexity). Limitation of the number of indices to a reasonable amount should be considered.

5.2.6 Further research should pay more attention in the area of landscape function.

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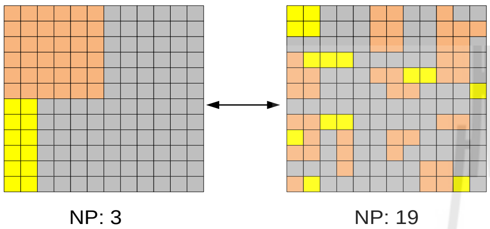
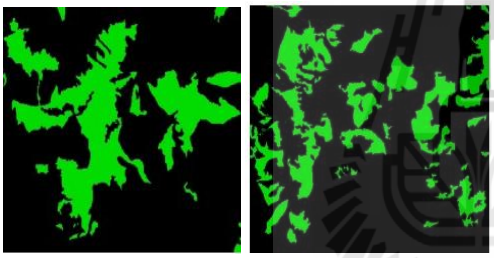
APPENDICES

APPENDIX A

INDICES USED IN LANDSCAPE PATTERN ANALYSIS

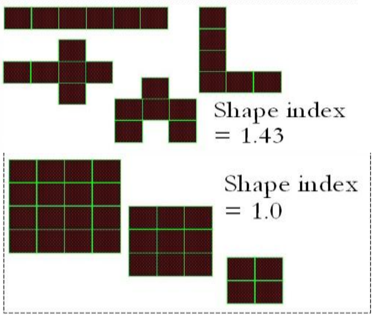
<table>
<tr>
<td>
</td>
<td>Number of Patch

N is Total number of patches

$NP = N$</td>
</tr>
<tr>
<td></td>
<td>Total edge (TE) and edge density (ED) –

$$TE = \sum_{k=1}^{m} e_{ik}$$
$$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10{,}000)$$
e_{ik} = total length (m) of edge in landscape involving patch type (class) i; includes landscape boundary and background segments involving patch type i.
A = total landscape area (m^2).</td>
</tr>
</table>

Figure A-1 Number of Patch (NP), Total Edge (TE) and Edge Density (ED).



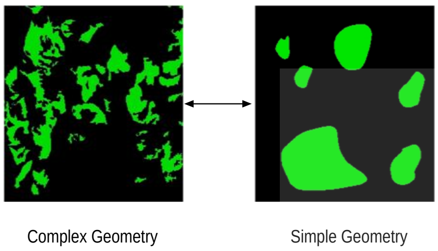
Shape Index

$$SI_i = \frac{p_i}{2\sqrt{\pi \times a_i}}$$

pi = perimeter (m) of patch i.
ai = area (m) of patch i.

Mean Shape Index

$$MSI = \frac{\sum_{i-1}^{m} SI_i}{NP}$$

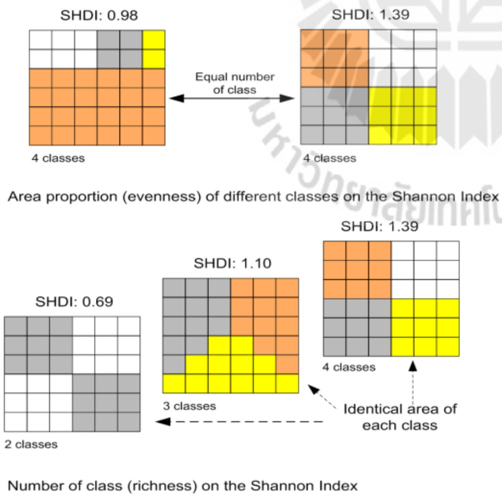


Mean patch fractal dimension (MPFD)

$$MPFD = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\frac{2\ln\left(0.25\,p_{ij}\right)}{\ln a_{ij}}\right)}{N}$$

p_{ij} = perimeter (m) of patch ij, a_{ij} is area (m^2) of patch ij, and N = total number of patches in the landscape.

Figure A-2 Mean Shape Index (MSI) and Mean Patch Fractal Dimension (MPFD).



Shannon's diversity index (SDI)

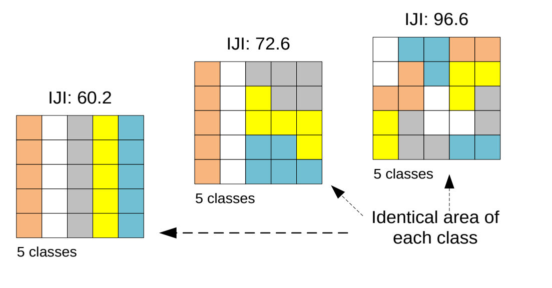
$$SDI = -\sum_{i=1}^{m}(Pi \ast \ln Pi)$$

P_i is proportion of the landscape occupied by patch type
i and m is number of patch types present in the landscape.

Shannon's Evenness index (SEI)

$$SEI = \frac{-\sum_{i=1}^{m}(Pi \ast \ln Pi)}{ln\ m}$$

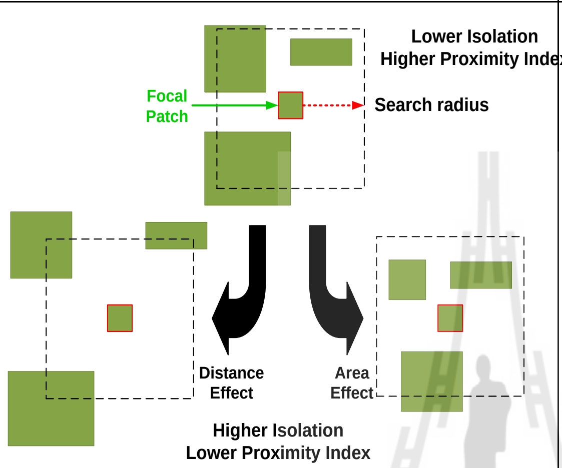
Figure A-3 Shannon's diversity index (SDI) and Shannon's Evenness index (SEI).



Interspersion Juxtaposition Index (IJI)

$$IJI = \frac{-\sum_{i=1}^{m'}\sum_{k=i+1}^{m'}\left[\left(\frac{e_{ik}}{E}\right)\circ\ln\left(\frac{e_{ik}}{E}\right)\right]}{\ln\left(\frac{1}{2}\left[m'(m'-1)\right]\right)}(100)$$

e_{ik} is total length (m) of edge in landscape between patch types *i* and *k*, *E* is total length (m) of edge in landscape and *m'* is number of patch types present in the landscape.



Mean Proximity Index

$$MPI = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{s=1}^{n}\frac{a_{ijs}}{h_{ijs}^{2}}}{N}$$

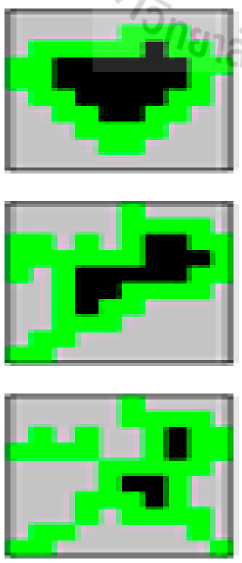
a_{ijs} is area (m^2) of patch *ijs* within specified neighborhood (m) of patch *ij*, h_{ijs} is distance (m) between patch *ij* to nearest neighboring patches of the same type, based on edge-to-edge distance, and *N* is total number of patches in the landscape

Mean Nearest Neighbor

$$MNN = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}x_{ij}}{N}$$

Figure A-4 Interspersion Juxtaposition Index (IJI), Mean Proximity Index (MPI) and Mean Nearest Neighbor (MNN).

Core Area Metrics: Total or relative core area



Total Core Area

$$TCA = \sum_{j=1}^{n} a_{ij}{}^{c}\left(\frac{1}{10{,}000}\right)$$

Mean Core Area

$$MCA = \frac{\sum_{j=1}^{n} a_{ij}{}^{c}}{A}$$

Total Core Area Index

$$TCAI = \sum_{j=1}^{n} a_{ij}{}^{c}\left(\frac{1}{10{,}000}\right)(100)$$

Core Area Density

$$CAD = \frac{\sum_{j=1}^{n} a_{ij}{}^{c}}{A}(100)$$

a_{ij} = core area (m^2) of patch ij based on specified edge depths (m).
A = total landscape area (m^2).

Figure A-5 Core Area Metrics: Total or relative core area.

APPENDIX B

FIELD WORK PHOTOGRAPHS AND EXAMPLES OF LAND USE LAND COVER DIGITIZING IN THE STUDY AREA

Figure B-1 Natural forest, distubed forest and miscellaneous areas.

Teak plantation

Eucalyptus plantation

Rubber Plantation

Figure B-2 Forest plantations

Field Crop: Cassava Field

Field Crop: Sugarcane Field

Paddy Field

Field Crop: Corn Field

Figure B-3 Field crops.

Figure B-4 Orchard/Tree.

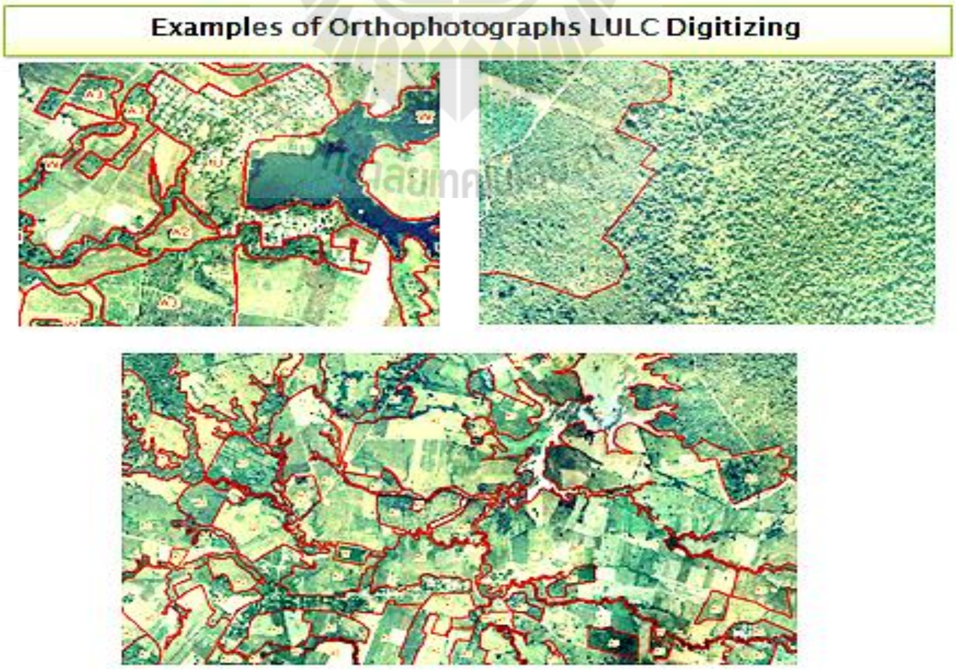


Figure B-5 Color orthophotomaps LULC digitizing.

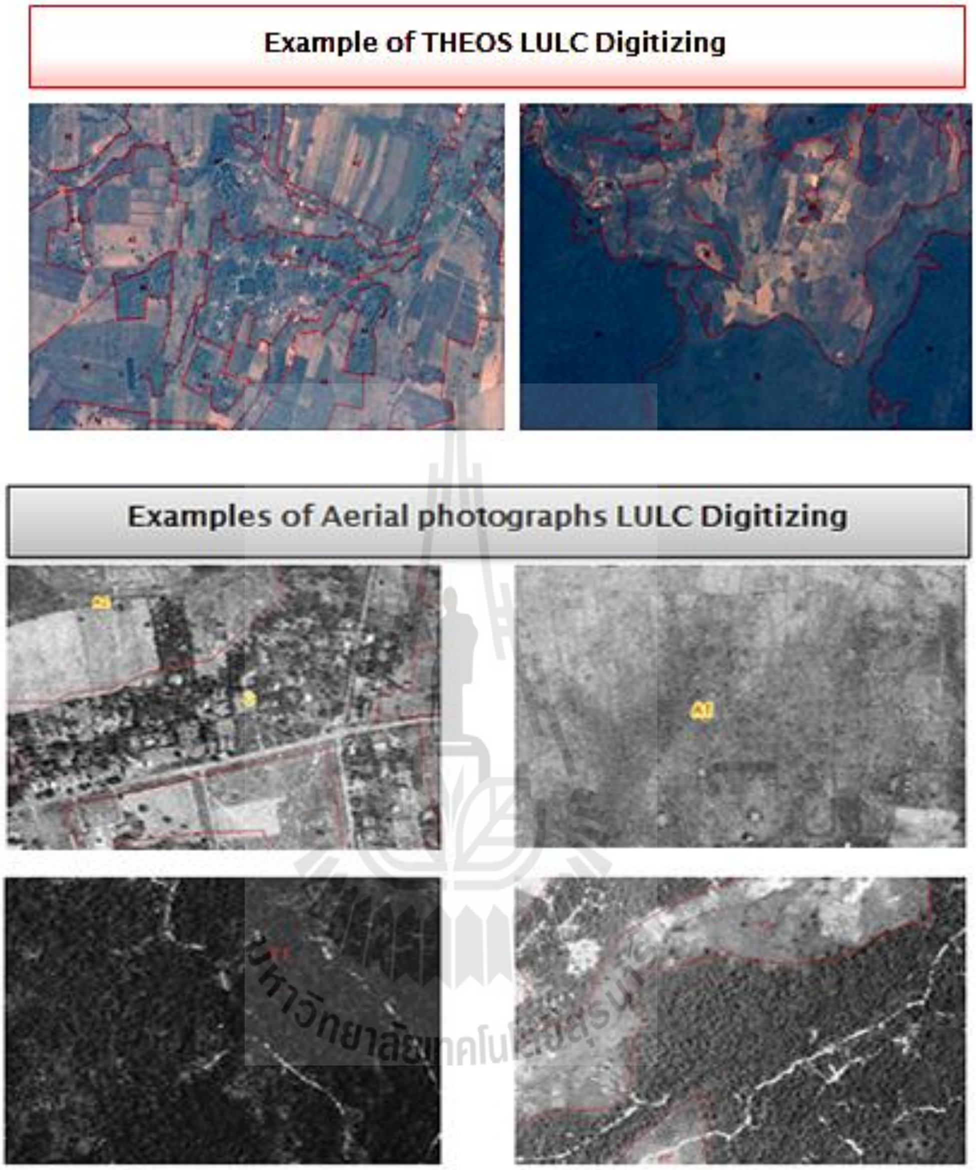


Figure B-6 THEOS imagery data and aerial photographs LULC digitizing.

CURRICULUM VITAE

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1985 Bachelor of Science (Forestry, Watershed Management): Faculty of Forestry, Kasetsart University, Bang Khen, Thailand

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Working experiences and scholarships

1988 Working at The Royal Forest Department as a forestry official.

1990 Scholarship of The Federal Republic of Germany for advanced professional training in applied remote sensing for coastal zone management at Asian Institute of Technology.

1993 Scholarship of Australian International Development Assistance Bureau for government official language training at University of Technology Sydney, Australia.

1994 Award of The Regional Community Forestry Training Center for training in community forestry and buffer zone management at Kasetsart University.

1996 Scholarship of The Royal Thai Government for graduate program at University of Minnesota, USA.