ASSESSMENT OF CHANGES IN MANGROVE FORESTS AFTER NARGIS CYCLONE USING REMOTE SENSING AND GIS: A CASE STUDY OF KADONKANI RESERVED FOREST IN BOGALAY, MYANMAR

MIN MIN OO

MASTER OF SCIENCE

IN

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Min Min Oo

Thesis Title	Assessment of Changes in Mangrove Forests after Nargis Cyclone Using Remote Sensing and GIS: A Case Study of Kadonkani Reserved Forests in Bogalay, Myanmar
Author	Min Min Oo
Degree	Master of Science (Natural Resources and Environmental Management)
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ABSTRACT

This study focused on the impact of the cyclone Nargis on Kadonkani Reserved Forests, Bogalay Township, Ayeyarwady Division in Myanmar. The area covered about 605.06 km^2 including about 202.22 km^2 of mangrove forests (FD, 2000). The objectives of this research are to determine the conditions of mangrove forests after the cyclone and to support management of these mangrove forests.

Remote Sensing and GIS were used as tools for assessment of the Landsat 5 images. Three of Landsat 5 satellite images with world-wide reference system path 133 and row 49 were also used. By using ENVI 4.5, the calculations of NDVI values for each image were carried out. The degraded condition of mangroves during 2006-2009 and the recovery condition of mangroves during 2009-2011 were determined with the NDVI value differences. Unsupervised and supervised classification methods were applied for the land cover classifications with ENVI 4.5, ERDAS IMAGINES 9.1 and ArcViewGIS. The analysis showed that the mangroves forests were highly degraded after the cyclone. The northwestern part was more degraded than lower southeastern part because of the distance of cyclone tract. The image study estimated the recovery rate of mangroves forests in 2009-2011 at 0.3730 km^2/yrs. The analysis of field data estimated the basal area growth rate was at 0.0165 m^2/ha/yrs. However, despite of regeneration, the mangroves forests covers in the Integrated Resources management (IRM) area of Kadonkani Reserved forest were still less than that of before the cyclone.

This study confirms a need for further restoration and plantations under the management plans of Forest Department in the IRM. The use of Remote Sensing and GIS is recommended as a reliable and cost-effective way to generate detailed spatial and temporal information to support the restoration program and future decision making.

Keywords: Change Detection/GIS/Mangroves /Reforestation/Remote Sensing

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ABBREVIATIONS AND SYMBOLS

FAO	Food and Agriculture Organization
FD	Forest Department
GIS	Geographic Information System
IRM	Integrated Resources Management
IUCN	International Union for Conservation of Nature
JICA	Japan International Cooperation Agency
NDPCC	National Disaster Preparedness Central Committee
NDBI	Normalise Different Built-up Area/ Bare Soil Index
NDVI	Normalise Different Vegetation Index
PONJA	Post Nargis Joint Assessment
RISC	Resources Information Standards Committee
ROI	Region of interests
RS	Remote Sensing
UN	United Nations
UNEP	United Nations Environmental Program

CHAPTER 1

INTRODUCTION

1.1 Background

Myanmar is a Southeast Asia country situated geographically between 10° N and 29° N latitude and 92° E and 101° E longitude. It has an area of 676,577 km^2 and extends about 936 km from east to west and 2,051 km from north to south. The southern parts of the country connect with open sea along the coast of the Bay of Bengal and the Andaman Sea which is about 3,000 km of coastline. The climate of Myanmar is a tropical monsoon climate but it has locally changes in some parts of the country by the topography. The rainfall patterns and temperature distributions are quite diverse throughout the country. There are more than 5,000 mm of annual rainfall in coastal regions whereas less than 1,000 mm of annual rainfall in the central part of Myanmar. During the hot season of March and April, the average highest temperature in the central region is above 43.3° C while it is about 36° C in the northern mountainous parts of the country and between 30° C and 35°C on the eastern Shan plateau.

As a result of the great variation in rainfall, temperature and topography, there are many different forest types in Myanmar. The most important forest types are: mixed deciduous forests including teak (38% of the total forest area); hill and mountain evergreen forests (25%); tropical evergreen forests (16%); dry forests (10%); deciduous dipterocarp forests (5%); tidal, beach and dune , swamp forests (4%) and fallow land (2%) according to Statistical Yearbook (2005), Planning and Statistics Division, Forest Department. The actual forest cover is estimated at being 343764 km^2 or approximately 51% of the total surface area of the country and the total mangrove forests including tidal, beach and dune, and swamp forests are 13,751 km^2 or 4% of the total forests (Oo, 2004).

The climatic conditions are favorable for the growth of mangrove forests in the coastal areas. There are two types of mangrove forests in Myanmar; (1) the Delta mangrove on the flood plain of Ayeyarwady, and (2) the coastal mangrove forests of Rakhine and Tanintharyi division as shown in the Figure 1.1.

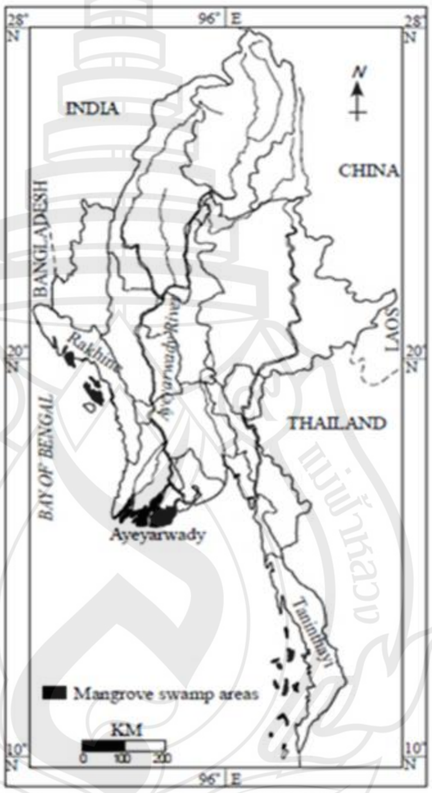


Figure 1.1 Distribution of Mangrove Forests in Myanmar

The total area of mangrove forests in Myanmar is approximately 3,821.68 km^2, the largest among these is in the Ayeyarwady Delta, and the extent of its mangrove area is 1,773.27 km^2. The change of land cover and land use in Ayeyarwady Delta was analyzed using 1995 and 2001 Landsat images and during a period of 6 years mangrove area decreased from 1,474.43 km^2 to 1,035.50 km^2 (Forest Department [FD] & Japan International Cooperation Agency [JICA], 2005).

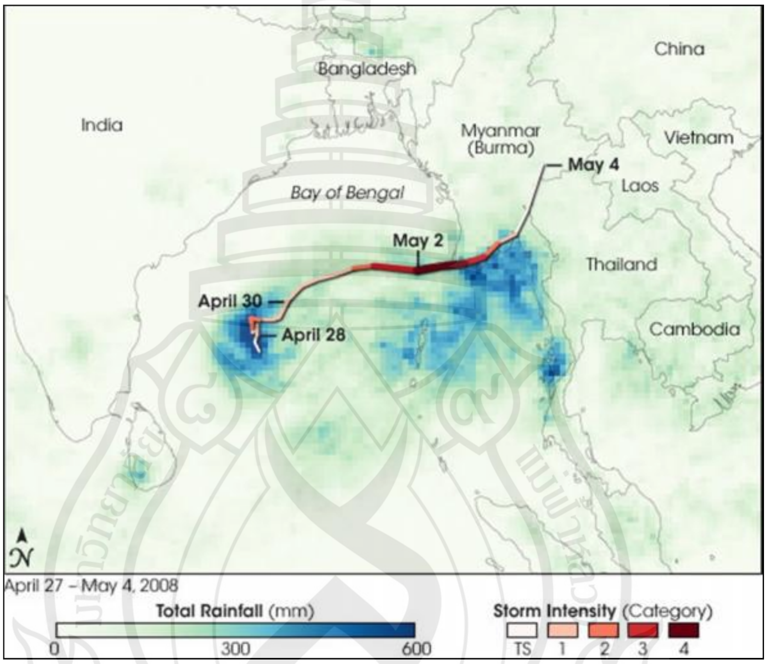
The mangrove ecosystems are the primary tree species in tropical/subtropical communities that grow in the intertidal regions of the world. They form forests of salt-tolerant species with complex food webs and ecosystem dynamics (Tomlinson, 1986). Mangrove forests are important in the coastal ecosystems that are valued for a variety of ecological and societal goods and services to coastal dwellers.

Mangrove forests in the Ayeyarwady Delta have been facing serious environmental and economic concern like many developing countries. The mangrove forests of Ayeyarwady Delta were good in structure and density in the past 30 years ago. However, the mangrove forests are being degraded and denuded with an alarming rate in the Ayeyarwady Delta as compared to other mangrove areas in Myanmar. It has been happened by human-induced activities and natural disasters such as tropical cyclones. An increasing human population has also led to mangrove forests degradation by overcutting and the encroachment of mangrove forests for their livelihoods being heavily used for food, timber, fuel, and medicine. Due to limited income opportunities, landlessness, and high unemployment, they intensively depend on mangrove forests and that lead to mangrove forests degradation. The main historical causes of mangrove degradation in Ayeyarwady Delta were allocation to human settlement in the 1960s, allocation to paddy cultivation in the 1970s, over-exploitation for charcoal and fuel wood, and continuous migrations of people from other parts of the country into the mangrove forests (Maung, 2005).

Mangrove forests in Ayeyarwady Delta are also threatened by the natural disasters like cyclones. In the past history, Ayeyarwady Delta has faced a number of tropical storms during the monsoon season and fires in the dry season. It is also exposed to low frequency and high impact events such as occasional cyclones and tsunamis. In the years 1990-2008, Myanmar had impacted by 21 natural disasters. The three storms that was hit Myanmar on 19 May 1926 and 10 May 1968 on were one of the worst natural disaster but all this changed with the Cyclone Nargis in 2008 (Asia-Pacific, 2008).

The worst natural disaster in recorded Myanmar history was Cyclone Nargis on the 2nd and 3rd of May, 2008. It covers 23,500 km^2 in Ayeyarwady Delta. It struck on 2nd May 2008 with wind speeds of up to 200 km/h and diameter of 240 km and affected more than 50 Townships, mainly in Yangon and Ayeyarwady Divisions.

Ayeyarwady Delta was severely impacted by the cyclone and the mangrove vegetations were damaged by storm winds and rain. It made landfall at 14:30 on May 2 in Haing Gyi Kyun, approximately 250 km Southwest of Yangon. It moved Northeast and it swept through the densely populated Ayeyarwady Delta region before reaching Yangon in the early morning on 3rd May 2008 as shown in the Figure1.2.



Source Thant, Than. & Mamoru. (2008).

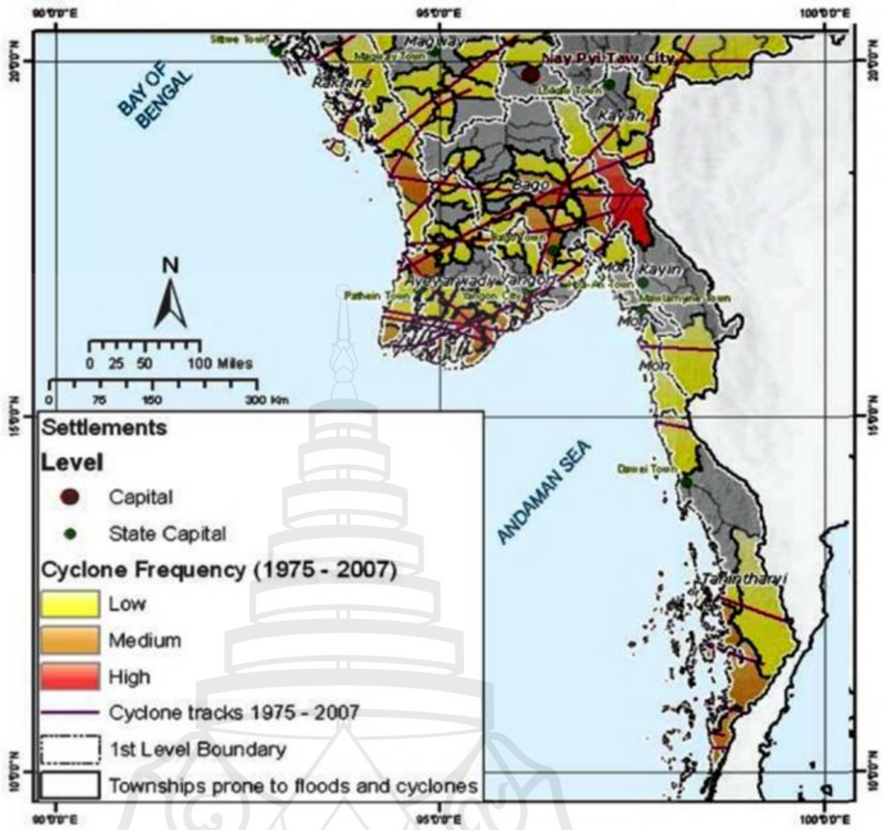
Figure 1.2 The Nargis Cyclone Track on May 2008

It passed through the Townships of Pyinsalu, Laputta, MawLamyinegyun, Bogalay, Pyapon and Kungyangon and led to Yangon. The storm surge and associated flooding were devastating and the destructive winds caused further damage. The devastation was most of severe in the Delta region, where the effects of the extreme winds were compounded by a 3.6 m storm surge. According to the Post Nargis Joint Assessment (PONJA) report, 33% of 7.35 million people are severely affected by the cyclone and 370000 households were completely destroyed. Over half of small mills and two-thirds of larger mills in the affected areas were damaged by the cyclone. The total area of damaged forest is estimated at 378 km^2 in the Ayeyarwady and Yangon Divisions. It is interesting how many forest cover change after the cyclone Nargis in 2008 and how much recover in these damaged mangrove forests in current year.

Some important studies of mangrove forests are mapping of land cover, change detection, identification of species / plant communities and biomass estimation using RS and GIS. RS and GIS is a very useful tool in monitoring and assessment study. The integrated application of RS and GIS in forest management plays an important role in measuring and predicting the extents and rates of forest loss and recovery conditions within specific period of time and within a short period of time. Forest Department has an obligation to monitor or assess all types of forests but they cannot report their result quickly within a few days and cannot monitor and assess continuously. In this case, RS and GIS could be cost-effective tools for them to conduct monitoring and assessment in timely fashion. This study aim at demonstrating the power of the tools and lends a support to Forest Department for decision making process of their proper management of mangrove forests.

1.2 Problem Statement

Cyclones, storms, floods, landslides, and tsunamis are all common phenomena because of the varied geophysical context of Myanmar. These are parallel with climate change that impacts to the biodiversity, habitat and natural resources of Myanmar (United Nation [UN], 2008). Moreover, the areas along the Myanmar coastline are exposed to the severe cyclone famous Bay of Bengal in the Indian Ocean. There are two cyclone seasons of the Bay of Bengal: April-May (the beginning of the rain) and September-November (the close of the raining season) in Myanmar. Myanmar coastline consists of Ayeyarwady Delta, Rakhine and Tanintharyi Coasts. These areas are subjected to multiple disasters more frequently and increasingly. The cyclone tracts and intensity of lower Myanmar including the Ayeyawady Delta in 1975-2007 are as shown in the Figure1.3.



Source Myanmar Information Management Unit. Cyclone Frequency and Township Prone to cyclone which experienced flooding between 2000-2011

Figure 1.3 Cyclone Frequency and Cyclone Track and Intensity of Lower Myanmar

The 24% of mangrove forests (from 2,345.15 km^2 to 1,786.42 km^2) were destroyed during 3 decades (from 1954 to 1984). According to 1990 assessment, the mangrove forests reduced 2.4 times faster than other forests in Myanmar (Bo, 1992). The rate of mangrove deforestation was low during 1976-1990 but the rate of mangrove deforestation was the highest in Myanmar (2.9%) among the Tsunami affected area of Asia (Giri, Zhu, Tieszen, Singh, Gillettee & Kelmelis, 2008).

The essential measures to protect the area against future disasters had been identified by the rehabilitation and regeneration of mangrove forests. The mangrove forest plantation and management of natural forests will be addressed to restore the mangrove forests that reduce the disaster risk. The natural regenerations of mangrove forests and the mangroves plantation around villages and along riverbanks will reduce the impact of future natural disasters. The national level comprehensive coastal zone management is also needed in the initial stages. The comprehensive coastal zone management concept should be introduced and developed with the intensive capacity building and institutional development in selected areas.

Forest Department introduced the plantation forestry and community forestry as tools for mangrove reforestation program in the area where the natural regeneration was difficult to grow and rich in weed species. The recovery condition was less than the uses of mangrove forests by the forest dwellers because of their likelihoods requirements in the Ayeyawady Delta. There have some gap to monitor or assess in the mangrove forest management by the addition of the natural regenerations, plantations and community forestry for management purpose. This study will address the effective technique to support the management of mangrove forests.

1.3 Research Questions

1.3.1 How did the Nargis cyclone affect the mangrove forest in Kadonkani reserved forest at Ayeyarwady Delta?

1.3.2 How did the mangrove forests recover in 2011-2012?

1.3.3 What was the difference recovery condition between the mangrove plantations and natural mangroves?

1.4 Objectives of the Study

The goal of this study is to assess the changes of mangrove forest for appropriate management in the future. The objectives of the study are;

1.4.1 To determine the mangrove forest cover change of the study area before the Nargis cyclone in 2006 and after the cyclone in 2009 by using Remote Sensing and GIS

1.4.2 To determine the existing mangrove forests cover of the study area in 2011-2012 by using Remote Sensing and GIS

1.4.3 To support better management for the mangrove forests

1.5 Scope and Limitation

1.5.1 There are three mangrove regions in Myanmar – Ayeyarwady Delta, Rakhine State, and Tanintharyi Division. However, the study is to be carried out in the Kadonkani Reserved Forests, Bogalay Towinship, Ayeyarwady Division of Myanmar. Mangrove forester cover changes have been affected by both natural disasters (Storms and Cyclones) and human-induced activities in this area. This study was developed from existing mangrove forest covers after Nargis cyclone in Myanmar.

1.5.2 Without consideration of mangrove deforestation by human impacts or Natural impacts, the study will only focus on the change of mangrove forest cover during the year 2006, 2009 and 2011.

1.5.3 It is difficult to get the secondary data sources concerning the mangrove forest cover changes because of the rare past records of mangrove forest conditions in Myanmar.

1.5.4 Field data are carried out to check the changes of mangrove forests resulting on the Landsat 5 image analysis and assessment of the mangrove forests cover changes in year 2011.

1.6 Research Procedure and Summary

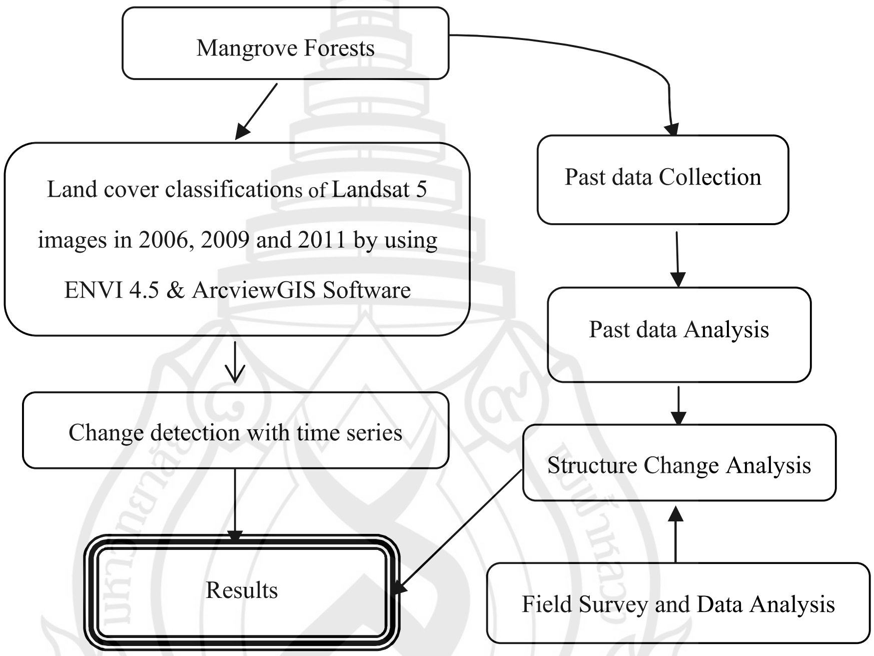


Figure 1.4 Research Flow Diagram

Table 1.1 Summary of Research

Objective	Methodology	Outcomes
To determine the mangrove forest cover change of the study area before cyclone in 2006 and after the cyclone 2009 using RS and GIS	1. Unsupervised/Supervised classifications of Landsat 5 images in 2006 and 2009 using ENVI 4.5 2. The calculation of NDVI in 2006, 2009 and 2011, 3. NDVI value difference in 2006-2009 and in 2009-2011	The changes of mangrove forest cover were carried out in the study area before the cyclone in 2006 and after the cyclone in 2009
Determine the existing mangrove forests cover of the study area after the cyclone in 2011 by using RS and GIS	1. Unsupervised/Supervised classifications of Landsat 5 images in 2012 using ENVI 4.5 2. The calculation of NDVI in 2006, 2009 and 2011, 3. NDVI value difference in 2006-2009 and in 2009-2011	The recovery conditions in 2012 and the rate of recovery of mangrove forests during 2008-2012 were calculated.
	1. Analysis of the secondary data before the cyclone in 2008 for the structural analysis 2. Analysis of the data collected on the field in 2012 for the structural analysis 3. Calculation of basal area growth rate	The structure and distribution of mangroves were described and the basal area growth rate was calculated.
To support better management for the recovery of mangroves	1. Comparative study and analysis of the land cover results and forest structure results	A proper management for the mangrove forests were found out and suggested in the conclusion and recommendation.

1.7 Structure of the Thesis

This study consists of five chapters, namely; Chapter-1(Introductions), Chapter-2 (Litearture review), Chapter-3 (Methodology), Chapter-4 (Results and Discussions) and Chapter-5 (Conclusions and Recommendations).

This current chapter described the background information of the study area, scope and limitations and problems of the study area and then introduced the research questions and objectives to support the thesis. Chapter 2 is reviewing the previous studies of the study area and other previous studies related to this study. Chapter 3, the research methodology is the description of study (where is this study, what is this study, how to study). Chapter 4 explains and discusses the results of this study. Chapter 5 concludes and provides the recommendations to the related sectors and further studies.

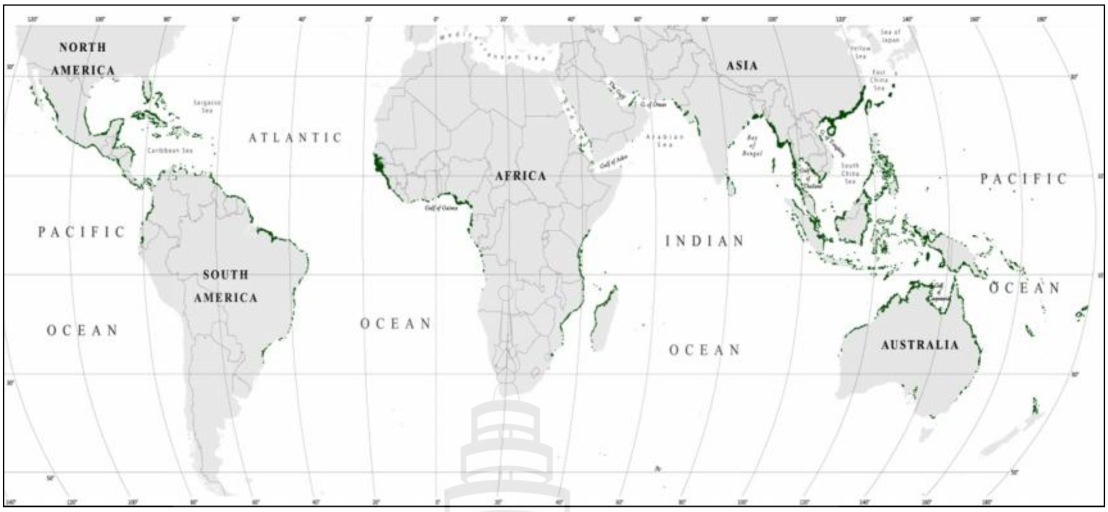
CHAPTER 2

LITERATURE REVIEW

2.1 Distribution of Mangrove Forests

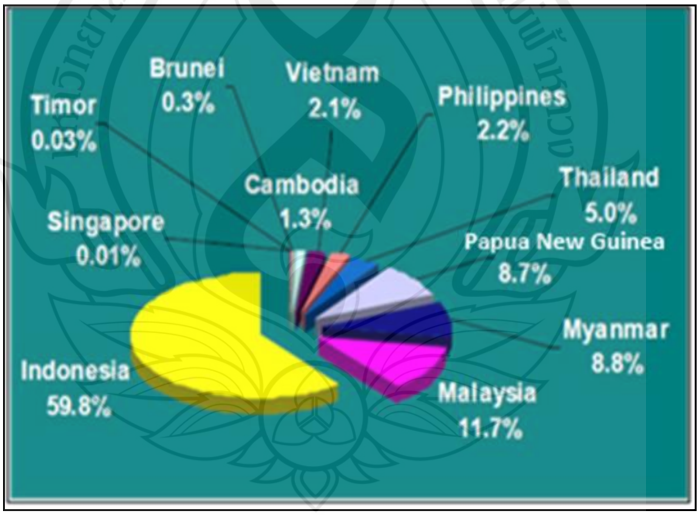
Mangroves are distributed latitudinally within the tropics and subtropics and their maximum development are between 25° N and 25° S (Hensel, Proffitt & Delagado,2002). Temperature, moisture and tidal current affect mangrove distribution. Elizabeth McLeod and Rodney V. Salm showed the map of the global distribution of mangrove forests in IUCN Resilience Science Group Working Paper Series - No 2 in 2006. (Giri et al., 2011) also estimated that the total mangrove forest area of the world in 2000 was 137,760 km^2 in 118 countries and territories. The total mangrove area accounts 0.7 % of the total tropical forests of the world as shown in the Figure. 2.1. The largest extent of mangroves is found in Asia (42%) followed by Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%). Approximately 75% of mangroves are concentrated in just 15 countries –See Table 2.1. (Giri et al., 2011). The largest percentage of mangroves is found between 5° N and 5° S (Giri et al., 2011). From a global perspective, Southeast Asia is well endowed as it supports the world's largest area of mangroves, originally extending over 6.8 million hectares and representing 34-42 percent of the world's total.

The largest areas of mangrove in Southeast Asia are found in Indonesia (almost 60 percent of Southeast Asia's total), Malaysia (11.7%), Myanmar (8.8%), Papua New Guinea (8.7%) and Thailand (5.0%) (FAO, 2006) as shown in the Figure 2.2



Source Status and Distribution of Mangrove Forests of The World Using Earth Observation Satellite Data (Giri et al., 2011)

Figure 2.1 Mangrove Distribution of The World 2000



Source Mangrove Guidebook for Southeast Asia.

Figure 2.2 Mangrove Forests in Southeast Asia

Table 2.1 The 15 Most Mangrove-Rich Countries and Their Cumulative Percentages

SN	Country	Area (ha)	% of global total	Cumulative %	Region
1	Indonesia	3,112,989	22.6	22.6	Asia
2	Australia	977,975	7.1	29.7	Oceania
3	Brazil	962,683	7.0	36.7	South America
4	Mexico	741,917	5.4	42.1	North and Central America
5	Nigeria	653,669	4.7	46.8	Africa
6	Malaysia	505,386	3.7	50.5	Asia
7	Myanmar (Burma)	494,584	3.6	54.1	Asia
8	Papua New Guinea	480,121	3.5	57.6	Oceania
9	Bangladesh	436,570	3.2	60.8	Asia
10	Cuba	421,538	3.1	63.9	North and Central America
11	India	368,276	2.7	66.6	Asia
12	Guinea Bissau	338,652	2.5	69.1	Africa
13	Mozambique	318,851	2.3	71.4	Africa
14	Madagascar	278,078	2.0	73.4	Africa
15	Philippines	263,137	1.9	75.3	Asia

Source Status and distribution of mangrove forests of the world using earth observation satellite data (Giri et al., 2011)

2.2 Ecologically and Economically Importance of Mangrove Forests

International Union for Conservation of Nature (IUCN) (2007) calculated the storm protection function of mangroves after Tsumani by using the cost of damages to property and livelihood. The actual value of damages in control site was US$ 213.825 without the mangrove cover present in the location. Thus, the damage cost avoided in Panama is calculated at US$ 125,613. The protective value of mangroves is calculated at 392.5 US$/ha. The storm protection and shoreline stabilization functions of a wetland may have indirect use value through reducing property damage. Total benefit to income groups poor, medium and high are 42%, 37% and 21% respectively. This study estimated that mangrove generated a value ranging from US$ 177.9 to US$ 474.3 per hectare of mangroves per year for fish breeding and value of US$ 392.5/ha/yr for coastline protection respectively for mangrove fish breeding habitats protected from extreme weather. IUCN report of Thailand demonstrated the economic and development wisdom of conserving the environment in post-tsunami reconstruction and of the importance of factoring ecosystems into coastal zone development and rebuilding.

From ecological point of view, it may stabilize the shore line and protect against soil erosion by trapping and stabilizing sediments and reducing the area of exposed riverbanks. Mangrove can serve as an effective barrier to protect Myanmar's coastline against strong winds, tidal bores and waves. It is very important buffer zone and also serves as a link between marine and terrestrial ecosystems. Another ecological benefit of mangrove is the protection of biodiversity by providing the physical habitats as a large variety of coastal species, including crocodiles, birds, monkeys, shellfish, fish and other invertebrates (Oo, 2002).

From economic point of view, it is important to inshore and offshore fisheries. They supply organic matter and nutrients through a variety of flora, while providing nurseries and shelter for improvement marine stocks. Mangrove products are used for building houses, boats, fences and fish traps. Nipa fruitcans is valuable for many purposes. The leaves are used for shelter and for roofs of houses, for making crab traps. In addition, Nipa Sap is a source of sugar, vinegar, alcohol and fermented beverages (Oo, 2002). Mangrove species are valuable as a direct source of fuel wood energy, both as firewood and charcoal. In the productions of both fire wood and charcoal, half of production of fire wood and almost all production of charcoal are exported to Yangon in every year (See Table.2.2). According to table 2.2, both productions of fire wood and charcoal are reduced in 1991. It shows that the mangrove forests are highly degraded and need some restoration program to be sustainable productions.

Table.2.2 Production and Export of Firewood and Charcoal from the Dalta Mangroves 1987-1991

Year	**Production(tons)**		**Export(tons)**	
	Firewood	**Charcoal**	**Firewood**	**Charcoal**
1987	105,045	601,391	63,027	481,113
1988	103,045	642,626	61,829	513,110
1989	109,742	534,763	65,445	427,810
1990	104,467	582,600	62,668	466,080
1991	90,491	456,083	54,295	364,688
Total	**512,790**	**2,817,463**	**307,264**	**2,252,801**

Source Report on mangrove forest products and utilization of Ayeyarwady Delta. (Ohn, 1992)

2.3 Mangrove Forest Cover Change

2.3.1 South-East Asia Region

(Giri et al., 2011) studied the status of distribution of mangrove forests of the world by using earth observation satellite data in year 2011 and also studied mangrove forest distribution and dynamics (1975-2005) of the tsunami affected region of Asia in year 2008. They applied hybrid supervised and unsupervised digital image classification techniques. Ground truth data and existing maps and data bases were also used.

(Giri et al., 2008) estimated that there were approximately 1.67 million ha of mangroves in their study region of Asia in 2005. Net deforestation peaked at 137,000 ha during 1990-2000, increasing from 97,000 ha during 1975-1990, and declining to 14,000 ha during 2000-2005. The major causes of deforestation were agricultural expansion (81%), aquaculture (12%) and urban development (2%).

There were the reduction of mangrove forests by the human interferences and development in the past. These mangrove forests are not healthily recover because of over exploitation. Therefore, there are needed to recognize conservation, management and restoration of mangrove forests.

2.3.2 North-Western Australia

Plaing, Kobryn and Humphreys (2008) studied the extent of mangrove change in the eastern Exmouth Gulf, north-western Australia over six years (1999-2004) after cyclone Vance on March, 1999 by using Landsat TM satellite imagery and aerial photography. Three sets of Landsat TM images from 1999, 2002 and 2004 were used in this study. The 1999 Landsat image was obtained a few days before cyclone Vane. There were three main steps: pre-processing, image interpretation, classification and validation, and change analysis. Data were processed by using ENVI^{TM} and IDRISI^{TM} software.

According to the study of mangrove changes after cyclone. (Plaing, Kobryn & Humphreys, 2008) showed that some 12,800 ha of mangrove habitat was present before cyclone and approximately 5,700 ha (44%) was removed by it. Most mangrove lost (74%) between 1999 and 2004 were converted either to bare sediment or to live saltmarshes and this occurred mostly between 1999 and 2002. Mangrove exhibited accelerated recovery within the period from the year 2002 to 2004, and around 1580 ha regenerated during this time, amounting to a return of 68 % of their former coverage. At this recovery rate, the mangrove forest should have returned to their pre-cyclone area by 2009 in Australia.

2.3.3 Thailand

Somjai Sremongkontip and other published the detecting changes in the mangrove forests of southern Thailand using remote remotely sensed data and GIS in international archives of photogrammetry and remote sensing, volume. XXXIII, part B7, 2000. They studied in Bang-Toey sub-district, PHang-Nga Province, Southern Thailand. They compared the land cover change map of 1976-1984 with 1984-1995. They found that change of mangrove forest during 1984-1995 was more than during 1976-1984.

In Thailand, mangrove forests are found in 23 provinces of the coastline. It was estimated that 168,682 ha in 1993. More than 50% of 199,217 ha of mangrove forests were lost during 1961-1993 (Sremongkontip, S. et al).

2.3.4 Vietnam

Phan Minh Thu and Jacques Populus (2006) studied the status of mangrove forest in Mekong Delta. They used images of SPOT XS (multispectral mode imagery form Satellite Pourl' Observation de la Terre), SPOT XP or SPOT pan (Panchromatic mode imagery form SPOT), Landsat TM (Landsat Thematic Mapper), Landsat MSS (Landsat Multispectral Scanner), MOS-1 MESSR (Multispectral Electronic Self-Scanning Radiometer carried out on the Marine Observation Satellite), JERS-1 (Japanese Earth Resources Satellite), ERS-1 SAR (Synthetic Aperture Rader carried on the European Remote Sensing Satellite), MK6 (Rusian Multispectral camera carried on the Sallyut-7 Satellite), and KATE-140 (Soviet panchromatic large format camera) with different image processing techniques.

In the USA-Vietnam War (1962-1971), about 36% of the total mangrove area (about 104,939 ha) in southern Vietnam were destroyed by spraying (NAS, 1974 cited by Thu, & Populus) found that mangrove forests were reduced to 12,797 ha (2001) from 21,221 ha (1965) in Tra Vinh, Vietnam.

2.3.5 Philippine

Long and Giri (2011) studied mapping the Philippines' mangrove forests using Landsat imagery. They applied Landsat data (61 Landsat images), ISODATA clustering and unsupervised classification technique. Conchedda, Durieux and Mayaux (2008) also studied an object-based method for mapping and change analysis in mangrove ecosystem of Low Casamance, Senegal. This research applied the object-based method to SPOT XS data to map. For land cover mapping and change detection analysis, multi-spectral SPOT 1 and 2 images from 1986 to 2006 covering 20 year period) were used.

Long and Giri (2011) estimated that the total areas of the Philippines/ mangrove forests were 2,56,185 ha in 2000. Conchedda, Durieux and Mayaux (2008) also estimated 76,550 ha of mangrove forests in Low Casamance, Southwestern

Senegal and this indicated an increase in mangroves of 2,390 ha or 3% in four year period before this study compared CSE 2002 study- the study by the center de Suivi Ecologique (CSE) of Dakar (Senegal).

2.3.6 Bangladesh

In Bangladesh, Uddin and Gurung (2010) studied that the land cover change analysis using remote sensing data over the whole Bangladesh from the period of 1997-2000. Landsat ETM+ and MSS are used. For multi-temporal (1997 and 2000) analysis of land cover, 14 MSS scenes from the year 1972 to 1977 (7 out of 14 are 1977 scenes) and 14 ETM scenes from the year 1999 to 2002 (6 out of 14 are 2000 scenes) are used and these images were classified using Expert classifier in Erdas Imagine 9.2.

In Bangladesh, Uddin and Gurung (2010) found that the mangrove forest covers were reduced from 4,122.23 km^2 in the year 1977 to 4,117.53 km^2 in the year 2000. The reduced areas were 139. 16 sq-km of water bodies, 12.79 km^2 of bare land and 2.33 km^2 of Agricultural land.

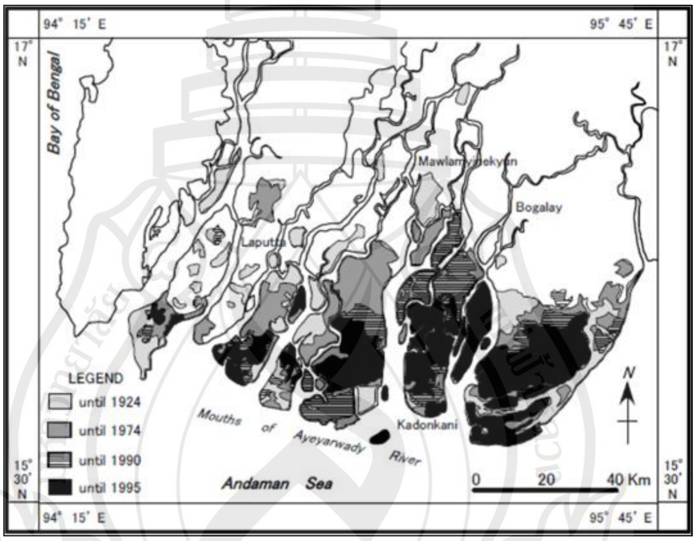
2.3.7 Myanmar

In Myanmar, Forest Department and Japan International Cooperation Agency researched the changes of land use and land cover in Ayeyarwady Delta in year1924 to 1995 and in the year 1995 to 2001. In Myanmar, the change of land cover and land use in Ayeyarwady Delta was analyzed from 1924 to 1995. During these periods, the mangrove area decreased from 2,534.28 km^2 to 311.39 km^2 as shown in Table.2.3. The change of land cover and land use in Ayeyarwady Delta was analyzed using 1995 and 2001 Landsat images and during a period of 6 years mangrove area decreased from 1,474.43 km^2 to 1,035.50 km^2 (FD & JICA, 2005). (See Figure.2.3. and 2.4.).

Table 2.3 Changes of Forest Area (sq-m) in Ayeyarwady Delta (km^2) 1924-1995.

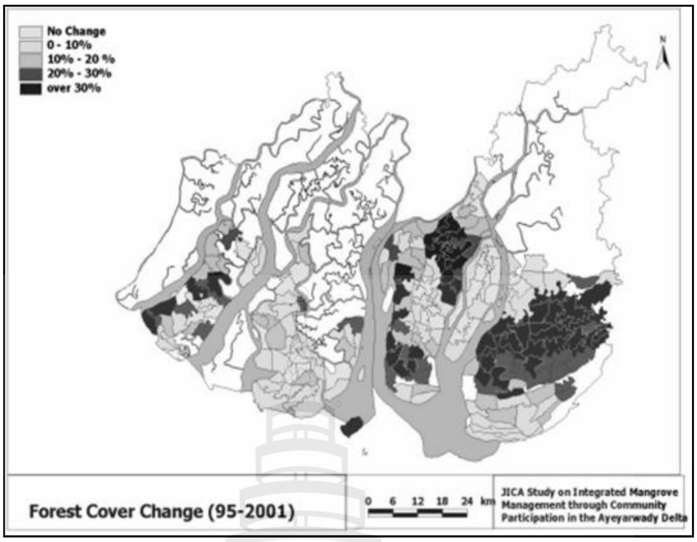
Townships	1924	1954	1984	1995
Bogalay	1,394.72	1,281.39	1,097.15	2,43.67
Laputta	934.56	881.66	664.28	67.13
Mawlamyinekyun	205.00	182.10	47.85	0.59
Total	**2,534.28**	**2,345.15**	**1,809.28**	**3,11.39**

Source Forest Department and JAPTA, 1995 citied by Oo (2004)



Source Forest Department and JAPTA, 1995 citied by Oo (2004)

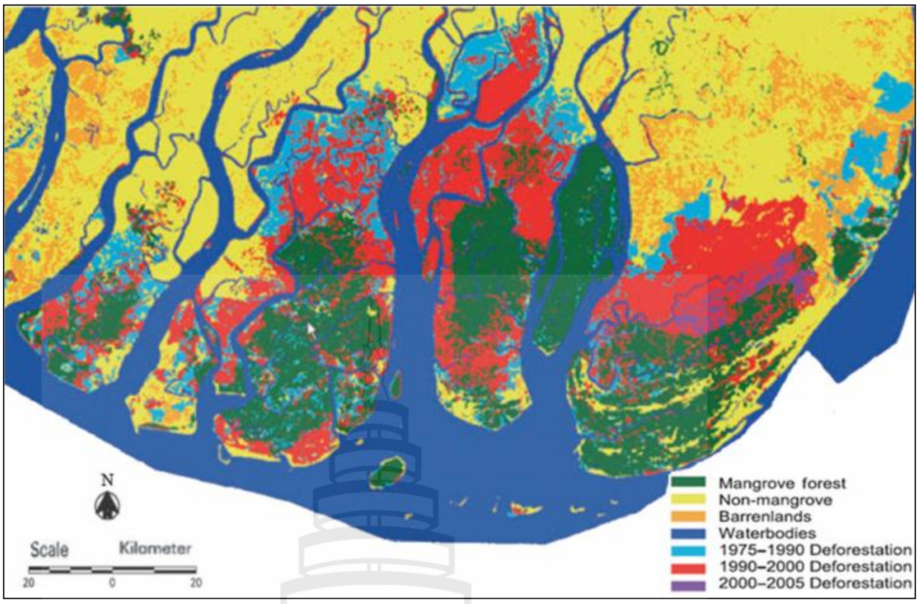
Figure 2.3 Distribution of Mangrove Forests and its changes in Ayeyarwady Delta (1924-1995).



Source Forest Department and Japan International Cooperation Agency (2001)

Figure 2.4 Change of Mangrove Forests in Ayeyarwady Delta (1995-2001)

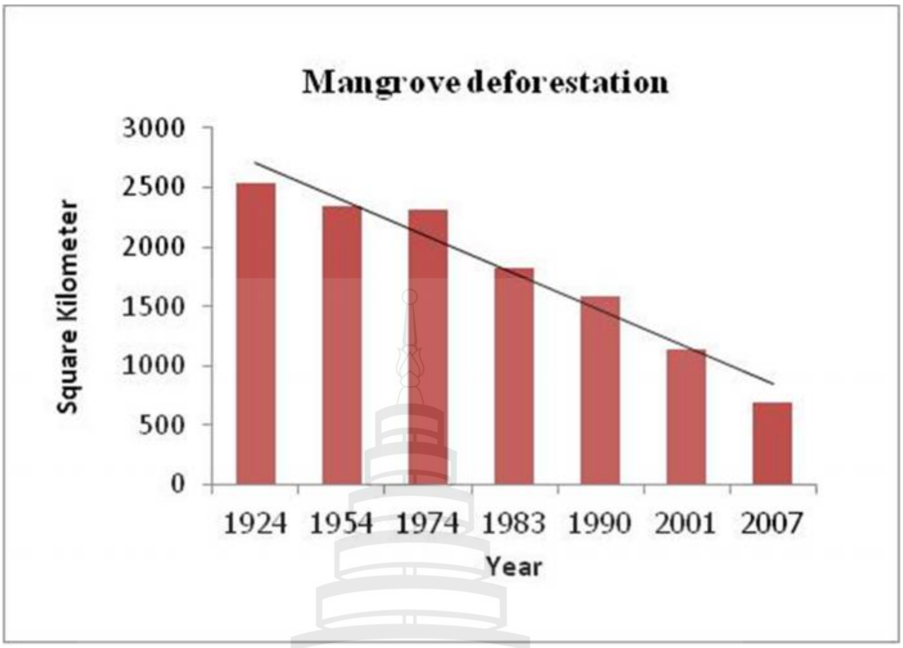
During 1990-2000, the rate of deforestation was highest as shown in figure 2.5. It was caused by overexploitation of mangrove forests for fuel wood collection charcoal production and illegal logging followed by encroachment for paddy cultivation. 98% (2,930.35 km^2) of mangrove deforestation by agricultural expansion and approximately 2% (68.70 km^2) of forests were converted into aquaculture during 1975-2005 as shown in the Figure.2.5. (Giri et al., 2008).



Source (Giri et al., 2008)

Figure 2.5 Spatial Distribution of Mangrove Deforestation in Ayeyarwady Delta 1975-1990, 1990-2000 and 2000-2005

Nearly 75 percent of mangroves in the Ayeyarwady Delta have been lost over the last 80 years as shown in the Figure 2.6. The data show that mangrove forests had declined from a peak of about 2531.63 km^2 (625,222 acres) in 1924 to 651.54 km^2 (160,930 acres) in 2007. There was nearly half of the decrease in mangroves over the last 15 years and especially after 2001 United Nations Enviromental Program (United Nations Environmental Program [UNEP], 2009)



Source UNEP (2009)

Figure 2.6 Mangrove Deforestation of Ayeyarwady Delta in 1924-2007

2.4 Management and Reforestations or Plantations Establishment

2.4.1 North-Western Australia

Particularly, valuable wetland habitats from an ecological and biodiversity perspective, can be conserved nationally or internationally (e.g. a national park, nature reserve, gazetted forest at national level, or e.g. Biosphere Reserve, Ramsar site, or World Heritage Site at the international level). It is important to keep a protective zone of mangroves as a buffer against coastal erosion. It requires a minimum of 100 m, but preferably up to 500 m or 1 km (as advocated in the Mekong Delta, Vietnam, which is subject to typhoons) at the open coast, and 30-50 m along riverbanks. For conservation and management of mangroves, the activities in the upland water catchment area should also be taken into consideration related to the linkage among different habitats, e.g. water catchment area - mangroves - seagrasses - coral reefs (Macintosh, Donald & Elizabeth, 2002).

2.4.2 Thailand

Recently, Thailand's mangrove forests are still slightly shrinking. Policies were applied as The Integrated Management Plan. Field observations and interviews with local communities showed that there is the willingness to conserve the mangrove area due to the possibility of using it as a sustainable resource of income. For forests as well as for plantations, silvicultural systems have been developed and logging activities all over the country have been banned, small-scale non-commercial uses are the only use of mangrove timber from state-owned land. At present, the establishment of mangrove plantations focuses only on environmental purposes (Bechteler, Annettee, Aura, Eidi, Jakob, Khanchai, Sri, Auvi & Syed, 2006)

2.4.3 Vietnam

By Forest department, the management plan has been prepared for difference units of management as the better protection purpose. The forest management activities in mangroves areas are primarily confined to establish plantations on barren land or to replace existing natural stands. Plantations have been established with the active participation of people since 1978, to restore forests destroyed during the war (Hong & Hoang. 1993).

2.4.4 Philippine

Sustainable conservation and management relies on their strict implementation. Zoning has also been recommended for the remaining mangrove forests into Protected forest, Productive forest, Reforestation, and Conversion zone to allow for integrated coastal zone management. "Greenbelt" or buffer zone requirement of 20-50 m along riverbanks and 50-100 m facing open seas and mangrove-friendly aquaculture technology are already being promoted (Rommel, 2005)

2.4.5 Bangladesh

Since last two decades, Bangladesh has been experiencing more frequent and intense natural disasters. Its southern coastal frontier is one of the most vulnerable regions of the world. As a damage control mechanism, Bangladesh government developed coastal fringes as green belts and converted to forest.

2.4.6 Myanmar

Forestry legislation has been promulgated, for example the 1992 Forest Law, the 1995 Forest Act, the Locally Owned Forest Plots Directives, and the Policy of Myanmar Forest 1995. Management of mangroves started in 1900. The reservation of the Ayeyarwady Delta mangroves began in 1985 and finished in 1904. Scientific management was first introduced in 1902 by means of working plans that involved prescribing working circles and fixing felling series and girth limits for fuel wood production. Forest working circles and divisions were often recognized for administrative purposes.

In Myanmar, Rakhine, Tanintharyi and Ayeyarwady Delta are the three main regions of mangrove forests. They are very similar to each other and use almost the same selection system. However, the Ayeyarwady Delta, which supplies fuel-wood and charcoal to Yangon, is the largest in area. Regulation of yield is on an annual coupe basis but with control based on the size of the trees. The annual allowable cut was determined by dividing the area in the felling series by the number of years in the felling cycle. The felling cycle is fixed at 40 years. However, during the insurgent period (1949–1972), the Forest Department could not manage the forests systematically. Under current practice, a license is given to take forest products from anywhere within the reserve, irrespective of the status of the forest stand (Ohn, 1992).

To conserve the mangrove forests, the Forest Department started to replant plots of mangrove in 1975. Reforestation was also carried out in plots for the village, and individually, in nursery gardens. From 1997, the local people in the Ayeyarwady reserved tidal forests started to replant mangrove forests. Reforestation was carried out at Kadonkani Reserved Forest of Bogalay in the Ayeyarwady delta. In 1993, the production and sale of firewood and charcoal from the mangrove forests of Ayeyarwady Delta were strictly prohibited.

After the prohibition of the commercial production of fuel-wood and charcoal, agriculture and fishing became the main occupations of the region, and economic development slowed down because of over-dependence on existing resources. With the development of fishing and other industries, opportunities to work in new fields other than forestry have been opened. The dependence on the mangrove forest will decrease and its conservation can be promoted. In order to protect and conserve the depleting mangrove resources in time, the Integrated Resource Management Approach is now being implemented. The goal of the new approach is the environmental management and economic development of Myanmar and its people (Oo, 2002).

The National Disaster Preparedness Central Committee (NDPCC) issued a "Program for Reconstruction of Cyclone Nargis Affected Areas in response to the damage caused by Cyclone Nargis. Implementation of the Plans for Preparedness and Protection from Future Natural Disasters", which summarized the recovery, plans of sectoral agencies. Sector-specific recovery plans had based on the environment and resource management. In particular, the Ministry of Forestry's recovery plans provide for extensive replanting and rehabilitation of mangrove forests, community forestry and private plantations, income-generating activities and capacity-building. It also included the usage of mangroves managed by the government, as a combination of modalities that include protected areas (UNEP, 2009).

The recovery plans by the forest department (UNEP, 2009) were implemented as fallows;

2.4.6.1 Forest restoration activities

The forest department already designated and protected as a wildlife sanctuary, the Meinmahla Reserved Forest and also applied IRM (Integrated Resource Management) in Kadonkani reserved forest. A five year plan including the gap planting, the improvement of the natural generation and the establishment of plantations in the degraded mangrove forests was implemented.

2.4.6.2 Establishment of disaster prevention zones

The forest department designated the prevention zones in high risk areas (the areas exposed to the sea). The forest department will totally protect the mangrove forests as the reserved forest and/or protected public forests. The restoration program or tending operations in mangrove forests will be used for well supporting the protection function of mangrove forests.

2.4.6.3 Expanding private tree plantations

The private tree plantation program was started in 2007 with the approval of the Ministry of Forestry. It intends to extend the private plantations in Ayeyarwady and Yangon Division suffered major impacts from Cyclone Nargis.

2.4.6.4 Promoting community forestry

In order to establish community forests, windbreaks and woodlots, there are plans to revive forest users' groups in the Ayeyarwady and Yangon Divisions respectively.

2.4.6.5 Involving local communities in planting programs

The government plans to plant mangrove species along riverbanks in the Ayeyarwady Delta. The Forest Department will implement in collaboration with local authorities and the local people's participation will be encouraged in planting activities and enhanced the role of the local community.

2.4.6.6 Windbreaks

Windbreaks will also be established to protect local community against high wind pressure and tidal surges. Planting trees around settlements, along roads and in woodlots will be involved.

2.4.6.7 Reviving livelihoods of local populations

It involve promoting income-generating activities such as cultivating "Migyaung Kunbut" (*Hygrophila obovata*), planting fruit trees, trapping crabs in mangrove forest areas, as well as horticulture and livestock breeding suited to local conditions.

2.4.6.8 Awareness-raising and extension

To raise awareness on the full range of ecosystem services of mangrove forests and develop improved resource management skills, all activities mentioned above will support for the capacity-building of local populations.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Biophysical and Geographical Descriptions of the Study Area

Ayeyarwady Delta is in the southern part of Myanmar. The total area of Ayeyarwady Division is approximately 155,795 km^2. The mangrove forests of Ayeyarwady Delta is the largest having 1,808 km^2 compared to other mangrove forests of Rakhine 648 km^2 and Taninthayi 1,405 km^2 (Oo, 2004). In Ayeyarwady Delta, the mangrove forests are mainly found in Bogalay and Laputa Townships. The Bogalay Township is located between north latitude 15° 30´ and 16° 40´, and east longitude90° 15´ and 96° 05´ as shown in the Figure 3.1.

The Mangrove forests in Bogalay are primarily located in three Reserved Forests, namely Kadonkani, Meinmahlakyun and Pyindaye Reserved Forests. The maximum and minimum temperature of the study area are 25.08°C and 11.05°C - 37.95°C and total annual rainfall is about 2,809 mm (110.62 inches). The average rainfall, temperature and climatological pattern in Bogalay, Ayeyarwaday Delta (2002-11) are shown in the Figure 3.2. The elevation of study area is 2.47 m (8.1 feet) above the sea level. Bogalay River, Kadon River, Chaung Byae Gyi, Htaw Paing Chaung, and Tae Pin Saik Chaung flow in the Bogalay Township. The area of Kadonkani Reserved Forests has about 605.06 km^2 (149,511 Acres) including about 202.22 km^2 (49,969 Acres) of mangrove forests area and 402.84 km^2 (99,542 Acres) of other land use (Forest Department [FD], 2000). Most of the areas are quite flat alluvial plain.

In the center of Kadonkani reserved forests, there are about 212.20 km^2 for the practice of the integrated resources management (IRM). The IRM area is subdivided into four different management zones, namely, Protected Reserve Areas (PRORA), Special Management Areas (SMA), Buffer Strips (BS), and Multiple Use Zones (MUZ).

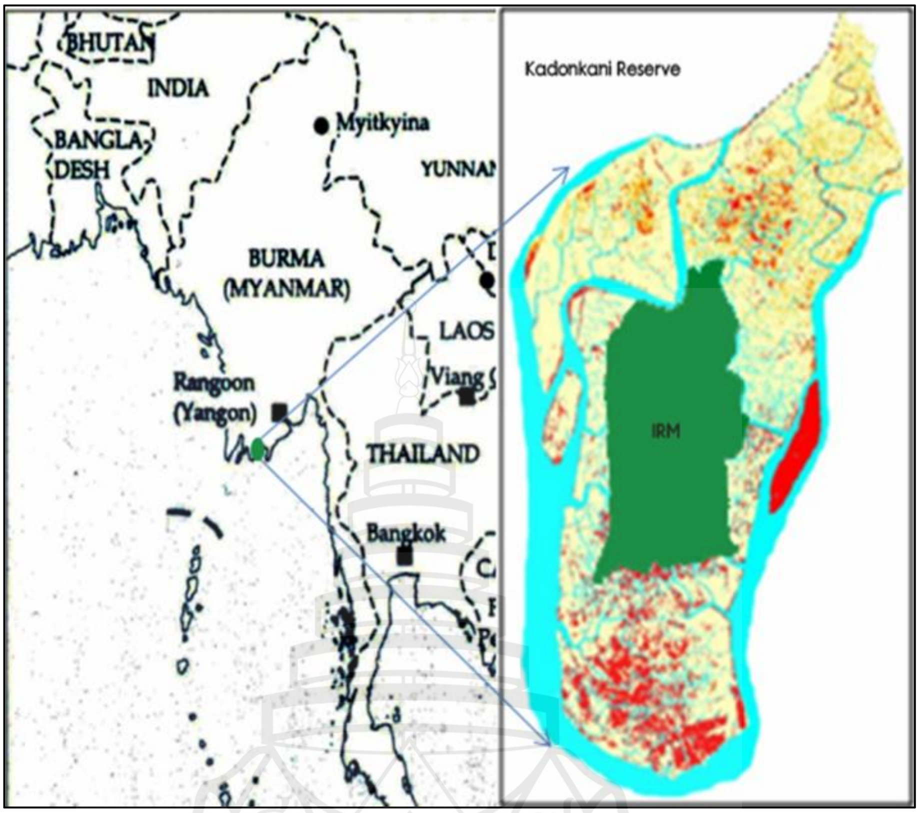
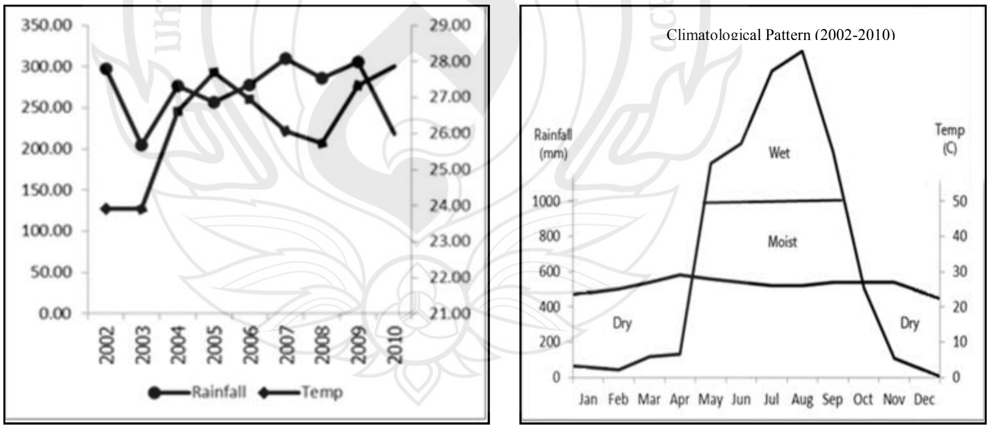


Figure 3.1 Location of the Study Area



Note. Data provided by Department of Agriculture in Bogalay Township

Figure 3.2 Average Rainfall, Temperature and Climatological pattern in Bogalay, Ayeyarwaday Delta (2002-10)

The IRM in the Kadonkani Reserved Forest was commenced in May, 1997 by delineation of the boundary of PRORA. The villages located inside PRORA were reallocated to MUZ areas and the reallocation completed on March 1998. In December 1996, there were 2,708 people in 574 households distributed in 12 temporary villages inside the PRORA including SMA and BS areas (In MUZ, there were 12 villages with the total of 5,143 people in 1,044 households). The goal of IRM in the Kadonkani Reserved Forest is to build a sustainable environment in the sphere of the regional development plan with active local participation, particularly with local organizations and CF user groups. Therefore, these Kadonkani reserved forest was chosen as my study site for sustainable mangrove forests.

3.2 Study of Changes of Mangrove Forests Using RS and GIS

Forest Department has an obligation to ensure that the rate of deforestation and reforestation is monitored, mapped and quantified. The RS and GIS technology would like to be highlighted as one of the most efficient techniques within specific time limit. Therefore, RS and GIS is used as a tool for my study. To find out the mangrove forests cover status in the time of year 2006, 2009 and 2011, the following analyses are performed;

3.2.1 Use 3 different years of Landsat 5 images with world-wide reference system path 133 and row 49 (in 2006, 2009 and 2011) and inventory data (primarily from Forest Department in Myanmar) to compare/assess the changes after the 2008 cyclone, by using RS/GIS with visual interpretation.

3.2.2 Calculation of different index by using ENVI software for the classification of land covers:

3.2.2.1 Normalized Difference Vegetation index (NDVI)

The normalized difference vegetation index (NDVI) is an estimate of the photosynthetically absorbed radiation over the land surfaces. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow. Negative values of NDVI (values approaching -1) correspond to water. Lastly, low positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests (values approaching 1) (Weier & Herring, 1999). In the reviews of this study, Uddin and Gurung (2010), Phan Minh Thu and Jacques Populus, (2007). Conchedda, Durieux and Mayaux (2008), Pling,. Kobryn and Humphreys (2008) Hayes and Sader (2001) were applied NDVI values for their studies. The values of NDVI are calculated as follow;

$$NDVI_i = \frac{(Band\ 4 - Band\ 3)}{(Band\ 4 + Band\ 3)}, \quad \text{.....................Equation(1)}$$

Where, $i = 2006$, 2009 and 2011

3.2.2.2 Normalized Difference Bare land or Built-up area index (NDBI)

The normalized difference built-up index (NDBI) is an indicator of the land surface radiation absorbed in MODIS imagery to classify urban built-up area. NDBI are calculated as follow;

$$NDBI_i = \frac{(Band\ 5 - Band\ 4)}{(Band\ 5 + Band\ 4)}, \quad \text{.....................Equation(2)}$$

Where, $i = 2006$, 2009 and 2011

The NDBI index were used as the reference for the classification of Landsat 5 images in 2006, 2009 and 2011.

3.2.3 Change detection analysis by using NDVI values in year 2006, 2009 and 2011 with ENVI 4.5. NDVI difference analysis in 2009-2006 and in 2011-2009 by using NDVI image differencing method (Hayes & Sader, 2001) was calculated as follow;

$$NDVI_{2009-2006} = NDVI_{2009} - NDVI_{2006} \quad \text{.................Equation(3)}$$

$$NDVI_{2011-2009} = NDVI_{2011} - NDVI_{2009} \quad \text{.................Equation(4)}$$

3.2.4 Classification of land covers in year 2006, 2009 and 2011 by using ENVI software and NDVI indices.

3.2.4.1 Unsupervised classification method

3.2.4.2 Supervised classification method with the reference images of the NDVI images, the unsupervised classification images and the field experience.

3.2.5 Mapping of forest covers in year 2006, 2009 and 2011 by ENVI4.5, and ArcView 3.3 software.

3.2.6 Change detection analysis and mapping in year 2006-2009 and 2009-2011 by using ENVI 4.5, ERDAS IMGINE 9.1 and ArcView 3.3 software.

3.2.7 The calculation of mangrove forest in 2006-2011 by using ENVI 4.5 and ArcView 3.3 software.

3.2.8 The annual rates of change of mangrove covers were calculated by using the following equation suggested by Puyravaud (2003);

$$R = \frac{1}{t_2 - t_1} \times \ln\left(\frac{A_2}{A_1}\right) \quad \text{..........................Equation(5)}$$

Where R = the rate of change of mangrove forests

t_1 = the initial time

t_2 = the final time

A_1= the area of mangrove forests at t_1

A_2= the area of mangrove forests at t_2

3.3 Field Survey

Before the Primary data collection, the collecting the secondary data (Species, diameter, numbers of trees and regenerations) in the year 2008 related the study area were carried out. These secondary data were used for the comparative study with the field data in the year 2012.

Primary data were collected to compare the results of software classification. Field survey follows FD guidelines to collect some quantitative data (no. species, diameter, height) within specific plots;

3.3.1 By using GPS, with the help of Mangrove Experts in the study area, starting point of sample plot is located and then field data were collected by using systematic sampling design.

3.3.2 Collect forest related data (forest species, height, diameter at breast height) to assess forest cover condition in year 2011 after Landsat 5 Satellite image study.

3.3.2.1 Plots size and design was considered with the FD sampling guidelines.

3.3.2.2 Sample plot (10 m x 10 m) with FD Guideline. Within each plot, trees were counted and measured with FD guideline. Tree diameters were measured above 5 cm at the breast height using the diameter tape and tree height were measured with height measuring pole.

3.2.2.3 Seedlings and sapling were counted and measured in 2m x 2m sub-plot.

3.3.3 Plot Design

This plot design is based on the design of Forest Department, Myanmar and modify a little in my design because of accessibility and working condition. About 50 sample plots (0.5 ha) was taken and field data was collected within 50 plots (0.5 ha) due to my limited time and budgets. (See in the Figure. 3.3. Plot Design**)**

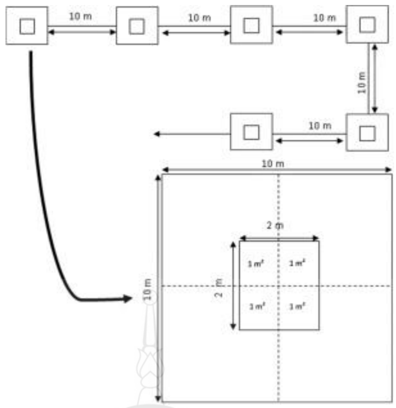


Figure 3.3 Plot Design

3.3.4 Entry the data and analyses the data by using Microsoft Excel sheet.

3.3.5 Data analysis by using statistics software package.

The basal equation of Resources Information Standards Committee (RISC), Resources Inventory Branch, Ministry of Sustainable Resource Management, British Columbia (Resources Information Standards Committee [RISC], 2005) was used to calculate the basal area;

$$Tree\ Basal\ Area\ (BA) = \pi \times \left(\frac{dbh}{200}\right)^2 \quad \text{.................................Equation(6)}$$

Where, BA = Tree Basal Area (m), dbh = diameter at breast Height (cm)

The calculation of tree basal area was based on the formula of the area calculation of circle (πr^2). The diameter (dbh) was divided by two to get the radius of circle (r). The unit conversion (cm to m) was carried out as the basal area was showed by the square meter.

The diameter, height and basal area were used to analyse for the assessment of forest structure according to the silviculture in the tropics (Lamprecht, 1986) and calculated mean and standard deviation of all variables of the field data.

The mean and standard deviation of the basal area were used the comparative study of the basal area with the different years with the test statistics (FAO, 1999) as follow;

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \quad \text{..............................Equation(7)}$$

$$t' = \frac{w_1 t_1 + w_2 t_2}{w_1 + w_2} \quad \text{..........................Equation(8)}$$

$where \quad w_1 = \frac{S_1^2}{n_1}, \quad w_2 = \frac{S_2^2}{n_2}$, t_1 and t_2 = tabular t-value at (n_1-1) and (n_2-1)

The results of t value and t' were used to decide the compare analysis for the basal areas with the different years.

Resources Information Standards Committee (RISC), Resources Inventory Branch, Ministry of Sustainable Resource Management, British Columbia formulated the following model to calculate the basal area growth rate;

$$current\ BA = previous\ BA\ (1 + growth\ rate)^{time}$$

$$growth\ rate = \sqrt[time]{\frac{current\ BA}{Previous\ BA}} - 1 \quad \text{..............Equation (9).}$$

The above equation (4) was used to calculate the basal area growth rate per hectare per year.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Assessment of Mangroves Using Landsat 5 Satellite Images Before and After Nargis Cyclone

The mangrove forests are important ecologically and economically for the coastal communities because they stabilize the shore line and reduce the impact of natural disasters such as tsunamis, hurricanes (Giri et al., 2008). However, the mangrove forests could also be damaged when hit by natural factors like cyclone, drought, fire, strong wind, etc. This damage can be assessed with the advanced technology and spatio-temporal data.

In this study, Landsat 5 images of 3 different years of 2006, 2009 and 2011 were used for the assessment of mangrove forests in Kandonkani Reserved forest as shown in the Table 4.1.

This research focused on the deforestation of mangrove forests before and after the cyclone Nargis and the recovery condition of mangrove forests. The cyclone Nargis passed through the study area on 2-3 May, 2008. Therefore, to analyse the mangrove forest before the cyclone, Landsat 5 image in 2006 was used and for the assessment of deforestation after the cyclone, Landsat 5 image in 2009 was used in this study. Landsat 5 image in 2011 was used for the assessment of the recovery of mangrove forest about 3 years after the cyclone Nargis.

Table 4.1 The Landsat 5 Satellite Images Applied in The Study

No.	Year	Scenes (Path & row)	Satellites	Acquisition dates
1.	2006	133/49	Landsat 5	15 January 2006
2.	2009	133/49	Landsat 5	15 January 2009
3.	2011	133/49	Landsat 5	5 November 2011

4.1.1 Assessment Using Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is a simple index that can be used to analyze and assess whether the target areas are green vegetation. It has been used to assess:

4.1.1.1 The vegetation dynamics or changes over time,

4.1.1.2 The biomass productions,

4.1.1.3 The grazing impacts related to grazing management

4.1.1.4 The vegetation or land cover classification

This study focused on the assessment of changes of mangrove forest after Nargis cyclone.

By using the following NDVI equation (Ryan, 1997) and ENVI 4.5, the NDVI values with same location of year 2006, 2009 and 2011 images were calculated.

$$NDVI_i = \frac{(Band\ 4 - Band\ 3)}{(Band\ 4 + Band\ 3)}, \quad \text{………….. Equation(1).}$$

Where, i = 2006, 2009 and 2011

After calculation, 100 numbers of the pixel location were selected and recorded NDVI values of those of 3 different years of images of mangroves in the IRM area of the study area by using ENVI4.5. These recorded data were analyzed by using the Statistical Software Package. The maximum, minimum, mean and standard deviation of NDVI values with their specific years are as shown in Table 4.2.

Table 4.2 The Results of NDVI Value by Years

Year	NDVI value			
	Minimum	**Maximum**	**Mean**	**Std Deviation**
2006	0.5818	0.9370	0.8389	0.0724
2009	0.3277	0.6963	0.5231	0.0810
2011	0.4745	0.7285	0.6508	0.0481

The NDVI value of 2011 is greater than that of 2009 but not more than that of 2006 as shown in Figure 4.1.

By NDVI image differencing method, NDVI values differences during 2006-2009 and 2009-2011 were calculated as follows;

$$NDVI_{2009-2006} = NDVI_{2009} - NDVI_{2006}$$ …….Equation (2), and

$$NDVI_{2011-2009} = NDVI_{2011} - NDVI_{2009}$$ ……….. Equation (3).

This study found that $NDVI_{2009\text{-}2006} < 0$, i.e., the mangrove forests were degraded during 2006-2009 and $NDVI_{2011\text{-}2009} > 0$, i.e., the mangrove forests were recovered during 2009-2011 as shown in the Figure 4.2

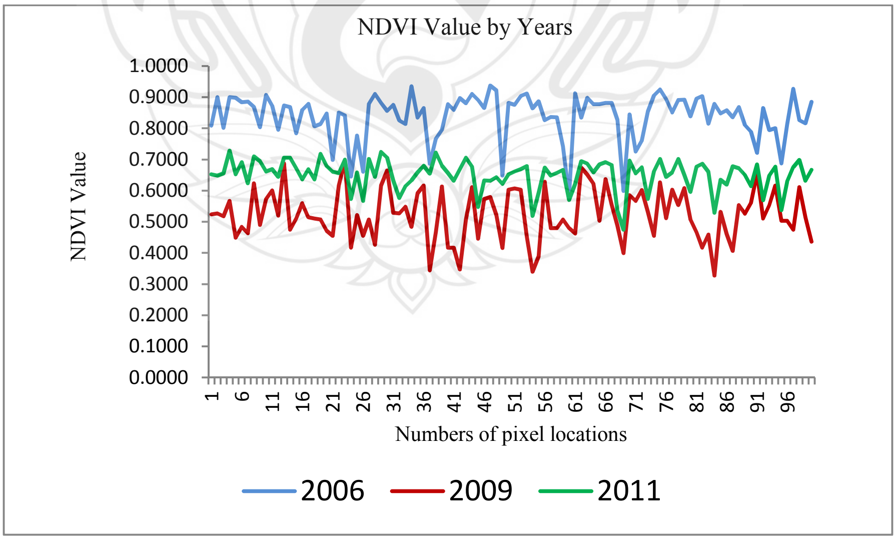


Figure 4.1 NDVI Value of The Study Area By Years

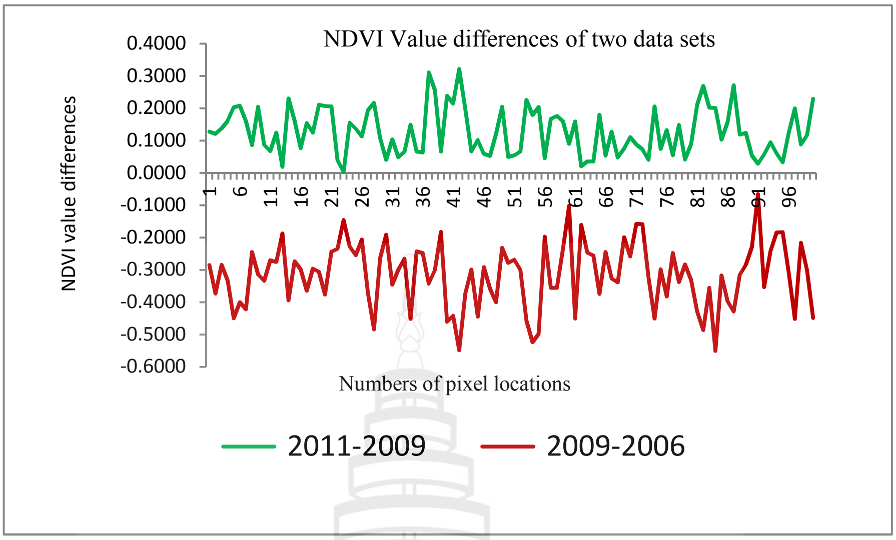
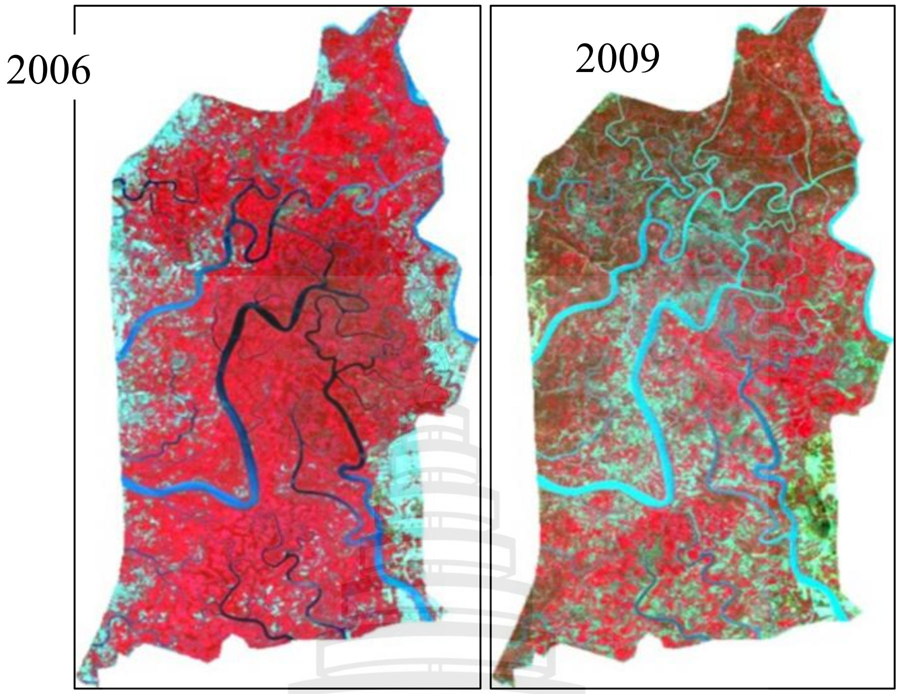


Figure 4.2 NDVI Value Differences of Two Data Sets

4.1.2 Classification of Images and Image Analysis

Three different years of Landsat 5 TM images (2006, 2009 and 2011) with Path 133 and row 49 were used for the assessment of mangrove forests in Kandonkani Reserved forest. These Landsat 5 images cover the study area. To reduce the seasonal effects (i.e., to reduce different radiations, reflections and color tone in different seasons), all images were selected for the winter season. Before image processing, the map projection checking were carried out the boundary map of IRM area and Landsat 5 images of the study area and the required map projections were carried out by using ArcView GIS 3.3. Map projection of the satellite images of the study area is Universal Transverse Mercator (UTM) within Zone 46 N-Datum World Geodetic System (WGS) 84 and the pixel size is 30 m x 30 m. Then, the three different years of Landsat 5 images of the IRM areas were subset. Landsat 5 band 2 (visible green), 3 (visible red), 4 (near infrared), and 5 (mid-infrared) were extracted from the original data sets for data processing. The Figure 4.3 illustrates the yearly false color composites (RGB: 432) of Landsat 5 images of IRM areas inside Kadonkani reserved forest.



Note. The red color represents the vegetation covers and it roughly shown the vegetation cover changes in the different year of 2006, 2009 and 2011 before image processing).

Figure 4.3 Three Different Years of Landsat 5 Images of IRM Area

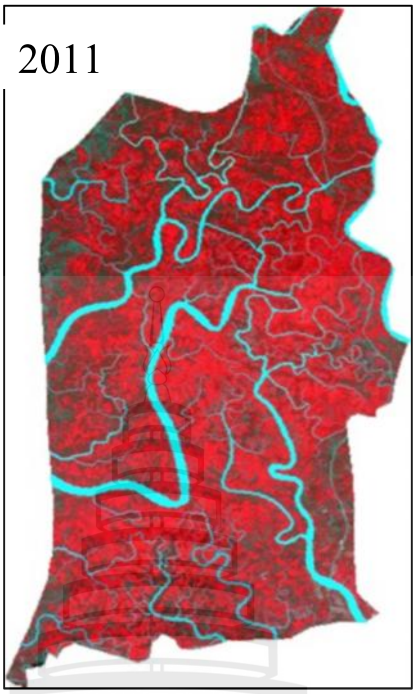


Figure 4.3 (Continued)

4.1.2.1 Unsupervised classification of images

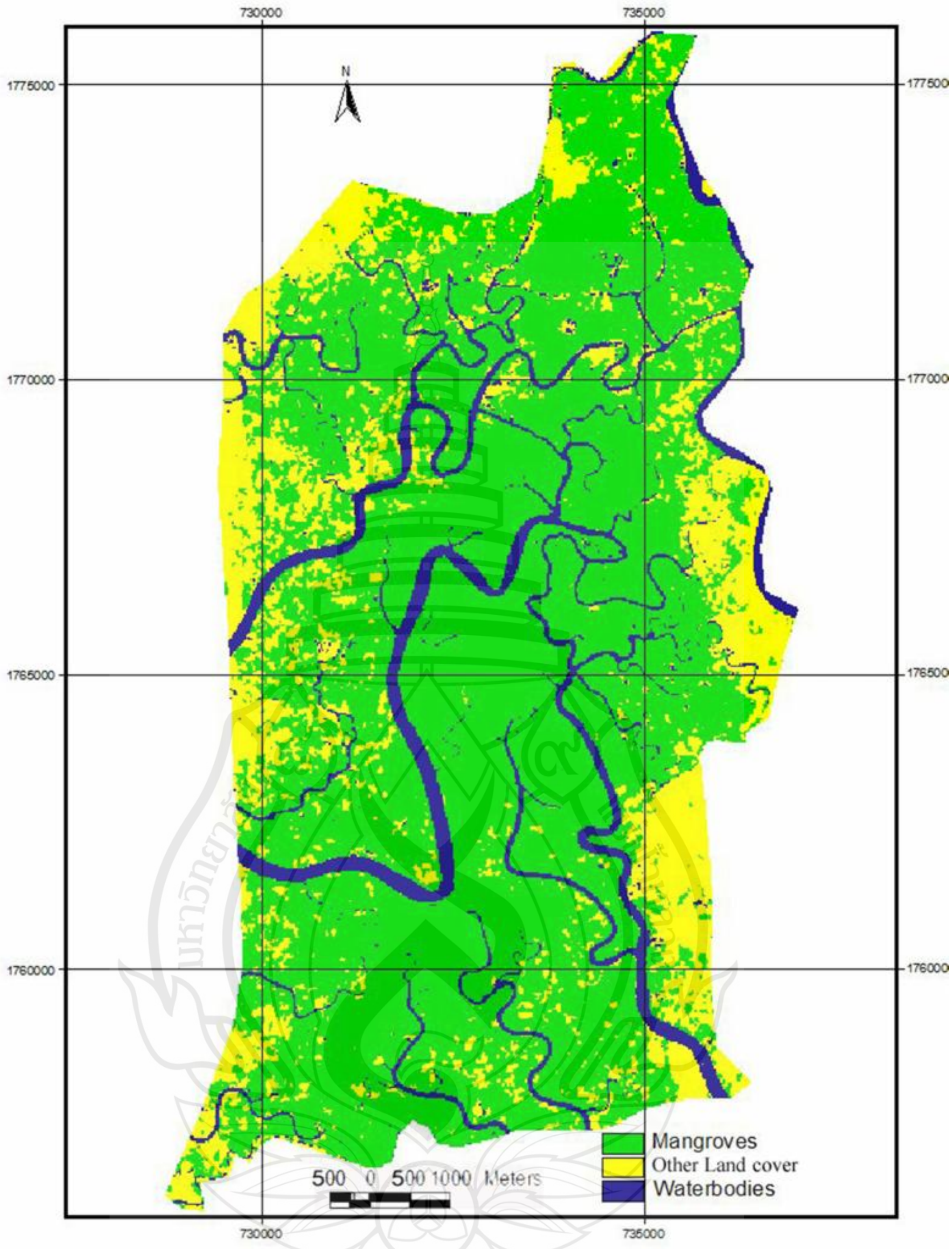
Image classification was developed by ISODATA unsupervised classification to identify spectrally distinct areas. By using ENVI 4.5, each date of the image was input into "isodata" under the unsupervised classification method with 3-7 numbers of spectral classes at 95% of convergence level. Isodata classified images were created by the isolated color groups of pixels through a combination of similar pixels. These classes were marked for all images to avoid the confusion of regions of interests (ROIs) in the land cover classification. These unsupervised classification map would be used for the supervised classification of images as the reference data together with NDVI values and NDBI (Normalized difference built-up index) values to reduced the classification errors. The detail calculations of NDBI can be seen in the chapter 3, the section 3.2

4.1.2.2 Supervised classification of images

Image classification was developed by the supervised classification to identify spectrally distinct areas. The region of interests (ROIs) of the study area including mangrove forests, non-mangroves or other land covers (like grass, weeds, bush, bare land, road etc,) and water bodies were recorded. These ROIs were recorded with the linkage of different displays including the image analysed by unsupervised classification, NDVI values, NDBI values and the past analysed image to reduce the recorded errors. These ROIs were used to identify the image classification with maximum likelihood under the supervised classification method. The Figure 4.4, 4.5 and 4.6 were the results of supervised classification of images for land cover classifications of three different years of 2006, 2009 and 2011.

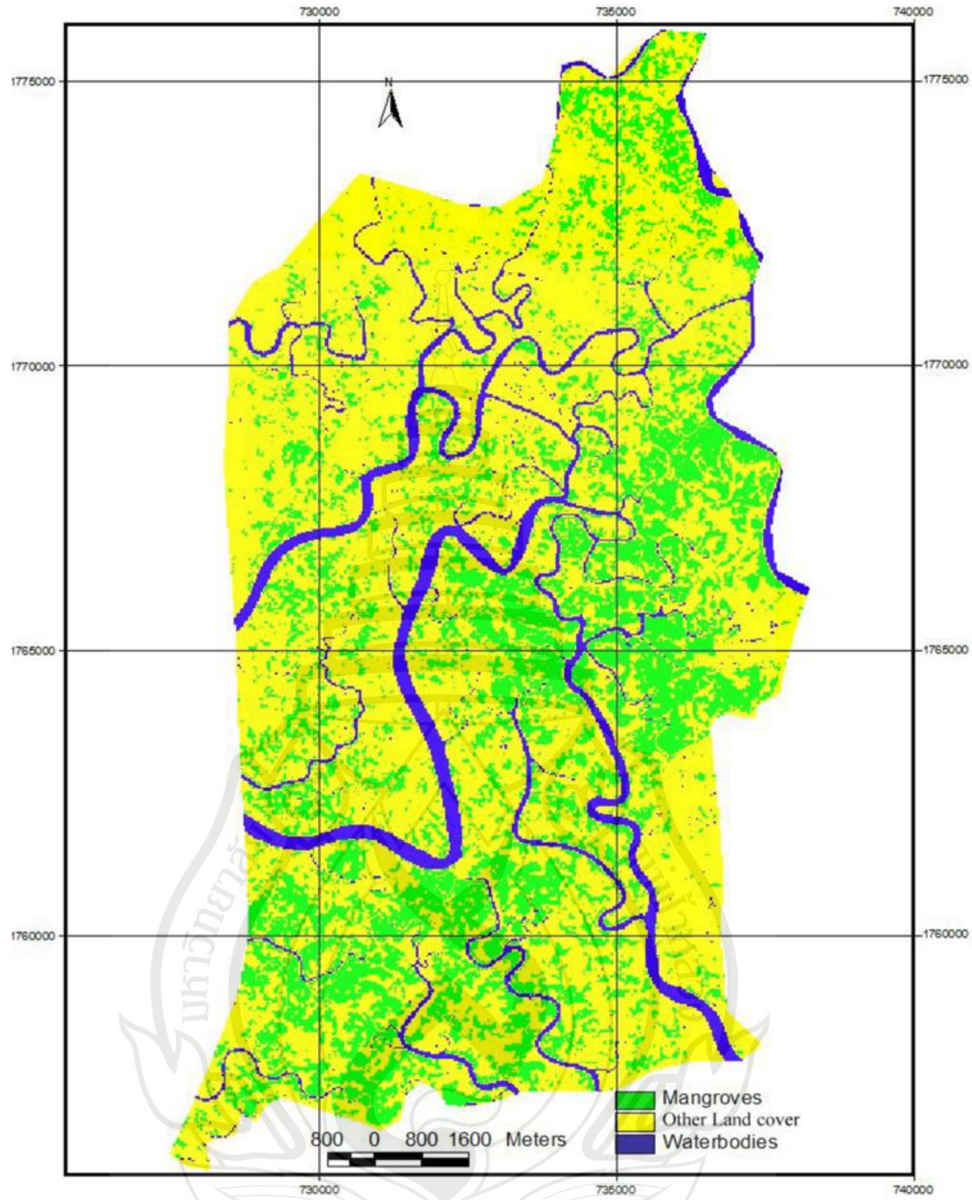
There were 3 different kinds of land cover classes – Mangroves forests cover, other land covers (like grass, weeds, bush, bare land, road etc,) and water bodies in all classification maps. The Figure 4.4 showed the conditions of mangrove forests before the cyclone Nargis. There were very large and dense mangrove forests represented by green color. Large amount of mangrove forests were damaged by the cyclone Nargis as shown in the Figure 4.5. The mangrove forests recover in the year 2011 but the density of mangrove forests was less than the density before the cyclone as shown in the Figure 4.6.

The result of all images would be used for the mapping of the change detection analysis of the mangrove forests in 2006-2009 and 2009-2011. Moreover, the area calculations of the different land cover classes of the 3 different years (2006, 2009 and 2011) would be carried out with the help of these all results of images.



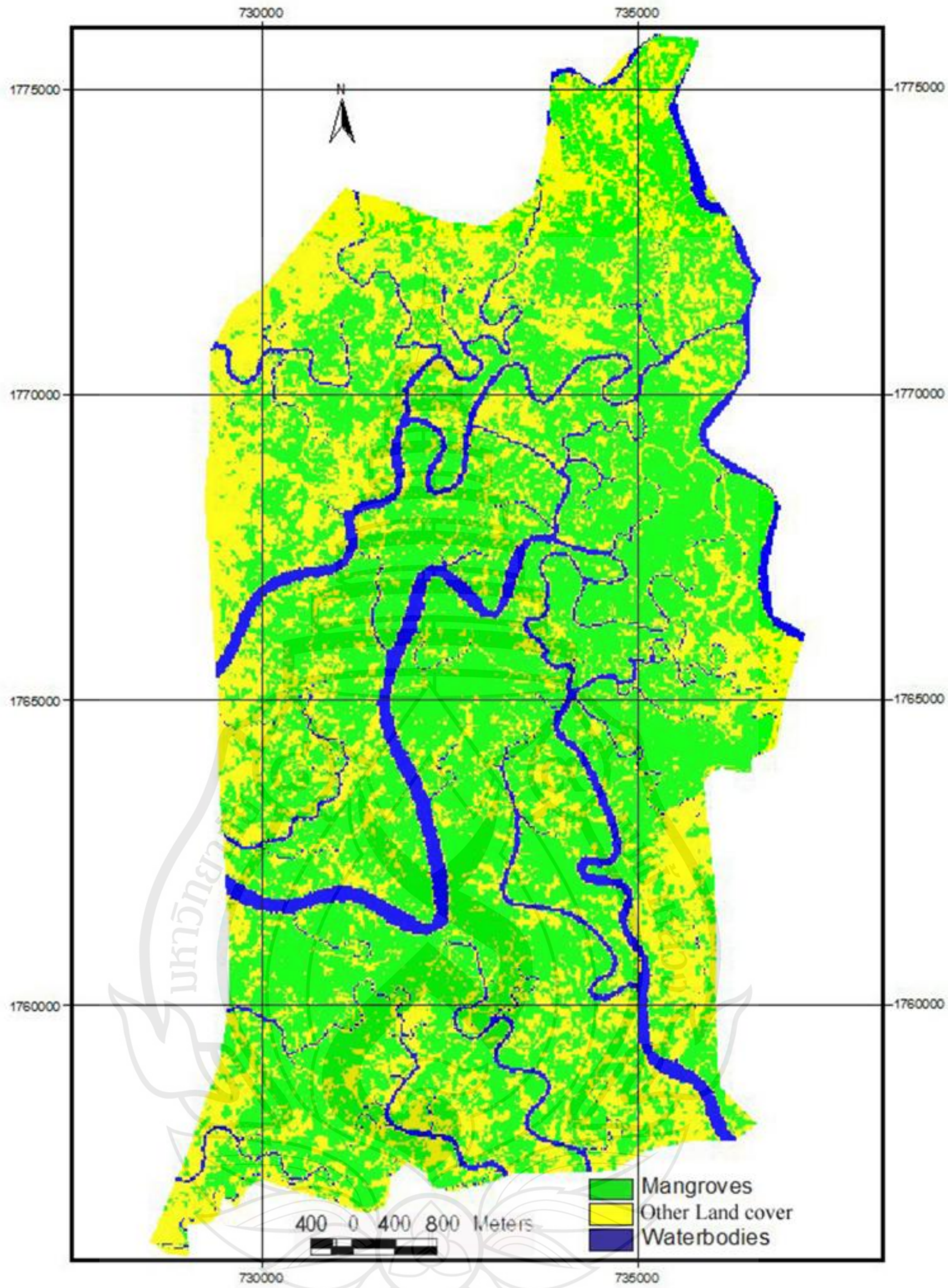
Note. It showed the mangrove forest cover before the cyclone Nargis in 2006. There were very dense and large mangroves in 2006)

Figure 4.4 The Conditions of Mangrove Forests of IRM in 2006



Note. It showed the deforestation of mangrove forest after the cyclone Nargis. The large amounts of mangrove forests were degraded in 2009.

Figure 4.5 The Conditions of Mangrove Forests of IRM in year 2009



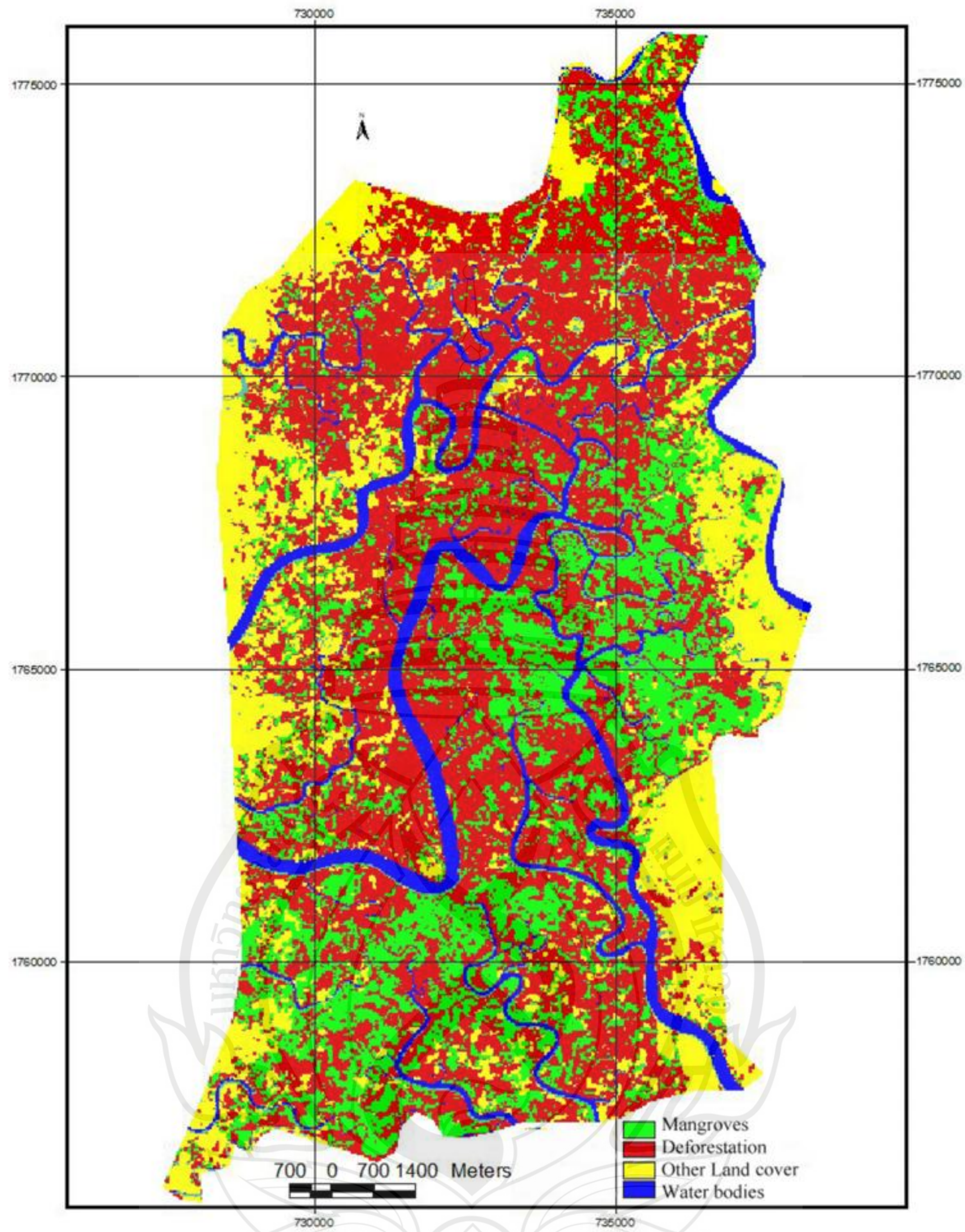
Note. It showed the recovery of mangrove forest after the cyclone Nargis in 2011

Figure 4.6 The Conditions of Mangrove Forests of IRM in year 2011

4.1.2.3 Change detection analysis of mangroves

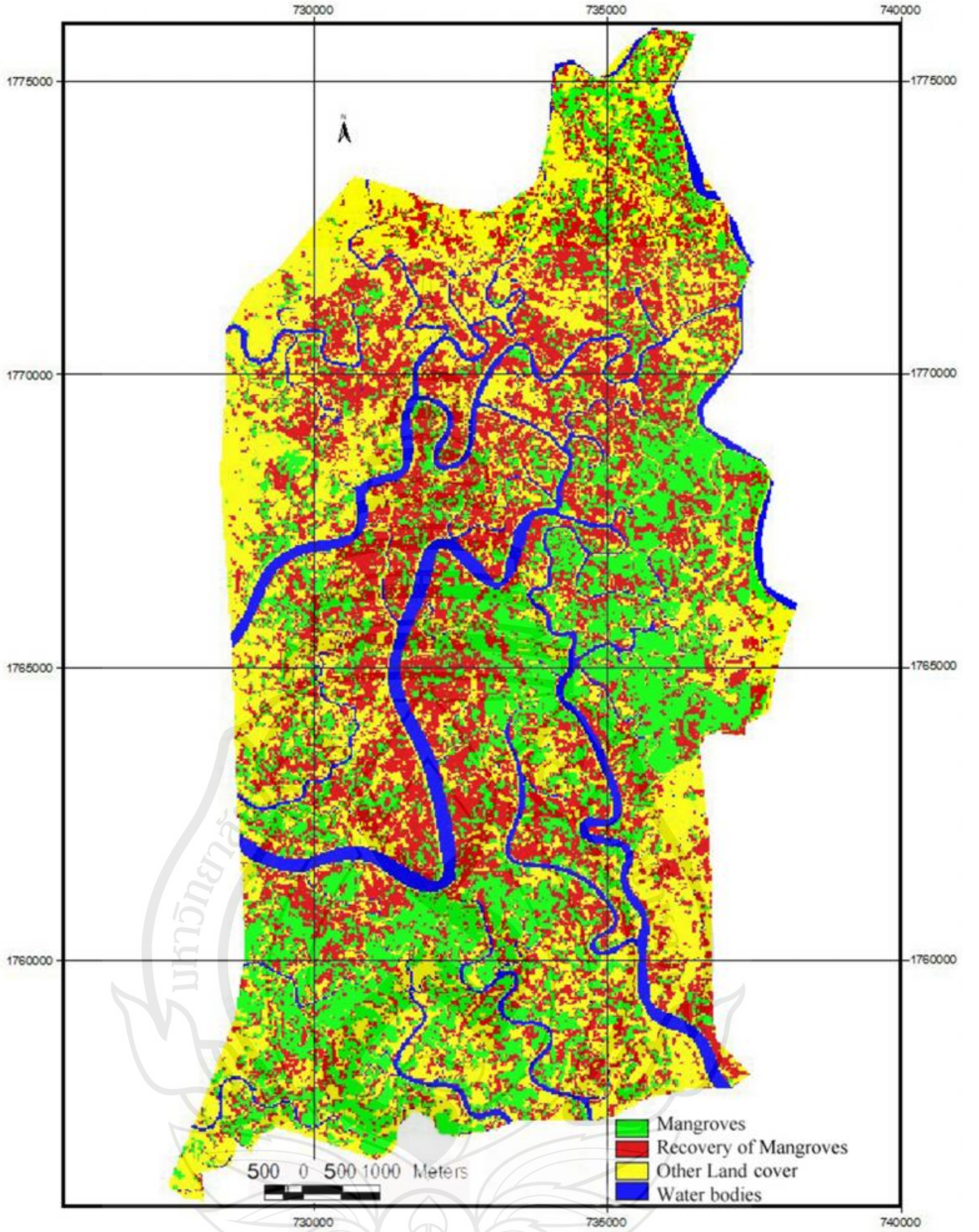
Using ERDAS IMAGINE 9.1, the change detections analysis from the year 2006 to the year 2009 and from the year 2009 to 2011 were taken with the Matrix of GIS analysis under the interpreter. The results of the changes of mangrove in 2006-2009 and in 2009-2011 are as shown in Figure 4.7 and figure 4.8. As the results of change detection analysis in 2006-2009, the mangroves forests were highly degraded after the cyclone Nargis. The mangrove forests were changed to other land covers after the cyclone Nargis in 2009. The reddish brown color in the Figure 4.7 represented the changes of land cover from the mangrove forests to other land covers. The upper northwestern part of IRM areas were more degraded because these areas were closer with the cyclone tract than that of lower southeastern parts.

The Forest Department established the total area of 13.5568 km^2 of the mangroves plantations during 2008-2012. The broadcasting of the mangrove seeds to the opened mangrove forests after the cyclone was also taken by the Forest Department. Therefore, the mangrove forests recovered within a few years. The reddish brown color in the Figure 4.8 represents the recovery of the mangrove forests from other land covers in 2011.



Note. It showed the result of change detection analysis of mangrove forests after the cyclone Nargis and the reddish brown color represented the damaged of mangrove forests after the cyclone in 2009.)

Figure 4.7 The Changes of Land Cover of IRM in 2006-2009



Note. It showed the result of change detection analysis of mangrove forests after the cyclone Nargis and the reddish brown color represented the recovery of mangrove forests after the cyclone in 2011.)

Figure 4.8 The Changes of Land Cover of IRM in 2009-2011

4.1.3 Post Classification of Images

It is the area calculation of the different land cover classes of all images after the maximum likelihood classification of all images. Mangroves, other land cover and water bodies of all images are classified under the maximum likelihood classification. There were accurate pixel numbers of each class and these can be used for the area calculation of all images. By using ArcView GIS 3.3, the land cover calculations were taken and the results of land cover calculation were shown in Table 4.3. According to the results, the mangrove forests were degraded from 99.8766 km^2 to 36.4437 km^2 after cyclone Nargis. It recovered to 76.8456 km^2 in the year 2011 but it was less amounts before cyclone.

Table 4.3 The Results of The Areas Calculation of The Different Land Cover Classes of Three Different Years of Images

Year	Class	Color annotation	Total pixels	Area (km^2)
2006	Mangroves	Green	110,974	99.8766
	Others Land cover	Yellow	32,157	28.9413
	Water bodies	Blue	14,796	13.3264
2009	Mangroves	Green	40,493	36.4437
	Others Land cover	Yellow	104,259	93.8331
	Water bodies	Blue	13,175	11.8575
2011	Mangroves	Green	85,384	76.8456
	Others Land cover	Yellow	59,278	53.3502
	Water bodies	Blue	13,143	11.8287

4.1.4. Annual Rate of Change of Mangroves Forests

After the Post classification of images, the annual rates of change of mangrove covers were calculated by using the following equation suggested by Puyravaud (2003)

$$R = \frac{1}{t_2 - t_1} \times \ln\left(\frac{A_2}{A_1}\right) \quad \text{.......................... Equation(4).}$$

Where R = the rate of change of mangrove forests

t_1 = the initial time

t_2 = the final time

A_1 = the area of mangrove forests at t_1

A_2 = the area of mangrove forests at t_2

Table 4.4 Annual Rate of Change of Mangroves Forests

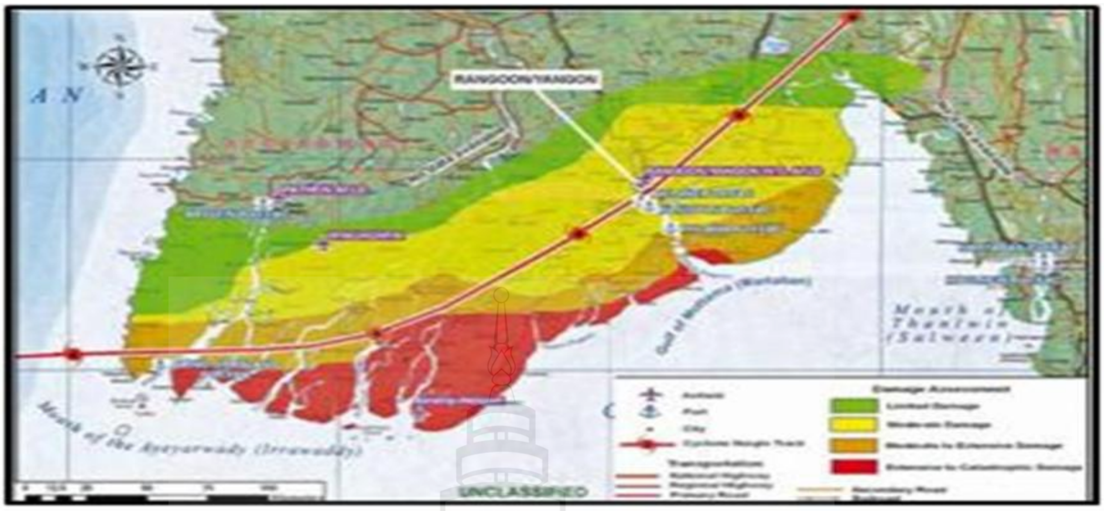
Time period	A_1(km^2)	A_2(km^2)	$\Delta t = t_2 - t_1$ (Year)	R (km^2/yr)
2009-2011	36.4437	76.8456	2	0.3730

In the above table 4.4, the rate of change in 2009-2011 described the annual rate of recovery of mangrove forests during 2009-2011. At this annual recovery rate, the mangrove forests will be returned to their pre-cyclone conditions in 2013.

4.1.5 Effectiveness of Plantation

According to the results of supervised classification, the mangrove forests were decreased from 99.8766 km^2 in 2006 to 36.4437 km^2 in 2009. It increased about 76.8456 km^2 in 2011.

The assessment of damage by the Cyclone Nargis (UNEP, 2009) was as shown in the Figure 4.9. There were 4 types of damage zones- limited damage (green colour zone), moderate damage (yellow colour zone), moderate to extensive damage (orange colour zone) and extensive to catastrophic damage (red zone).



Source UNEP (2009)

Figure 4.9 Map of The Assessment of Damages Caused by Cyclone Nargis

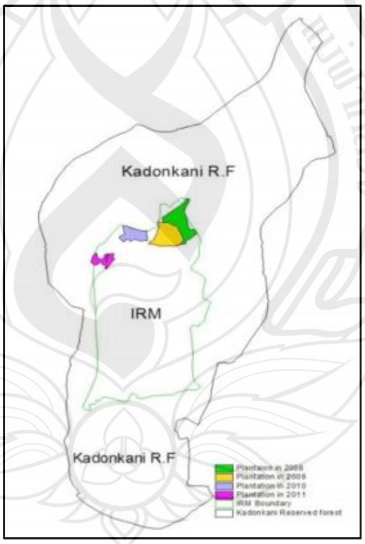


Figure 4.10 Map of Plantation Areas Inside IRM by Year

Table 4.5 Total Areas of Plantations with Their Species Inside The RIM in 2008-2011 after The Cyclone Nargis by The Forest Department

Year	Area(km^2)	Local names	Scientific name
2008	4.0468	Thame	*Avicennia officinalis*
		Byushwewa	*Bruguiera sexangula*
		Madama	*Ceriops decandra*
		Kanaso	*Heritiera fomes*
2009	4.0468	Thame	*Avicennia officinalis*
		Byushwewa	*Bruguiera sexangula*
		Madama	*Ceriops decandra*
		Kanaso	*Heritiera fomes*
2010	3.0351	Thame	*Avicennia officinalis*
		Madama	*Ceriops decandra*
		Kanaso	*Heritiera fomes*
		Byu	*Dillenia aurea*
2011	2.4281	Thame	*Avicennia officinalis*
		Madama	*Ceriops decandra*
		Kanaso	*Heritiera fomes*
		Byu	*Dillenia aurea*

The Northwestern parts of the Kadonkani Reserved forests are close to the cyclone tract. Therefore, the mangrove forests in the Northwestern part of the Kadonkani Reserved forests were more destroyed by the cyclone Nargis. To recover these damage forests, the Forest Department established the plantations in year 2008-2011 in the border of the IRM areas to be clear the boundary of IRM areas as shown in the Figure 4.10. and the Figure 4.11. The amount of hectare and species in 2008-2011 established by the Forest Department are shown in the Table 4.5.

With the result of supervised classification, the calculation of the mangrove forest cover by the plantations (A) and then the annual rate of mangrove forest cover by the plantations (R) were carried out. The results of mangrove forests cover and the annual growth rate of mangrove forest cover by the plantations were as shown in Table 4.6

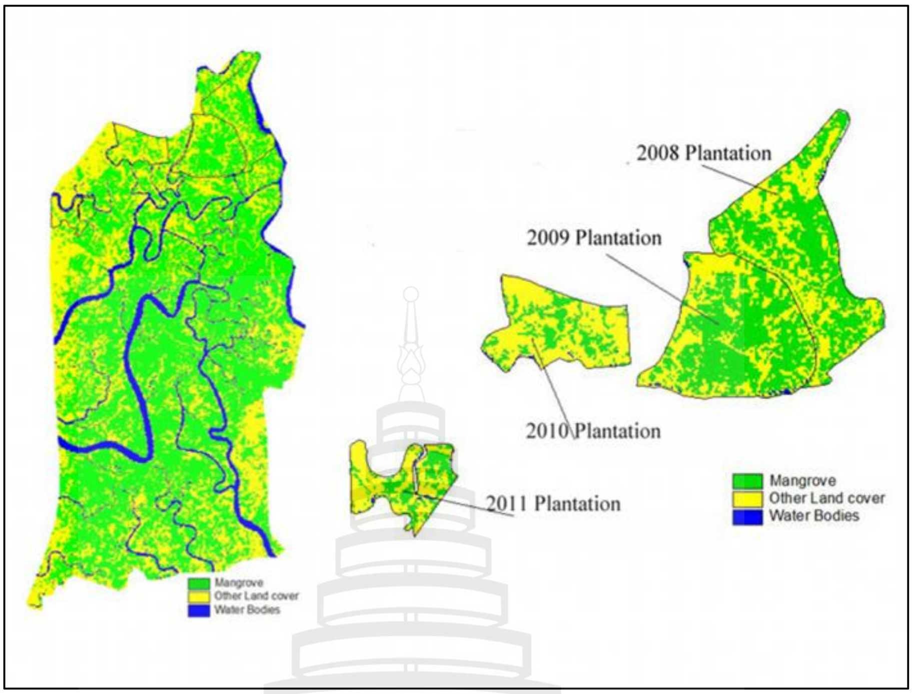


Figure 4.11 The Mangrove Forest Cover by Plantation 2008-2011

Table 4.6 The Mangrove Forest Cover and The Annual Growth Rate of The Mangrove Forests Cover by Plantations

Year of Plantations	Area of Plantation in km^2	Forest cover in 2009 (A_1) km^2	Forest cover in 2011 (A_2) km^2	R (km^2/yr)
2008	4.0468	1.3626	2.4354	0.2904
2009	4.0468	0.7290	1.7856	0.4479
2010	3.0351	0.0630	0.6471	1.1647
2011	2.4281	0.1800	0.4590	0.4680
Total	**13.5568**	**2.3346**	**5.3271**	**0.4125**

The results of mangrove cover by plantations in 2008-2011 showed that $A_{2(2008)} > A_{2(2009)} > A_{2(2010)} > A_{2(2011)}$. The mangrove forest covers were large if the age of plantation was older. Therefore, the plantations influence on the forest cover and forest cover growth rate and they are important to restore the degraded mangrove forests.

Table 4.7 The Mangrove Forest Cover and The Annual Growth Rate of The Mangrove Forests Cover by Natural Mangrove Forests

Total area of IRM	**Area of IRM in km^2 without 2008-2011 Plantations Area**	**Forest cover of IRM in 2009 (A_1) km^2 without 2008-2011 Plantations Cover**	**Forest cover of IRM in 2011(A_2) km^2 without 2008-2011 Plantations Cover**	**R (km^2/yrs)**
212.20	198.6432	34.1091	71.5185	0.3702

According to Table 4.6 and 4.7, the annual growth rate of mangrove cover by the plantation is 0.4125 km^2/yrs and the annual growth rate of mangrove cover by the natural forests is 0.3702 km^2/yrs. The annual growth rate of mangrove cover by the plantation is greater than by the natural mangrove forests. Therefore, the efficiency of the mangrove plantations is important role in the restoration program of mangrove forests.

4.2 Assessment of Mangroves Using Field Data

RS and GIS study of this research in the previous section 4.1 cannot support the conditions of the structure of mangrove forests. Thus, the field data were used to assess the changes of mangrove structure and to calculate the basal area growth rate. The test statistics was used to analyse the mean basal area in the year 2008 compared with the mean basal area in the year 2012. This analysis is used to support the calculation of growth rate and to estimate the volume or biomass of forest in the future.

After Nargis cyclone in the year 2008, Forest Department carried out the Forest Inventory in the study area. These data in the year 2008 were used as secondary data for the comparative study with the field data of the study in the year 2012. The primary data were also collected in the compartment 49 and 51 of Kadonkani Reserved forest, Bogalay Township. There were 65 sample plots and 10 m x 10 m of each plot. Field data also were collected in the compartment 49 and 51. By using GPS, 10 m x 10 m square sample plots were recorded with 20 m equal distance within my study area. In each plot, trees with > 5 cm DBH were measured by using diameter tape and tree-heights were measured by using height measuring pole. The regenerations were counted within 1 m x 1 m sub-plot of each 10 m x 10 m plot (See in chapter 3 Fig 3.3.1). Species names are recorded by local names with the help of local forestry staff and local people in my study area and then were converted to scientific names. There were totally counted 50 sample plots in the study area. More information on the field survey can be found in the Chapter 3.

4.2.1 Field Data Analysis, Results and Discussions

Field data were entered by using Microsoft Excel sheet according to a field data sheet; number of sample plot, name of the species, diameters of species (cm) and heights of species (m). In Resources Information Standards Committee's report (RISC's report), Resources Inventory Branch, Ministry of Sustainable Resource Management, British Columbia, the basal area (BA) for a tree is calculated by the area formula for a circle, using the diameter at breast height (DBH) as input data. Basal area is expressed in square meters. For basal area calculation, the following mathematical equation is applied;

$$Tree\ Basal\ Area\ (BA) = \pi \left(\frac{dbh}{200}\right)^2 \quad \text{.......................... Equation(5).}$$

Note: dbh is in cm and tree basal area is in meters.

After entering the field data, to calculate the data with 95% confidence level, Statistical Software Package is applied. The number of stems with diameter distribution of the forest is one important parameter for regulating the forest in line with sustainable management. In normal distribution (Lamprecht, 1986)

4.2.1.1 The smaller DBH classes have the bigger stem numbers and gradually declining to bigger DBH classes.

4.2.1.2 The smaller DBH classes have the smaller basal area and increasing to bigger DBH classes.

4.2.1.3 The basal areas of smaller DBH classes are smaller and high amounts, that of bigger DBH classes are bigger and less amounts.

4.2.1.4 The heights of the species were also normal distributed with their DBH classes.

According to the secondary data in the year 2008 after Nargis cyclone, there were lost in smaller DBH classes and the regeneration of some species were lost. The diameter distribution curve was beyond the normal distribution but the diameter-basal area relationship was still normally distributed and arises from smaller to higher diameter class as shown in the Figure 4.12

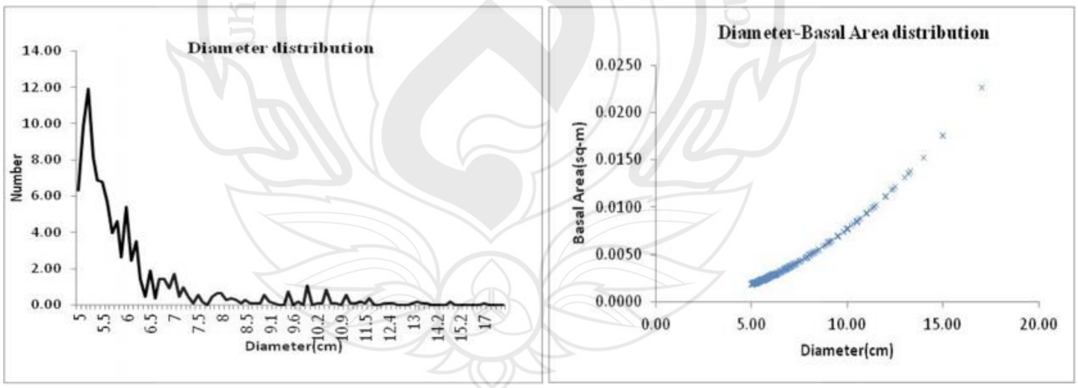


Figure 4.12 Structure of Mangroves in 2008 After Nargis Cyclone

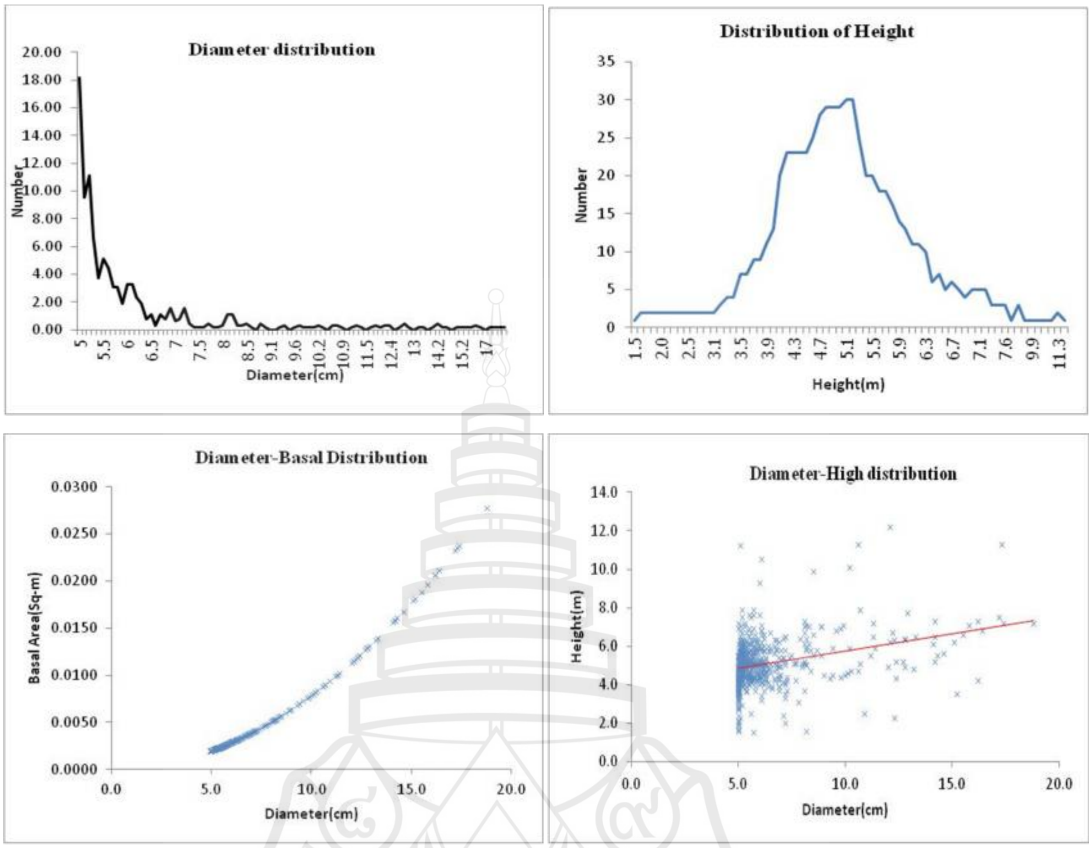


Figure 4.13 Structure of Mangroves in 2012 After Nargis Cyclone

In the study area according to the data collected in year 2012, it can clearly be seen that most of trees were in small diameter classes in all stands and the reserve of small-diameter trees in the study area is adequate to replace the losses in large diameter trees. The stand structures of the study area follow the normal distribution and the development pattern. Therefore, Kadonkani Reserve follows the ideal structure having more trees in smaller diameter classes, normal distribution of the height of the species and basal area of the species as shown in the Figure 4.13.

In the Figure 4.14, the distributions of mangrove regenerations in the year 2008 and 2012 are nearly the same but the distribution of mangrove tree species are different in the year 2008 and 2012. It showed that the rural community used the mangrove forests for housing and other requirements after cyclone. The natural regeneration will not recover these degraded of mangrove forests. Therefore, the government plantation and private plantation were introduced in the cyclone affected areas with the permission of Forest Department.

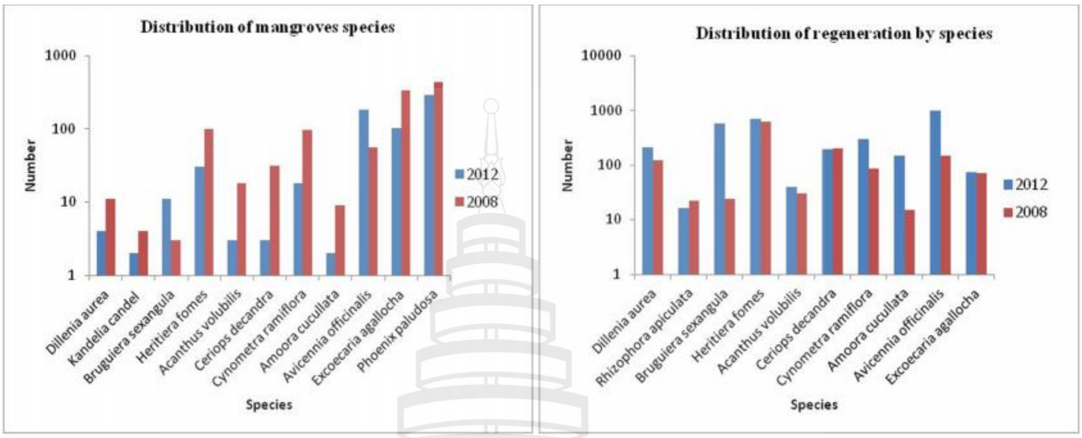


Figure 4.14 Mangroves Species in 2008 and 2012

According to the table 4.8, there have an average number of total numbers of trees of 2.8615 per hectare, an average number of regenerations of 12.2386 per hectare, an average diameter of 9.3158 cm per hectare and an average basal area of 0.0047 Sq-m per hectare in the year 2008. In year 2012, there have an average number of trees of 7.4788 per hectare, an average number of regenerations of 16.5728 per hectare, an average height of 10.1242 m per hectare, an average diameter of 12.5420 cm per hectare and an average basal area of 0.0069 Sq-m per hectare.

Table 4.8 Conditions of Mangroves in 2008 and 2012 After Nargis Cyclone

Categories	N	Minimum	Maximum	Mean	Std. Deviation
In year 2008					
Diameter.cm	1108	5.0000	17.0000	6.0553	1.4713
BeasalArea.sq.m	1108	0.0020	0.0227	0.0030	0.0019
No.Regeneration	156	1.0000	50.0000	7.9551	7.4143
Total no.	**1264**	**1.0000**	**50.0000**	**1.8600**	**3.4620**
In year 2012					
Diameter.cm	649	5.0000	18.8000	6.2710	2.1917
Height.m	649	1.5000	12.2000	5.0621	1.2319
BasalArea.sq.m	649	0.0020	0.02770	0.0034	0.0033
No.Regeneration	391	1.0000	43.0000	8.2864	6.8713
Total no.	**1040**	**1.0000**	**43.0000**	**3.7394**	**5.4946**

Note. 65 Sample Plots (0.65 ha) in The Year 2008 and 50 Sample Plots (0.5 ha) in The Year 2012.

4.2.2 Comparative Analysis of Variables

It is desirable to compare means of two groups of observations representing different populations to find out whether the populations differ with respect to their locations. In this case (FAO, 1999);

The null hypothesis, $H_0 : \bar{x}_1 = \bar{x}_2$ and

The alternative hypothesis, $H_1 : \bar{x}_1 \neq \bar{x}_2$ i.e., $\bar{x}_1 < \bar{x}_2$ or $\bar{x}_1 > \bar{x}_2$.

The test statistic is used under certain assumptions; (1) the variables involved are continuous, (2) the populations from which the samples are drawn to follow the normal distribution, (3) the samples are drawn independently, and (4) the variances of the two populations from which the samples are drawn are homogeneous or equal

(FAO, 1999). Under the assumption of equality of variances of two populations, the following equation can be used in the analysis;

$$t = \frac{(\bar{x}_1 - \bar{x}_1)}{\sqrt{S^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$ ....Equation(6)

If the variances of two populations are not equal, the above equation is not applicable. In such cases, a slightly different equation can be used as follows;

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$ ....Equation(7)

Let $\bar{x}_1$ be the average basal area in year 2012, $\bar{x}_2$ be the average basal area in year 2008 and S_1^2 be variance of basal area in year 2012, and S_2^2 be variance of basal area in year 2008.

$\bar{x}_1 = 0.003464$, $\bar{x}_2 = 0.003044$ and

$S_1^2 = (0.0033264)^2$, $S_1^2 = (0.0019339)^2$

Hypothesis, $H_0 : \bar{x}_1 = \bar{x}_2$

$H_1 : \bar{x}_1 \geq \bar{x}_2$

Compute the value of test statistic (t) using the following formula,

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$ ....Equation(7)

Compare the computed t value with weighted tabular t value (t') at the desired level of probability. The weighted tabular t value is computed as shown below,

$$t' = \frac{w_1 t_1 + w_2 t_2}{w_1 + w_2}$$ ....Equation(8)

$$where \quad w_1 = \frac{S_1^2}{n_1}, \quad w_2 = \frac{S_2^2}{n_2} \ .$$

t_1 and t_2 are the tabular t-values at $(n_1$-1) and $(n_2$-1) degrees of freedom respectively, at the chosen level of probability. At 95% confidence level of Student's t distribution table,

$$t_1 = 1.64 \text{ and } t_2 = 1.64$$

After calculation of t and t', the following results are obtained;

$$t = 2.94 \text{ and } t' = 1.69$$
$$t(2.94) > t'(1.69)$$

In this study, $H_0 : \bar{x}_1 = \bar{x}_2$, $H_1 : \bar{x}_1 \geq \bar{x}_2$, and then $t > t'$. Therefore, the two means are significantly different and then, $H_0 : \bar{x}_1 = \bar{x}_2$ is rejected and $H_1 : \bar{x}_1 \geq \bar{x}_2$ is accepted. This study showed that the basal area in the year 2012 is greater than those in 2008. Therefore, there had the basal area growth during 2008-2012, or there had some acceptable recovery of mangroves in the year 2012.

4.2.3 Basal Area Growth Rate

Annual basal area growth rates were calculated at time intervals of 4 years to previous sampling. The input data used were measured lengths taken from increment cores at the two time intervals, the DBH over bark thickness. Growth rate is calculated based on the compound increment function by Resources Information Standards Committee (RISC), Resources Inventory Branch, Ministry of Sustainable Resource Management, British Columbia;

$$current\ BA = previous\ BA\ (1 + growth\ rate)^{time}$$

$$growth\ rate = \sqrt[time]{\frac{current\ BA}{Previous\ BA}} - 1 \qquad \text{……………..... Equation(9).}$$

$$current\ BA = 0.003464 \text{ m}^2$$

$$previous\ BA = 0.003044 \text{ m}^2$$

$$time = 4$$

$$growth\ rate = 0.033\ m^2 \text{ (for 0.5 ha/4 years)}$$

The result of basal area growth rate of the study area is 0.0165 m^2/ha/yr. This growth rate can be used the estimation of mangrove forest in the future.

4.3 Comparative Study Between The Results of Mangrove Forest Cover and Mangrove Forest Structure

As the results of mangrove forest cover in the section 4.1 and the results of mangrove forest structure in the section 4.2, the summary of the comparative study were shown in the Table 4.9 and the conditions were found as follow:

4.3.1 The minimum and maximum NDVI values were increased in 2009-2011 and the forest cover condition also increased in 2009-2011. Therefore, the forest cover conditions with RGB=432 of Landsat 5 image changed from light red color to bright red color and from scatter to dense.

4.3.2 The average diameter, basal area, the number of tree, and the number of regenerations were increased in 2008-2012.

4.3.3 The mangrove forest covers were scatter and the structures of mangrove forests were less in the deforestation condition. The mangrove forest covers were dense with bright red color and the structures of mangrove forests were increased in the recovery condition. Therefore, the mangrove forest covers were directly related to the structure of mangrove forests. The more mangrove forest cover will be dense, the better the structures of mangrove forests will be and then, the mangrove forests will follow the normal forests.

Table 4.9 Land Cover Condition of Satellite Imagery and Structural Condition of The Mangrove Forests Status

Changes	**Forest cover with RGB=432 of the Landsat 5 image**	**Photo with structural characteristics of mangrove forests**
Deforestation	 1. Light red, scatter cover 2. 36.4437 km^2 forest cover inside IRM 3. NDVI Min 0.3277 Max 0.6963	 Mean Diameter (9.3158 cm/ha) Basal area (0.0047 m^2/ha) No. regeneration (12.2386/ha) No. Tree (2.8515/ha)
Recovery	 1. Brightt red, dense cover 2. 76.8456 km^2 forest cover inside IRM 3. NDVI Min 0.4745 Max 0.7285	 Mean Diameter (12.5420 cm/ha) Basal area (0.0069 m^2/ha) No. regeneration (16.5728/ha) No. Tree (7.4788/ha)

CHAPTER 5

CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions

The updated and reliable information about forest cover is vital important to investigate the tropical forest degradation and to manage forests sustainably. In this study, three different years of Landsat 5 images were applied to assess the changes of mangroves forests. The changes assessment with NDVI values of these images and with land cover classification methods such ISODATA unsupervised classification and Maximum likelihood supervised classification. It is a cost-effective method with the reliable results and these results can be used to study in mangrove forests cover assessment. The geospatial data generated by Landsat 5 satellite images supported the up to date, consistent and unbiased distribution, the extent and dynamic of mangrove forests for the time series analysis. The spatial and temporal detail information may be more reliable because it reduced the measurement error of the data collection in the field.

This study demonstrated that the changes of NDVI values with related changes of mangroves forests in the different years of time period and the classification methods for the assessment on the changes of mangroves forests by using the geospatial analysis were the useful technique for the monitoring and the assessment of mangrove forests. As the results of NDVI values and the land cover images of this study at the chapter 4, the mangrove forests after the cyclone in 2011 is lower density before cyclone in 2006. Maximum likelihood classification can produce the most accurate and sound classification results because of their representative ROIs with the accurate reference data of NDVI image, NDBI image and the image of the past study. However, it requires more work to define the ROIs with the reference data.

Therefore, the knowledge of the interpreters, the resolution of images used in this study and the available ground information are the vital role in the determining the classification of the images to get accurate results. By using the accurate results of the maximum likelihood classification maps and change detection analysed map, the potential site for restoration or reforestation program can be easily chosen and decide for the management plan.

Land cover changes of mangroves forests, the changes of the physical features of the mangroves forests on the earth surface were affected by the deforestation, replanting and the natural restoration. The Cyclone Nargis reduced the extent of mangroves forests but the mangroves forests recovered in the protected area like IRM areas of Kadonkani reserved forests. Both the protected area system and the reforestation program are the effective tools for improving the mangrove ecosystem for the conservation and protection of mangrove forest under the mangrove forests management. The geospatial data or information of land cover map can support in decision making to conserve and rehabilitate the existing mangroves forests and to conduct the land use planning for the management of the mangroves forests in the future.

This regional analysis is the initial stage to assess the changes of mangroves forests and role of mangrove forests for the local people facing with natural disasters such the cyclone Nargis 2008. This study may be referenced to assess the future changes of mangrove forests of the study area and mangroves forests of Ayeyarwady Delta and may assist the decision making processes for rehabilitation and conservation efforts that will be needed to protect and restore the degraded and deforested mangroves forests. The degraded and deforested mangroves forests were enhance under the mangrove forest managements and plantation management according to the results. Moreover, RS and GIS technique should be applied as a tool in the sustainable mangroves management for the protection and conservation purposes in the future. The technical assistance and training program will be required to manage the mangrove forests with the advance technologies.

5.2 Recommendations

The challenge of the deforestation and degradation of mangrove forests are facing in all over the world. The mangrove forests are very important because of their protection functions and production functions supporting for the local people. The lack of mangrove forests decreases the coastal protection function and increase of disaster risks and vulnerability of the livelihoods of coastal community relied on the mangroves according the different parts of scientific studies in the world. The restoration of mangrove forest is the important role to reduce the disaster risk and vulnerability. The effective plantations were highlighted in the restoration program of the mangrove forest and it can be used as the effective tool for the management of mangrove forest in the future. The RS and GIS can also be used as a tool for the monitoring and evaluation of the mangrove forests in the future.

Nowadays, the modernized technologies and materials are applied in the different parts of scientific studies of the world. The further studies related to the assessments of mangrove forests are as the follows;

5.2.1 The different parameters such as climatic conditions, soil, tidal fluctuation, geographic data and socioeconomic data should be incorporated to the future study for the assessment of mangroves forests.

5.2.2 After the changes of mangrove by deforestation, the ecological adaptation and dynamic of mangrove vegetations should be studied to assess mangrove species compositions and the extent because some species may be extinct or rare in the future.

5.2.3 The effectiveness of the disaster risk reduction of coastal protection related to the changes of mangrove forest should also be studied by using RS & GIS.

5.2.4 The assessment of the ecosystem services in the mangrove forest related to the mangrove deforestation.

The mangrove biomass and the carbon sequestration of the mangrove forests should be predicted for future carbon market of the mangrove forests. The relationship between the changes of mangrove habitats and the population mangrove animal species should be analysed because some mangrove plant and animal species are the endanger species and should be protected.

The structures of mangrove forests are very important to determine the conditions and changes of mangrove forests. It take very long period of time to collect field information because of the mangrove root systems and tidal conditions. However, the structure of mangrove forests using high resolution satellite images and aerial photographs could be analysed in the inaccessible areas for supporting the management of mangrove forests. The relationship between the conditions of changes of the mangrove forest and the natural disasters like cyclone and tsunami in the past history should also be assessed by using RS and GIS for the management of mangrove forests against high speed wind, cyclone and tsunami.

The systematic and cost-effective forest management should be encouraged to maintain the sustainability of mangrove forest resources using the information and knowledge of the past and further studies related to the mangrove forest management. Monitoring and evaluation of mangroves forests by using the geospatial analysis to support the useful data source for the management of mangrove forests in the future should be continued. Moreover, the more experts and the young researchers related to mangrove forest management are also needed for the conservation and sustainable management of mangrove forests in the future.

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APPENDICES

APPENDIX A

Field Sheet for Collection of Tree Species

Date	Plot no	Plot-GPS point	Specie name	Diameter	Height	Remark

APPENDIX B

Field Sheet for Collection of Regenerations

Date	Plot no	Plot-GPS point	Specie name	Number	Remark

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