Doctoral Dissertation

博士論文

Resilience of the Mangrove Ecosystem and Its Restoration Perspectives in the Mega Delta of Myanmar

ミャンマーのメガデルタにおけるマングローブ生態系の回復力とその復元

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Chapter I

Background of the Study

1.1 What is mangrove?

Regarding the term of mangrove, there are a variety of definitions described by many authors, amongst which one of the well-known biologists, Tomlinson (1986) states that mangroves are trees, but their form is very versatile: in marginal habitats they are low, scrubby plants, whereas under favorable conditions they can form majestic forests with the canopy 30 to 40 m tall. According to Mckee (1988), the term “mangrove” refers to an assemblage of tropical trees and shrubs that grows in the intertidal zones, and it includes approximately 16 families and 40 to 50 species. A mangrove is also defined as a tree, shrub, palm or ground fern, generally exceeding one half meter in height, that normally grow above mean sea level in the intertidal zone of marine coastal environments and estuarine margins, and it is also the tidal habitat comprising such trees and shrubs (Duke 2006).

1.2 Geographical distribution of mangroves

Mangrove distribution is circum-global with the majority of populations occurring between the latitudes of 30° N and S (Tomlinson 1986). At one time, 60-75 % of the world’s tropical and subtropical coastlines were covered by mangroves (Spalding *et al.* 1997); however, their extent has been significantly reduced due to human activities. According to the World Atlas of Mangroves 2010 in Figure 1.1 (Spalding *et al.* 2010), there are two main bio-geographical distribution of mangrove diversity: the Eastern hemisphere, also called Old World Mangroves, including Australia, Southeast Asia, India, East Africa, and the Western Pacific where the total number of species is approximately 40 ~ 48, and the Western hemisphere, also called New World Mangroves, including West Africa, Caribbean, Florida, Atlantic South America, and Pacific North and South America where the number of species is approximately 8 ~ 12. Thus, the New World mangroves are relatively depauperate compared to the Old World mangroves. The total area of these invaluable mangrove resources in the world has been assessed to be approximately 16, 670,000 hectares (ha), including 7,487, 000 ha in tropical Asia, 5, 781,000 ha in tropical America and 3,402, 000 ha in tropical Africa.

(a) **(b)**

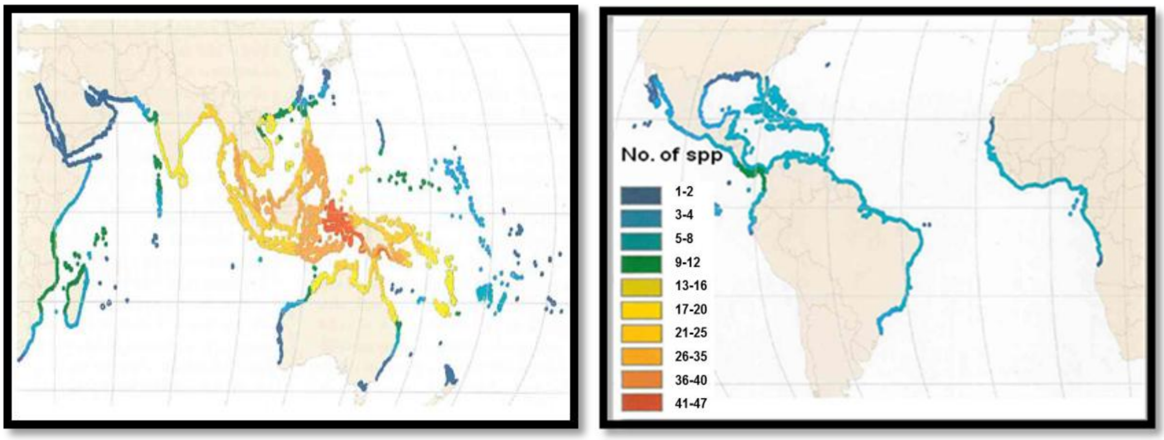


Figure 1. 1 World distribution of mangrove (a) Old world mangroves (b) New World mangroves (Adapted from World Atlas of Mangroves, Spalding *et al.* 2010)

1.3 Role of mangroves

Ecologically, economically and socially, mangroves play a pivotal role to support goods and services to human well-being. Their existence between land and sea are extreme significant if compared to other terrestrial and marine ecosystems as their formation represents both ecosystem. These specific environmental conditions make mangroves produce timber, fuel, construction materials, fodder and medicine and food such as fish, crabs, shrimp, prawn and shells as well. Rather than these tangible benefits, services such as erosion control, coastline stabilization, protection from tsunami and storms and so on. More importantly, although the area covered by mangrove forests represents only a small fraction of tropical forests, their position at the terrestrial-ocean interface and potential exchange with coastal waters suggests these forests make a unique contribution to carbon biogeochemistry in coastal ocean (Twilley *et al.* 1992). Their ability to capture carbon may be on average five times that of tropical rainforests, so they have become of interest to carbon-focused conservation strategists (Crumpton, 2012), and mangroves sequester approximately 1.5 metric ton/hectare/year of carbon (Mangroves Action Project MAP homepage). Mangroves also support land building processes that are likely to keep pace with sea level rise (Aongi 2008). Given that this hypothesis is true, a number of isolated countries would be relatively safe from sinking to the sea because of the gradual rise of sea level. Furthermore, in the developing world, the majority of people dwelling in the mangroves rely primarily on the products of mangroves for their livelihoods directly.

1.4 Impacts on mangroves

Like tropical rain forests, mangroves are being degraded globally on a large scale through the overexploitation of their potentially renewable products and through conversion to single-use options such as agriculture. The large-scale conversion of mangroves to shrimp ponds and to salt evaporation pond is of further critical concern. Due to the increasingly impacts of biotic and abiotic disturbances, mangrove forests are becoming one of the world’s most threatened ecosystems, and are rapidly disappearing in many tropical countries where the abundant mangroves existed once. The following issues are the major impediments to the sustainable management of mangroves and their associated resources in the worldwide condition (ISME 2004).

1. Conversion to agriculture, especially for paddy cultivation
2. Conversion to aquaculture

3. Pollution and sedimentation

4. Hydrological modification

5. Coastal land use changes – infrastructure, buildings and reclamation

6. Lack of appropriate legislation and enforcement of regulation

7. Shortage of capacity, mangrove specialists, managers and technicians

8. Inadequate communication, education, public awareness and participation

9. Climate change and sea level rise

Over time, mangroves have been facing these challenges throughout the world, and there might have been more undiscovered issues that indirectly affect mangrove habitats. For instance, shifting cultivation and overexploitation of timber clearing the upland forests, and the consequences of these activities can be sediment loading, land building, salinity altering that cause mangrove habitat shift to others. In terms of the tsunami-affected region in Asia, Giri *et al.* (2008) state that the major impacts to mangroves were agricultural expansion (81%), aquaculture (12%) and urban development (2%).

1.5 Mangroves in Myanmar: Backdrops of the Ayeyarwady Mega Delta

With a land area of 676, 577 km^2, Myanmar is the largest country in the Continental Southeast Asia region, stretches 2090 km North to South, and 805 km East to West (FAO 1997) with a varied geography which includes islands, extensive rice plains, river valleys and forested hills and mountains. The coastal line of Myanmar has 2,832 km on the Indian Ocean, in which the extensive formation of mangroves occur in Rakhine State, Ayeyarwady Mega Delta and Tanintharyi Division. Since 2008 after the impact of Cyclone Nargis in the Ayeyarwady Mega Delta, the present study has started in the eastern part of the Ayeyarwady Mega Delta as shown in Figure 1.2.

1.5.1 History of the study region

The Ayeyarwady Mega Delta is one of the three main tracts of mangroves in Myanmar. It is one of the ten mega deltas in Asia and Africa, which is approximately 20,600- 35,000 km^2 (Seto 2011), are intersected by a complex network of rivers, streams, and water bodies. The extensive mangroves in this region was 83, 393 hectares in 2005 (FAO 2010) that was reduced from 253, 428 hectares in 1924 (Oo 2004), showing the highest decline rate if compared to other two main mangrove tracts located in the Rakhine State and the Tanintharyi Division.Giri *et al.* (2008) state that annual mangrove deforestation was the highest in Myanmar among the continental Asia during a period of 1975-1995. In terms of the history of the Ayeyarwady mangroves, Than (2001) thoroughly reviewed that when the British occupied the lower part of the country in 1852, the delta was tall jungle with high grass. During that period, native colonists from the parched fields in the formerly Upper Burma became attracted by the delta and started clearing the jungle because of the regularity of its fertilizing rainfall and unfailing monsoon. Many of those pioneers died due to harsh conditions but their descendent benefited by staying. The colonial government encouraged the immigration from Upper Burma by adopting “dama-u-gya” system which had allowed any person to clear and cultivate any land to which no pervious occupant laid claim. Thus the land became the private property of the cultivator, on which he could mortgage, sell, or bequeath to his descendents, and this process encouraged an onset of massive human settlement in the Ayeyarwady Delta, encroachment to intact mangrove forests. In terms of the management history of the current study area according to forest management plan by Forest Department (unpublished data) for this study region and MSN (2006), there was no systematic management on mangroves before 1923, and in 1924, reserved mangrove forests were started to delineate under forest law. These reserved areas were continued to manage from 1924 to 1948 under Ring Fence Manual. But after 1949, the mangrove forests were like a shelter during insurgent period with weak law enforcement. During 1960s, much more human settlement was said to be allowed and as a consequence, the promotion of rice production campaign extended and cleared these Ayeyarwady mangroves.

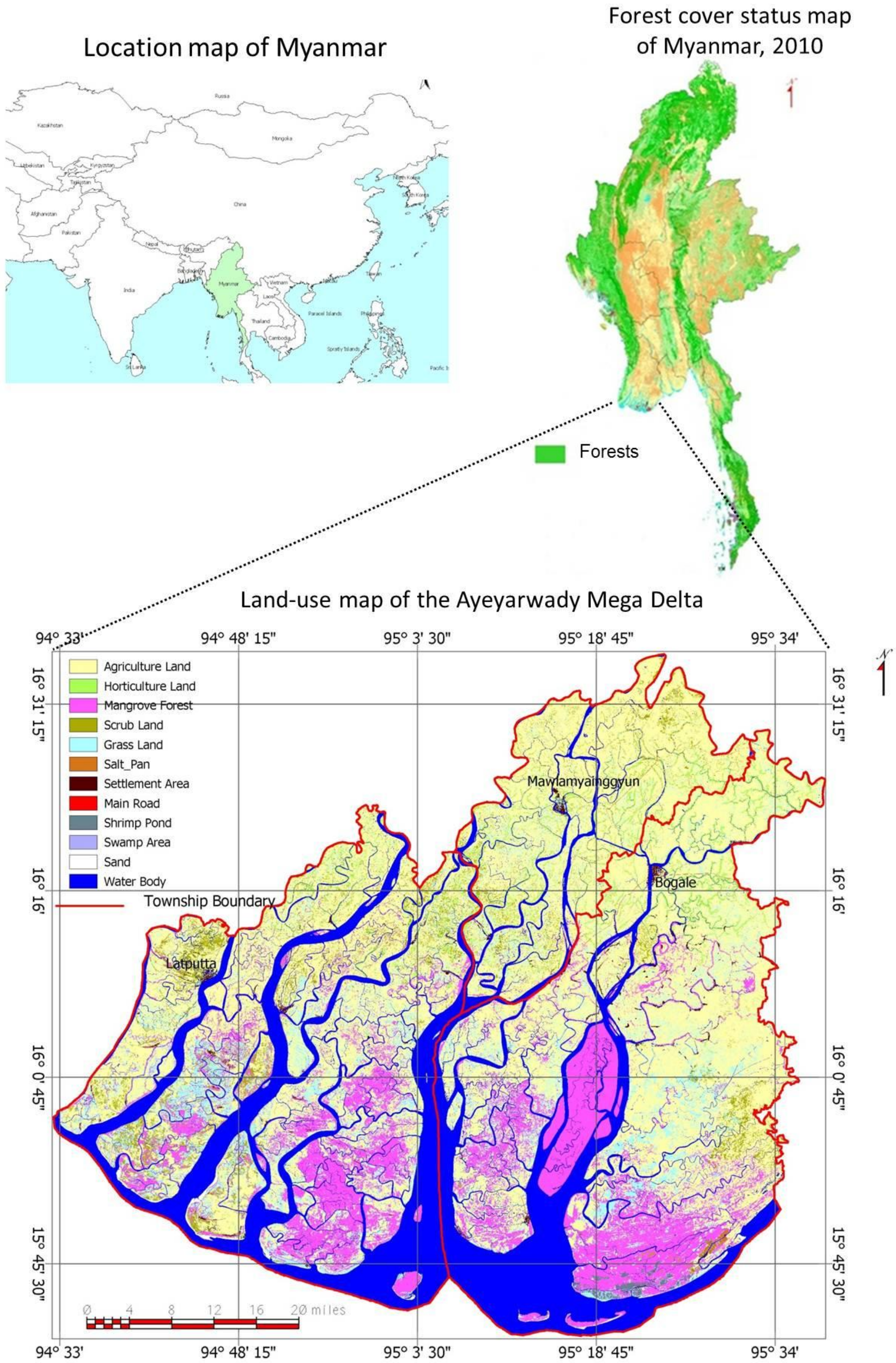


Figure 1. 2 Map showing the coverage of mangroves and other land uses in the Ayeyarwady Mega Delta. (Source: GIS and RS section, Forest Department 2010)

Until 1992, due to the shortage of electricity in Yangon capital city, charcoal and firewood markets for approximately 4 million people primarily were exploited from the Ayeyarwady mangroves. In 1993, the government took action on this issue, and totally banned charcoal production in this study area.

Regarding the aquaculture practices, Win (2000) reports that there had been plans to develop 40,000 ha of ponds for semi-intensive shrimp culture as shrimps were considered as a potentially large generator of foreign exchange. Since then, extensive and improved extensive shrimp cultures seemed to have started practicing until now together with much more extension of illegal farming by clearing mangrove habitat under weak law enforcement. Under this long history of mismanaging practices as wasteland and neglecting ecological services of mangrove forests, more or less similar elsewhere to the developing world, the various forms of human interventions have deliberately occurred in this study area, which caused a remarkable decline of mangroves.

1.5.2 Vegetation

Heritiera fomes is a characteristic species of the Ayeyarwady Delta (Chapman, 1976), while most of the mangroves in other parts of the world are dominated by the members of the families *Rhizophoraceae* and *Avicenniaceae* or the genus *Laguncularia* (Hussain and Acharya 1994). In terms of the number of species, descriptions vary with different methods. Kogo (1993) reports that there are 29 mangrove species in the Ayeyarwady Delta. Throughout Myanmar, Giesen *et al.* (2006) describe 34 true mangroves species, and there are a total of 148 species out of 268 species including major mangrove species, minor mangrove species, and associate mangrove species in “Mangrove Guide Book for the Southeast Asia (2007)”. The most common species found in the study region are *Heritiera fomes*, *Excoecaria* *agallocha*, *Cynometra ramiflora*, *Ceriops decandra*, *Bruguiera gymnorhiza* and *Avicennia officinalis*. Nowadays, Palm species such as *Phoenix paludosa*, and other herbaceous species such as *Acrostichum aureum*, *Acanthus illicifolius* and *Dalbergia spinosa* have replaced the habitats of true mangrove species showing the remarkable symptoms of degraded mangroves.

As for community-level classification of mangrove species across Myanmar, Than (2006) classified 10- community types:1. *Avicennia alba comm.*, 2. *Avicennia marina comm.*,3. *Rhizophora apiculata comm.,* 4. *Bruguiera cylindrica comm.,* 5. *Bruguiera* spp *comm.,* 6. *Heritiera fomes comm.,* 7. *Excoecaria agallocha comm.,* 8. *Sonneratia caseolaris comm.,* 9. *Ceriops decandra comm.,* 10. *Avicennia officinalis comm.* For the Ayeyarwady Delta alone, Aung *et al.* (2004) describe a total of 13 community types based on three geographical categories: the coastal and river-bank communities include 1) *Sonneratio albae-Avicennietum albae* 2) *Sonneratia apetala* community, 3) *Avicennia alba-Avicennia officinalis* community 4) *Avicennia officinalis* community 5) *Sonneratetum caseolaris* Miyaki et al., 1985, 6) *Kandela candel* community, 7) *Rhizophora apiculata* community, 8) *Sarcolobus globosus-Brownlowia tersa* community and 9) *Ipomea tuba-Hibiscus tiliaceus* community. The inland communities consist of 1) *Amooro- Heritieretum fomes* community 2) *Aegiceras corniculatum- Ceriops decandra* community, and 3) *Phoenix paludosa* community. The marsh community contains 1) *Leptochlo filiformis* community.

1.5.3 Climate

This Ayeyarwady Mega Delta is influenced by a tropical monsoon climate with high temperature and abundant rainfall characterized by three seasons: the rainy, cold, and summer seasons. Based on the data from the nearest meteorological station called Pyapon, over a recent 10-year period, the average annual rainfall is over 3200 mm, the average number of rainy days per year is about 80 to 110, and the highest rainfall usually comes in June and July. The mean temperature is 25.8 °C, the average maximum temperature 28.7 °C and the average minimum temperature is 23.8 °C (Figure 1.3).

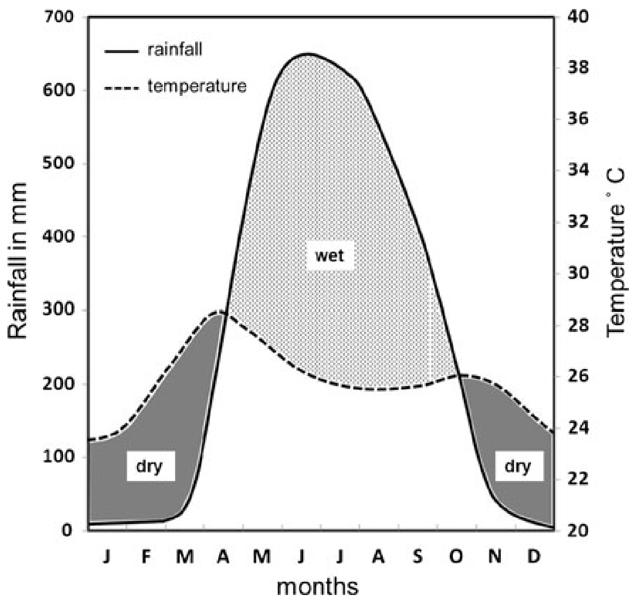


Figure 1. 3 Mean rainfall and temperature over a 10-year interval (1999–2008) in the study area (Note: Adopted 1999 and 2008 data of the eastern Ayeyarwady Delta, Pyapon station from Meteorological Department, Myanmar)

1.5.4 Nature of tide

Tides are important natural occurrences for the stability of the mangrove ecosystem and for the determination of soil formation. Semi-diurnal tide commonly occurs in the delta, it means the tide rise and fall two times a day. The duration of each rise or fall of tide lasts six hour, and it takes place about 48 minutes later with each coming day. During spring tides, most of the low lying and middle ground areas are inundated by saline and brackish water. When the tide is at its lowest level, the ground is relatively dry and only the low lying mangrove areas are inundated. Myanmar lunar calendar (Table 1.1) is very useful to observe the nature of tides, rise and fall. In this traditional calendar, two portions, waxing and waning, can be separated, and each portion has 14 to 15 days depending on individual month. The spring tide can be seen in every third of waxing and waning day. During the spring tide days most of the areas are inundated. Every 10th of waxing and waning is neap tide, i.e. the lowest tide.

The mangrove areas in the Ayeyawady Mega Delta are classified in terms of topography including the tide level or frequency of tidal inundation such as low ground, medium ground, and high ground (Table 1.2). The low ground is inundated by brackish water at least 20 days per month while the medium ground is tidally inundated every spring tide at least 7 days per month. The high ground is inundated during the highest tide at least one day per month while the extremely high ground areas are not tidally inundated, and only flooded by rain water during the rainy season.

1.5.5 Water salinity

Salinity of river water is strongly related to the distance from the sea, topography, tidal action and the rains. It is an important factor that influences the rates of growth, height, survival and distribution of mangrove vegetation. Low salinity can be found in the river far from the coasts, at the same time of low tides, and during the rainy season. In the rainy season, the salinity of river water is almost absent or 0.1% whereas the salinity in the dry season becomes higher. The salinity in the western part of the mega delta is slightly higher than that of the eastern part. Generally, it varies from 0.1 to 2.8% depending on tidal and seasonal conditions. In the rainy season, the salinity of river water was almost fresh or 0.2 % based on the data collected from 2000 to 2004 by Than et al. (2006).

Table 1. 1 Relationship between Myanmar dates and nature of the tides

No	Day, waxing or waning	Time of rise A.M/P.M		Nature of tides	Myanmar term
		Hour	Minute		
1	first	7	12	High rise	Yehta
2	second	8	0	High rise	Yehta
3	thrid	8	48	High rise, spring tide	Gaungye
4	fourth	9	36	Almost as high as gaungye	Yesahmi
5	Fifth	10	24	The beginning of the low rises, i.e, medium rise (lower each day)	Yethe-u
6	Sixth	11	12	The beginning of the low rises	Yethu-u
7	Seventh	12	0	The beginning of the low rises	Yethe-u
8	Eighth	12	48	Low rise	Yethe
9	Ninth	1	36	Low rise	Yethe
10	Tenth	2	24	Lowest rises, neap tide	Yesinsin-the
11	Eleventh	3	12	Small rise	Yenuhta
12	Twelfth	4	0	Small rise	Yenuhta
13	Thirteenth	4	48	Small rise	Yenuhta
14	Fourteenth	5	36	The beginning of the low rises, i.e. medium rise (higher each day)	Yehta-u
15	Fifteenth	6	24	The beginning of the low rises, i.e. medium rise (higher each day)	Yehta-u

Source: Kogo 1993

Table 1. 2 Frequency of tidal inundation in the Ayeyarwady Mega Delta

Mangrove land area class	Tide level (m) above sea level/Admiralty datum	Days of tidal inundation per month during dry season	Tidal inundation class based on Watson Classificatgion	Frequency of tidal inundation per month based on Watson classification
Low Ground Level 1	0.1-1.7	All high tides (at least 20 days/month)	1	56-62
Low Ground Level 2	1.7-2.0	Every medium high tide/every start of spring tides (10-19 days/month)	2	45-59
Medium Ground Level 1	2.0-2.3	Every normal high tide/mid spring tides (3-9 days/month)	3	20-45
Medium Ground Level 2	2.3-2.6	Every spring high tide (at least 2 days/month)	4	2-20
High Ground Level	2.6-2.7	4 times in dry season by equinoctial/abnormal high tides	5	0-2
Extremely High Ground Level	2.7-3.3	Only flooded by rain water during rainy season	6	none

Source: Table modified from Watson (1928) and Kogo (1993)

1.5.6 Natural impacts: Cyclone Nargis in 2008

At the beginning of May 2008, Cyclone Nargis crossed the Ayeyarwady Mega Delta and Yangon City, affecting more than 50 townships with massive destruction to personal property and natural ecosystems, including tremendous destruction of mangrove forests. It was as a category 3 storm with recorded wind speeds of up to 215 km/h and a diameter of 240 km. The damage was most severe in the Ayeyarwady Delta region, where the effects of the extreme winds were compounded by 3.6 meter storm surge, with peak surge height up to 5.65 m according to the Department of Meteorology and Hydrology in Myanmar. This cyclone was the worst natural disaster in the history of Myanmar and the most devastating cyclone to strike Asia since 1991 (TCG 2008). The path of this Cyclone Nargis is shown in Appendix I, Plate 1.

In tracing back to the history of cyclone occurrences, the higher number of tropical cyclones, about 33 % of the world total, form in the western North Pacific, which is a vast area of very warm water about 30 °C (Frank 1985). According to Ali (1999), the Bay of Bengal shared 5.5 % of tropical storms; in which India represent 3.34 %, Bangladesh 0.93 %, Myanmar 0.51 % and Sri Lanka 0.22 % over 118-year period. About 53 % of the world deaths from these cyclones took place in Bangladesh and about 23 % in India. Bangladesh and India suffer most, although both of them together are hit by only 4.27 % of the world storm. Particularly in Myanmar, there were a total of 71 times with 24 depressions, 23 cyclonic storms and 24 severe cyclonic storms. Then, also in TCG report (2009), the Ayeyarwady region is also exposed to low-frequency, high-impact events such as occasional cyclones and tsunamis, with 11 severe tropical cyclones hitting Myanmar over the last 60 years, two of which made land fall in the region. Nevertheless, no storm was so severe like 2008 Cyclone Nargis that was one of the top ten deadliest cyclones worldwide caused the worst natural disaster in the recorded history of Myanmar. Considering potential frequency and intensity of cyclones in future, Ali (1999) reports that there was no corresponding increase in cyclone frequency, but cyclone intensity is likely to increase.

1.5.7 Human impacts

The conversion of mangroves to paddy field and cutting for fuel wood are common in the Ayeyarwady mangroves for a long history. One of the other remarkable impacts on mangroves has been strictly prohibited in 1993. That was charcoal production from mangroves. However, other disturbances have continued to make mangrove habitat convert to a variety of land uses, primarily agriculture, followed by human settlement, aquaculture, salt pan and other unexplained factors. Since 2002, extensive shrimp cultures have extended to mangrove reserved forests. Giri *et al.* 2008 estimated that 98 % (293, 035 ha) of mangrove deforestation in Myanmar during the period 1975-2005 was due to agricultural expansion. During the same period, approximately 2 % (6870 ha) of forests were converted to aquaculture.

1.5.8 Trends of mangroves

The analysis of Landsat TM imageries has indicated that Myanmar is still endowed with one of the most extensive natural forest cover in the world. Mangrove forests are included in the category of tidal, beach and dune, and swamp forests, which amounts to 4 % of the total forest area. According to the *World Atlas of Mangroves* (Spalding *et al.* 2010), the total area of mangroves in Myanmar was 5029.11 km^2 and 4380 km^2 (FAO 2010), distributing in Rakhine State, Tanintharyi Division and Ayeyarwady Delta (Table 1.3). Among these three areas, the largest extent of mangroves occurs in the Ayeyarwady Mega Delta, and the corresponding mangrove coverage of these three areas is described by Forest Department 2007 as follows.

Table 1. 3 The extent of mangroves in three main regions of Myanmar

Region	Area (Acres) in 1980	Area (Acres) in 2002
Rakhine State	414,470	158,080
Ayeyarwaddy Division	679,019	341,848
Taninthayi Division	647,571	203,585
Total	1,741,060	703,515

The periodic decreases of mangrove cover by reserved forests in the Ayeyarwaddy Delta by Forest Department (2008) are shown in Table (1.4) and Figure (1.4) shows the trends of mangrove decline in this delta by FAO (2003).

Table 1. 4 The extent of mangroves in the reserved forests of the Ayeyarwady Mega Delta

Sr.	Reserved Forests (Acres)	1924	1954	1974	1983	1995	2001	2007
1	Kyakankwinpauk	66,650	64,401	61,429	32,094	37,986	24,893	10,761
2	Pyinalan	97,809	87,362	90,035	70,868	69,211	62,952	31,500
3	Kakakyan	66,471	66,095	66,431	57,249	29,552	19,317	7,196
4	Labutkwe	12,846	7,304	6,055	1,969	1,669	1,432	39
5	Kalayaik	21,345	21,295	18,686	6,046	1,378	1,020	232
6	Nyinaung	16,465	16,398	16,465	9,272	228	181	-
7	**Kadonkani**	**133,563**	**128,103**	**124,633**	**105,019**	**83,998**	**52,123**	**28,942**
8	**Pyindaye**	**31,115**	**30,991**	**30,980**	**31,073**	**30,489**	**30,319**	**27,061**
9	**Meinmahla**	**178,958**	**157,538**	**156,202**	**137,040**	**142,666**	**84,369**	**55,200**
	Total	625,222	579,487	570,916	450,630	397,177	276,606	160,931

Source: Planning and Statistics Division (Forest Department 2008)

Notes: The present study focuses mainly on Kadonkani Reserved Forest, Pyindaye Reserved Forest and Meinmahla Kyun Wildlife Sancturary.

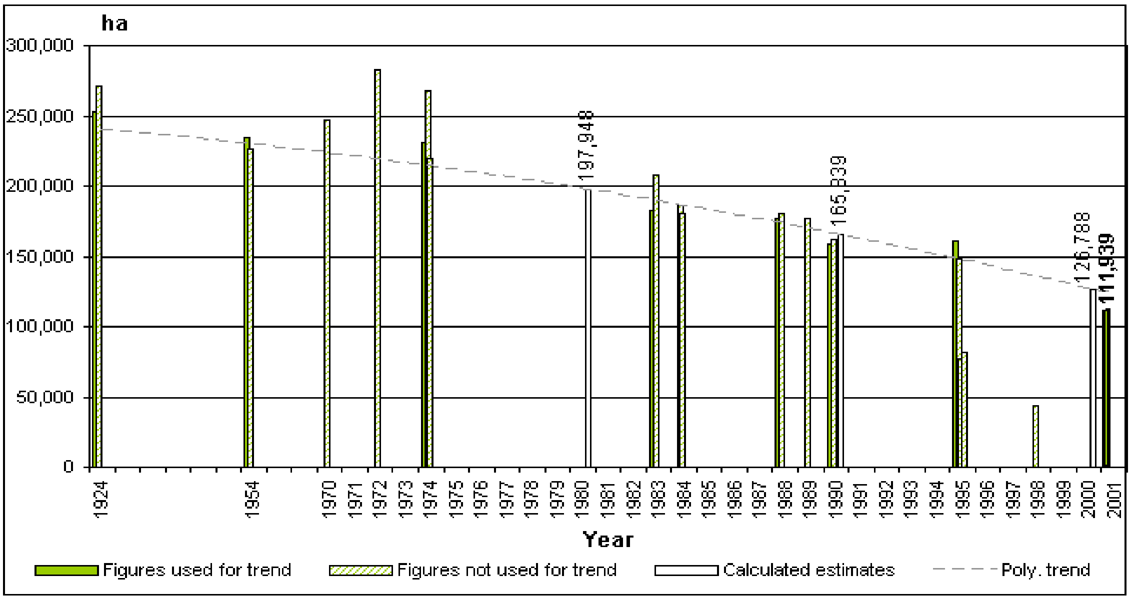


Figure 1. 4 The extent of the Ayeyarwady Delta mangroves covering a time span of nearly 80 years (Adapted from FAO 2003)

1.6 Why study mangrove resilience after natural and anthropogenic impacts?

As mentioned above, mangroves in the study area have been facing a number of challenges with natural disaster as well as continuous anthropogenic impacts over time. The extent of mangroves in this Mega Delta region has also shown an alarming downward trend, and there have been almost no intact mangroves left in the Ayeyarwady region. After the disturbances, now is time to better understand how much extent the remaining degraded mangroves have illustrated any evidence to be persistent, how they have responded to the anthropogenic and human impacts until now, and how their potential existence in future is. Alongi (2002) explains that the long-term changes in mangrove forest structure have rarely been studied and only few data sets available offer some important insights into gap and stand dynamics, especially in relation to recovery from disturbance. Based on these frameworks, the mangrove situation after the catastrophic disturbances in the Ayeyarwady

Mega Delta 2008 has encouraged grasping this rare opportunity in order to clarify the resilience of mangroves under the natural and anthropogenic impacts.

1.6.1 Basic concepts of disturbance, resilience and restoration

Understanding about disturbance is of crucial importance for mangrove resilience. Three types of disturbance based on its intensity and severity by Frelich (2002) are as follows.

1. Low-severity disturbances are those that kill small pieces of the forest understory or overstory (or both), resulting in scattered minor mortality. Windstorms that pick off a few larger trees and create scattered tree fall gaps.

2. Moderate-severity disturbances kill most/all of either the understory or overstory, but leave a substantial legacy of intact mature trees or seedlings. Windstorms and clear cutting that remove the canopy but leave the seedling layer intact.

3. High-severity disturbances kill most of the understory and overstory layers. Clear-cutting followed by burning of the remaining slash are examples.

Due to the disturbance, as shown in Figure 1.5, there are two types of damage classified such as structural damage and compositional damage (Everham III & Brokaw 1996). It is suggested that the recovery may be a function of both the type and severity of damage, and other factors might influence recovery, including edaphic characteristics, topography, response differences among species, and previous disturbance.

The paths of recovery and its mechanisms have also been reviewed by Everham III and Brokaw (1996). In their review, the recovery from the catastrophic wind disturbance, specifically wind-induced disturbance, might be expected to follow one or more of four paths: regrowth, release, recruitment, or repression as shown in (Figure 1.6). The critical questions addressed in their reviews were "Will the forests of 10-20 years` time be dominated by regrowth of damaged trees or will saplings and seedlings ‘released’ by disturbance play a significant role (Sugden 1992)? In other words, will there be a shift in the community structure during recovery?

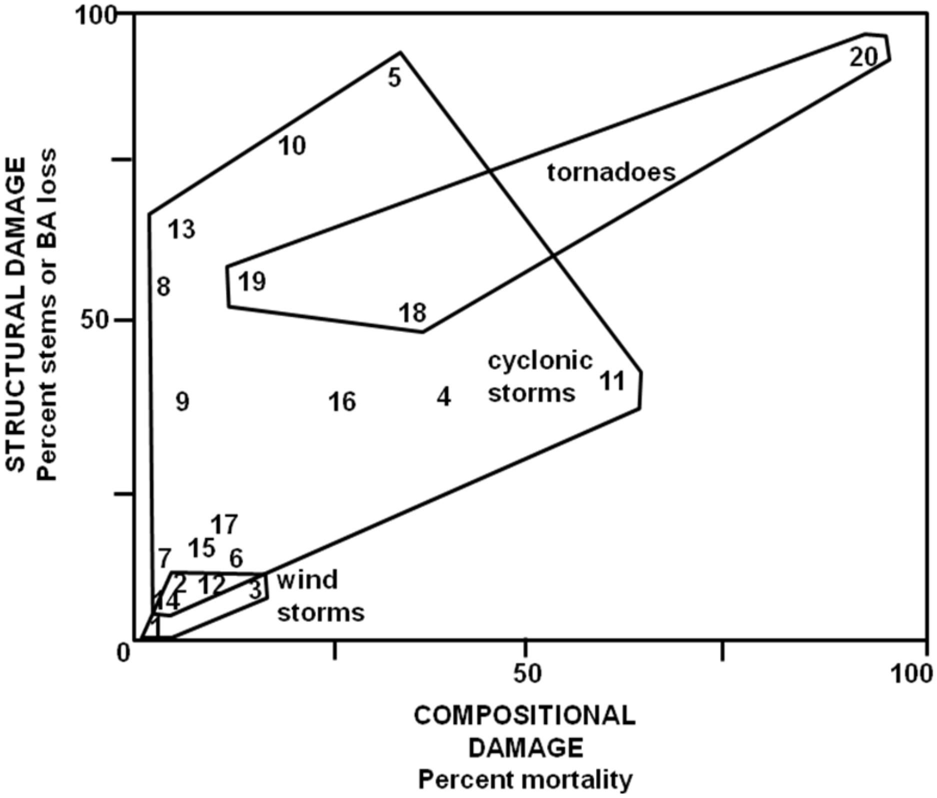


Figure 1. 5 Gradient Space for severity of catastrophic wind events. Structural damage is quantified as percent basal area damaged or percent stems damaged. Compositional damage is quantified as percent stems killed. (Adapted from Everham III and Brokaw 1996)

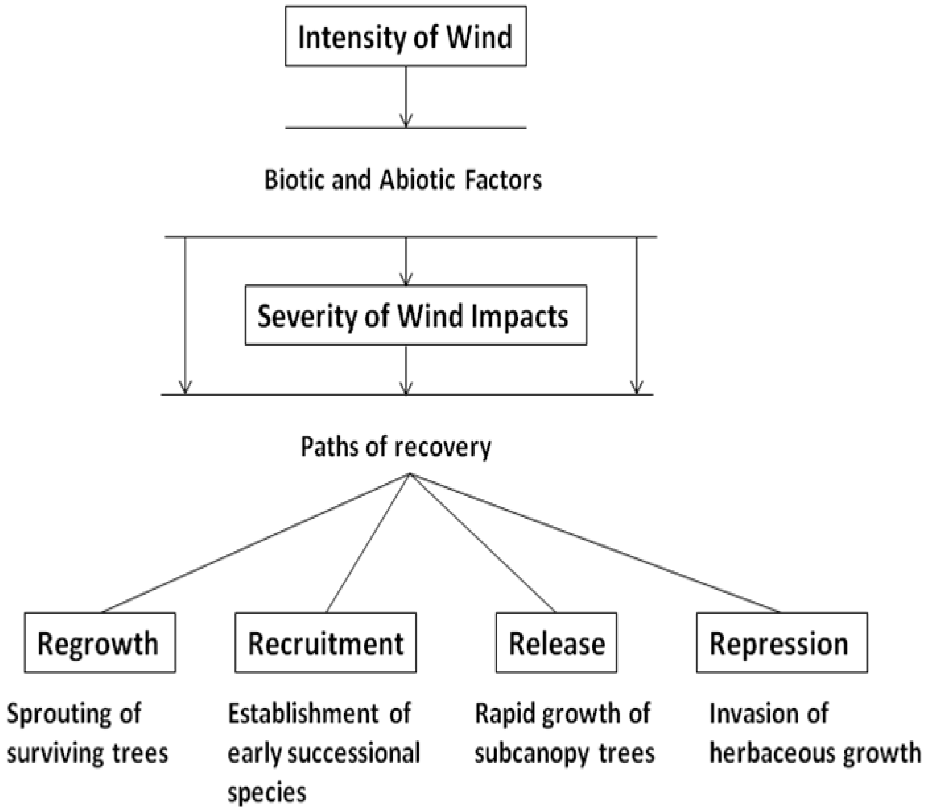


Figure 1. 6 Paths to recovery from catastrophic wind disturbance. Intensity of wind disturbance is filtered through biotic and abiotic factors which amplify or mitigate the severity of damage. The severity of damage, in conjunction with the abiotic and biotic factors, influences the paths to recovery. (Adapted from Everham III and Brokaw 1996)

The word "resilience" is supposed to be initially introduced by Holling (1973), defined as a measure of a system's persistence and its ability to absorb change and disturbance but still maintain the same relationships among population or state variables. A system can be highly unstable, but very resilient (e.g. grassland persistence is reliant on frequently occurring fires). Specifically, regarding the mangrove resilience after the disturbances, there are six key features that contribute to the resilience of mangroves to disturbance, whether they are acute disasters such as a tsunami or millennial change in climate (Alongi 2008). These characteristics are: (1) a large reservoir of below-ground nutrients that serve to replenish nutrient losses; (2) rapid rates of nutrient flux and microbial decomposition that facilitate rapid biotic turnover; (3) complex and highly efficient biotic controls (e.g., high rates of water-use and nutrient-use efficiency) that allow predominantly internal reuse of resources to augment recovery; (4) self-design and simple architecture that lead to rapid reconstruction and rehabilitation post-disturbance, despite different species composition; (5) redundancy of keystone species, or species legacies, which can lead to restoration and recovery of key forest functions and structure; and (6) positive and negative feedback pathways that provide malleability to help dampen oscillations during recovery to a more stable, persistent state.

Eventually, after one can understand the extent of resilience based on the frequency and intensity of disturbances on mangroves, restoration needs to be determined whether it is compulsory or not to facilitate recovery process. Presumably, restoration is almost indispensable in the sites where deforestation and serious degradation occur. What is restoration? Regarding the term of restoration, there have been a number of definitions stated by National Oceanic and Atmospheric Administration (NOAA 2012 online, coastalscience.noaa.gov), most of them share similar ideas. They often refer to the return of an area to a previous condition by improving the biological structure and function. Some examples of definitions of restoration put forth by various authors and agencies are as follows:

- A putting or bringing back into a former, normal, or unimpaired state or condition (McKechnie 1983).
- A return from a disturbed or totally altered condition to a previously existing natural or altered condition by some action of man (Lewis 1990).
- Returning an ecosystem to a close approximation of its condition prior to disturbance (NRC 1992; Claw *et al.* 1998).

- Returning a degraded wetland or former wetland to a pre-existing condition or as close to that condition as is possible or the process of reestablishing a self-sustaining habitat that closely resembles a natural condition in terms of structure and function (NOAA 2002 online).
- The rehabilitation of wetlands that may be degraded or hydrologically altered; often involves reestablishing the vegetation (Mitsch and Gosselink 2000).
- The process of assisting the recovery and management of ecological integrity including a critical range of variability in biodiversity, ecological processes and structure, regional and historical context, and sustainable cultural practices (SER 2002).
- An attempt to reset the ecological clock and return a damaged ecosystem to its pre-disturbed state in structure and function (Cunningham *et al.* 1994).

Furthermore, the term "restoration" has been described as the recreation, recovery, or return of a damaged ecosystem to its original condition, with a dominance of a group of indigenous organisms that are within the natural limits for the structure and function of the ecosystem for the local geographic area (Cairns & Buikema 1984; Howell 1986). This study mostly follows the terms defined by NRC (1992) and Claw *et al.* (1998).

1.6.2 Synthesis and future directions

This study tried to fulfill the need of long-term studies for predicting the population sizes of mangrove species after post-cyclone period through stage-structure population model. Attempts have also been made to understand the recovered vegetation not only after natural impacts, but also human impacts. The results are expectedly invaluable for supporting useful information to better understand various impacts, mangrove responses to disturbances, and the needs for thinking about restoration and rehabilitation. Until now in Myanmar, not only long-term studies on mangroves, but also mangrove ecological studies are scanty in literature. The overall work of this study tried to organize the perspectives of ecology and management. Immediately after Cyclone Nargis 2008, annual censuses have been made on the community and species-specific levels of mangroves, and so the work here was based on the five-year observation from 2008 to 2012 in the eastern part of the Ayeyarwady Mega Delta. As a result, it is expected that the findings here are fairly accurate and reliable information to better understand the dynamics of the Ayeyarwady mangroves. However, collectively, even this five-year experience would not be complete, and still require more extended time for clear understanding on the trends to generalize the whole patterns of mangroves. Further investigation is intended to continue the long-term patterns of post-cyclone mangroves and human-disturbed mangroves as well. In addition, validation on the current findings of the study would be also helpful with continued research on the permanent sites.

1.6.3 Flow chart and the overall goal of the study

This dissertation is structured that the first Chapter (I) and the last Chapter (VII) are composed of background information and overall conclusions. In terms of the main contents, there are five main chapters in which Chapter (II) and (III) were to predict the recovery pathways of mangroves after the catastrophic cyclone called Cyclone Nargis 2008, and the patterns of recovered or actual living vegetation after human impacts such as rice field affected sites (agriculture) and brackish water shrimp ponds affected ones (aquaculture). Then, the overall views of recovery status after both natural and anthropogenic impacts were also assessed for the whole landscapes of the study area in Chapter (IV). After clarifying the

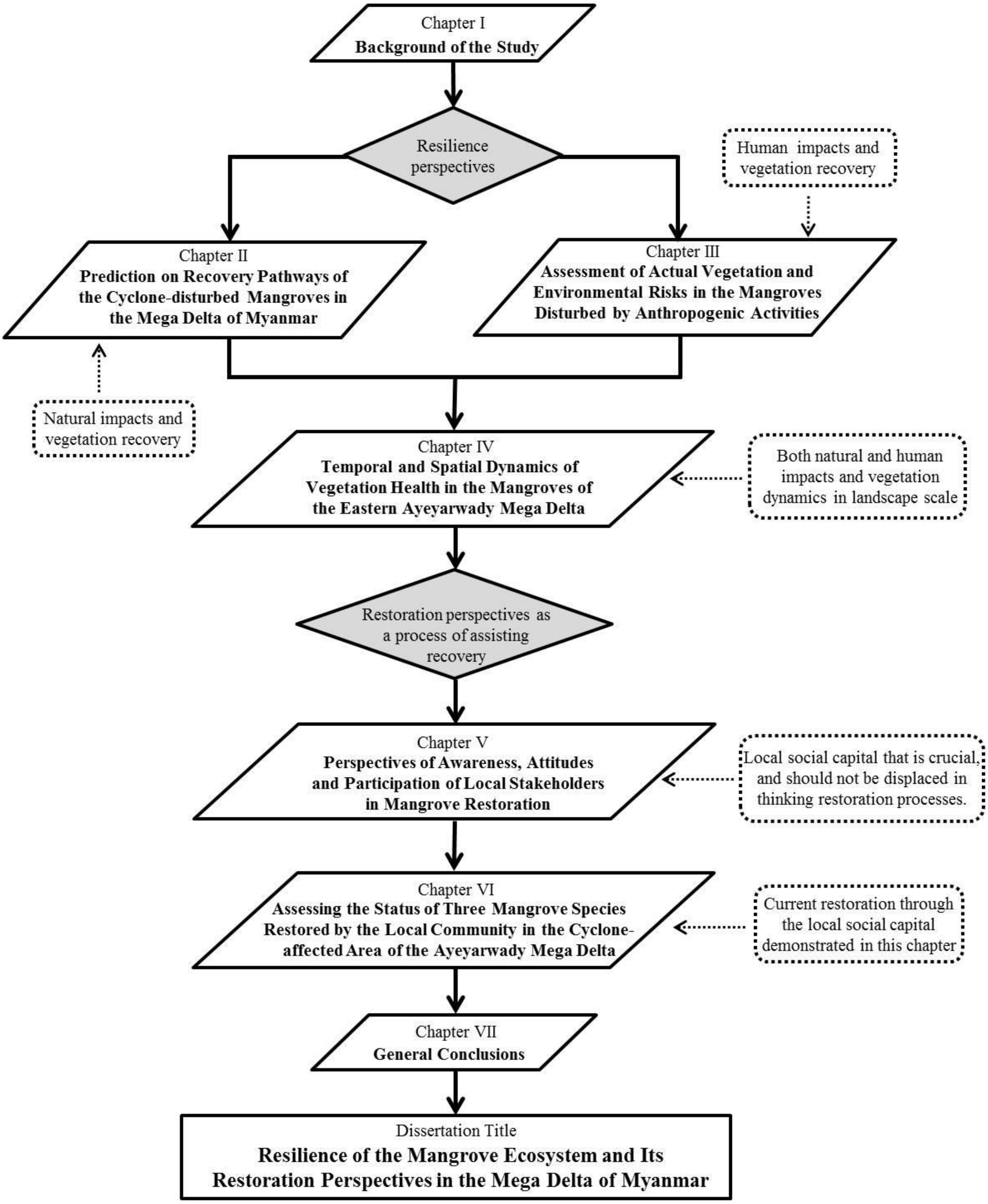


Figure 1. 7 Flow chart of the present study

recover potential of mangroves, the latter part of dissertation tried to proceed to fulfill the gaps necessary for restoration measures that is, in most cases, a must to assist recovery process. In these restoration measures, the role of local stakeholders is of critical importance, and so their awareness, attitudes and participation in mangrove restoration measures were tested in Chapter (V). In the current restoration measures by the Forest Department, community forestry, that is, community-based mangrove management, with a 30-year land lease have been initiated since 1995. Under this program, mangrove plantations established from 1999-2002, through community forest user groups or in other words through local social capital, were taken examples to assess the extent of success as baseline information for restoration in Chapter (VI). The attempts of this study, therefore, were made to solve unclear research questions regarding mangrove dynamics by the natural and human impacts, and then to highlight the needs and status for restoration processes by critical local social capital. In general, the structure of this dissertation can be divided into two main parts; Chapter II, III and IV are concerning resilience perspectives and Chapter V and VI are pertaining to restoration perspectives. According to this logical framework, the flow of my dissertation was constructed in (Figure 1.7).

To sum up, the overall goal of this study is to provide useful and reliable information for the management and restoration measures of the Ayeyarwady Mega Delta mangroves. Specific objectives and research questions are described in each corresponding chapter in order to clearly give information step by step. Hopefully, the findings from this long-term research can contribute to the conservation and restoration of mangroves, specifically the ones affected by the natural and anthropogenic impacts.

Chapter II

Prediction on Recovery Pathways of the Cyclone-disturbed Mangroves in the Mega Delta of Myanmar

Abstract

Mangroves in the Ayeyarwady Mega Delta of Myanmar are of crucial importance from the perspectives of ecology, society and economy. At the beginning of May 2008, a severe cyclonic storm, Cyclone Nargis, struck these Ayeyarwady mangroves. Since that time, the current long-term study has been exploring the dynamics of post-cyclone mangrove vegetation. First, the study looked at the vegetative responses to catastrophic cyclone disturbance, by examining 13 mangrove species, including 1,662 individuals. The results showed that *Avicennia officinalis*, followed by *Sonneratia apetala*, *Heritiera fomes* and *Sonneratia caseolaris*, represented the greatest number of epicormic sprouts, while most of the *Rhizophoraceae* groups, including the genus of *Rhizophora* and *Bruguiera*, had limited ability to produce vegetative sprouts. Next, a census was taken every year since 2008 Cyclone Nargis on 10 permanent plots (each measuring 10 m x 10 m) for six mangrove communities, in order to predict their long-term recovery trends. Each selected mangrove community was dominated either by *Avicennia officinalis*, *Bruguiera sexangula*, *Excoecaria agallocha*, *Heritiera fomes*, *Rhizophora apiculata*, or *Sonneratia caseolaris*. Mortality among the *Rhizophoraceae* groups, including *B. sexangula* and *R. apiculata* adult individuals, showed more than 90 %, whereas for other species belonging to the non-*Rhizophoraceae* group, it was found to be less than 20 %. Based on the five-year assessment, mangroves have showed considerable resilience after catastrophic cyclone disturbance. However, the species-specific recovery potential was relatively varied and, in particular, the communities where *R. apiculata* dominated demonstrated slow recovery processes. The reasons for the vulnerability of this *Rhizophora* species to cyclone disturbance is assumed to be the result of three indirect post-cyclone consequences: high mortality caused by limited sprouting ability after wind-induced disturbance, erosion that occurred in the stressful habitat on riverbank mud flats with frequent tidal inundation and delayed reproduction after the catastrophic disturbance. The generalized recovery rate of mangroves through the crown closure of six species has shown 61.06 % for a span of three years and eight months later after Cyclone Nargis. Demonstrating these patterns and processes among the most dominant mangrove species after the cyclone disturbance, therefore, should provide reliable information for forest managers, ecologists and local people to help them make their management decisions for developing mangrove restoration measures.

Keywords: mangroves, Cyclone Nargis, catastrophic disturbance, recovery, management intervention

2.1 Introduction

All ecosystems are subject to a variety of disturbances, both natural and anthropogenic, which vary in their duration, frequency, size and intensity and play a crucial role in facilitating adaptive change (Odum & Barrett 2004). Mangroves are among the world's threatened ecosystems. Their distribution along low-latitude seacoasts inevitably places mangrove swamps among the terrestrial ecosystems most prone to experience the passage of hurricanes and other tropical cyclones (Roth 1992). Consequently, mangroves are fairly robust and highly adaptable (or tolerant) to life in waterlogged saline soils within warm, subtropical and tropical seascapes (Alongi 2008).

Myanmar is a naturally resource-rich country with a coastline that extends approximately 2,832 km. The country's edaphic and coastal features, together with high rainfall and significant inputs from rivers, favour the development of well-structured mangroves. According to the World Atlas of Mangroves (Spalding *et al.* 2010), mangroves in Myanmar ranked seventh among the top 12 countries, that have the largest mangrove areas in the world. Together, the mangroves in these top countries account for over 68 % of all those throughout the world. In Myanmar, there are three main tracts of land where mangroves grow: the Ayeyarwady Mega Delta, Rakhine State and the Tanintharyi Division. Among these tracts, the Ayeyarwady Mega Delta has the large extent of mangroves, however, the mangroves in this region are the ones that are most affected by dense population. Methods for proper management should be revised, based on empirical studies that have looked at ecological, social and economic considerations. In spite of the variety of types and different areas where they grow, mangroves stretch across 5,029.11 km^2 of Myanmar, according to the World Atlas of Mangroves (Spalding *et al.* 2010). Oo (2004) states that about 24 % of the mangroves in this mega delta had been lost by 1984, and a more recent study showed an additional 20 % loss of those that had remained, in the single decade from 1990 to 2000 (Leimgruber *et al.* 2005). Overall, the mangroves in this mega delta appear to have already reduced to almost half their original numbers in recent decades.

In addition to the effects of recurrent anthropogenic stressors, such as agricultural expansion, conversion to aquaculture and cutting for firewood, Cyclone Nargis, which was a natural disturbance, severely affected this mega-delta region on May 2 and 3, 2008, resulting in at least 134,000 deaths and also devastating the mangroves. This was the ninth among the top 10 deadliest cyclones throughout the history of the world (www.wunderground.com). After this cyclone impact, Thant *et al.* (2010) investigated the mitigation effects of mangroves as a natural shield, showing evidence that the more mangroves there were, the more the lives of people were safe. There can be no doubt, therefore, that mangrove ecosystems provide an invaluable service, and that it is imperative to understand their responses to cyclone disturbance. A number of studies have been done on the structure and composition of cyclones, and of their influence on biological diversity, nutrient cycling and plant interactions (Walker *et al.* 1991; Everham & Brokaw 1996; Quigley & Platt, 1996; Imbert *et al.* 1996; Herbert 1999; Baldwin *et al.* 2001). However, a limited amount of literature has been done on the responses of mangrove species and their recovery potential using long-term observation. A better understanding of wind impacts is also required, not only to address the need for conservation and to improve the management of ecosystems, but also because both the frequency and intensity of such storms may increase (Everham & Brokaw 1996). It is also essential to understand the biology and the ecology of mangrove establishment, so that restoration of these systems may be undertaken with a reasonable expectation of success (Moore 2004). Understanding species-level and community-level responses, therefore, would also assist forest managers, user groups in community-based forest management and other stakeholders, especially for outlining conservation and restoration in cyclone-prone regions. Being able to observe disturbances immediately after the impact of a cyclone, then, has given us an opportunity to prove the theory of the underlying resilience of mangroves. It has also helped to answer other unsolved questions; 1) how do mangrove species respond immediately after cyclone disturbance? 2) have mangroves shown resilience after cyclone disturbance, 3) Are species-level or community-level mangroves persistent or vulnerable to cyclone impact in the long run and 4) how extent are mangroves able to have recovered during the five-year monitoring period? Furthermore, there continue to be challenges related to social, ecological and economic issues in this area of study and any attempt to conserve and manage mangroves without thinking about social needs would result in failure. For this reason, the present study takes into account management intervention in terms of the cutting or harvesting tolerance of mangroves. Essentially, it investigates the extent to which most common mangrove species can tolerate being cut by local people for their subsistence needs while still maintaining the initial population size of each species.

2.2 Materials and methods

2.2.1 Study site

The current research has been underway in the mega-delta region, called Ayeyarwady, in Myanmar, since two months after the cyclone disturbance in May 2008. The main area of focus is located between latitudes 15º 42′ and 16º 12′ north and longitudes 95º 5′ and 96º 35′ east, including the Meinmahla Kyun Wildlife Sanctuary, Byonehmwe Island and the Pyindaye Reserved Forest (Figure 2.1).

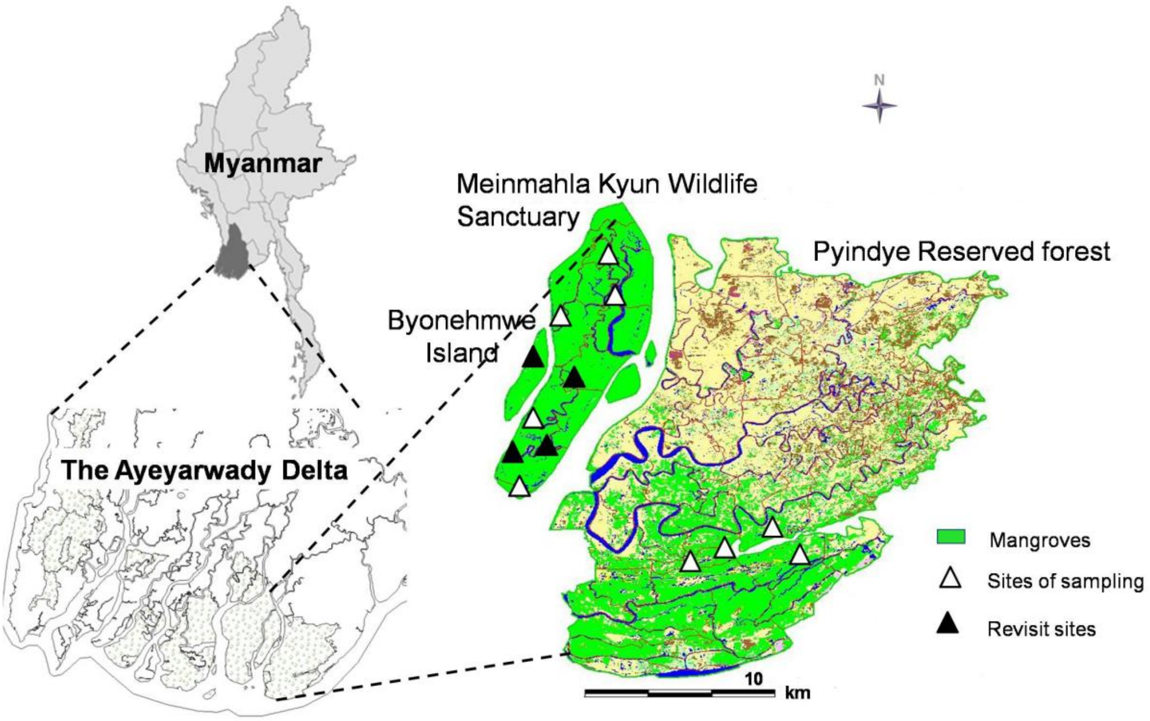


Figure 2. 1 Map showing the study sites in Byonehmwe Island, Meinmahla Kyun Wildlife Sanctuary, and Pyindaye Reserved Forest

2.2.2 Census plots

First, the study looked at the responses of 13 mangrove species, representing 1,662 individuals. The height of the species and the damage category of all trees ≥ 5 cm in diameter were recorded. As a result of the cyclone, the trees in the sample plots showed damage. There are eight categories of damage classified as shown in Table 2.1, ranging from relatively light (I) to severe (IV-b). The number of individuals explored for each species is shown in Table 2.2.

Table 2. 1 Description of damage categories of mangrove individuals in the sample plots

Damage category			Definition (essential characteristics)	Remarks
I	**-**	No damage	No obvious damage or little damage found.	-
II	**a**	Minimal damage	≤ 25 % of the crown was damaged or defoliated.	
	b	Extensive defoliation	25 - 75 % of the crown was defoliated.	Foliage damage
	c	Complete defoliation	Nearly 100 % of the crown was defoliated.	
III	**a**	Snapped branches	Almost all side branches were broken.	Stem damage
	b	Snapped bole	Main stem was broken.	
IV	**a**	Leaning	Tree body was leaning between 30º - 60º relative to the ground	Root damage
	b	Uprooting	Whole tree had fallen and roots were exposed above the ground.	

Next, in order to explore vegetative reproduction, the number of sprouts reproduced up to 2.5 m of tree height was counted. In cases where trees were leaning and uprooted, the sprouts along the trunk, up to 2.5 m from the base of the stems, were considered. Sixty monitoring plots (each 10 m x 10 m) were then set up as permanent sites in six selected communities, in order to conduct long-term observation on the mortality, survival, reproduction and growth for individuals of each life history stage. There were 10 plots representing each community and they were all dominated either by *Avicennia officinalis* L., *Bruguiera sexangula* (Lour.) Poir., *Excoecaria agallocha* L., *Heritiera fomes* Buch. Ham., *Rhizophora apiculata* Blume or *Sonneratia caseolaris* (L.) Engl. These community types of mangrove and their habitats in the present study region have been classified and reported by Aung (2004) and Than (2006), and the average tidal ranges of the six types are shown in Figure 2.2. The individuals among the mangrove species represented five life history stages, from small seedling (< 0.8 m in height), large seedling (0.8 - 1.3 m), small sapling (< 3 cm in dbh and > 1.3 m in height) and large sapling (> 3 cm in dbh and < 5 cm in dbh), to adult (all > 5 cm in dbh). All individuals were recorded and tagged, and their heights were also measured, but diameters were only recorded for the adults. The definition of the life history stages was marked differently for *B. sexangula* and *R. apiculata* because of their relatively larger sizes, such as small seedling (< 1 m in height), large seedling (1 - 1.5 m) and small sapling (< 3 cm in dbh and > 1.5 m in height). For observing herbaceous species, the phytosociological method (Braun-Blanquet 1964; Fujiwara 1987) was used to record the abundance and cover of each species within the same plots, by dividing them into subplots. After this, we revisited the monitoring sites every year, during the opening season when the recruitment of new seedlings can be observed. This is also a time when it is more convenient to collect data because there is little rainfall. The openness of the canopy in each community was photographed using the Nikon Coolpix P6000 with wider lens WC-E76. The images were analysed with CanopOn2 software. When taking the photographs, the camera was placed in the middle of each subplot (5 m x 5 m) and at a height of 1.5 m to avoid the extruding vegetation at the understory layer, in order to catch crown extension after the cyclone impact.

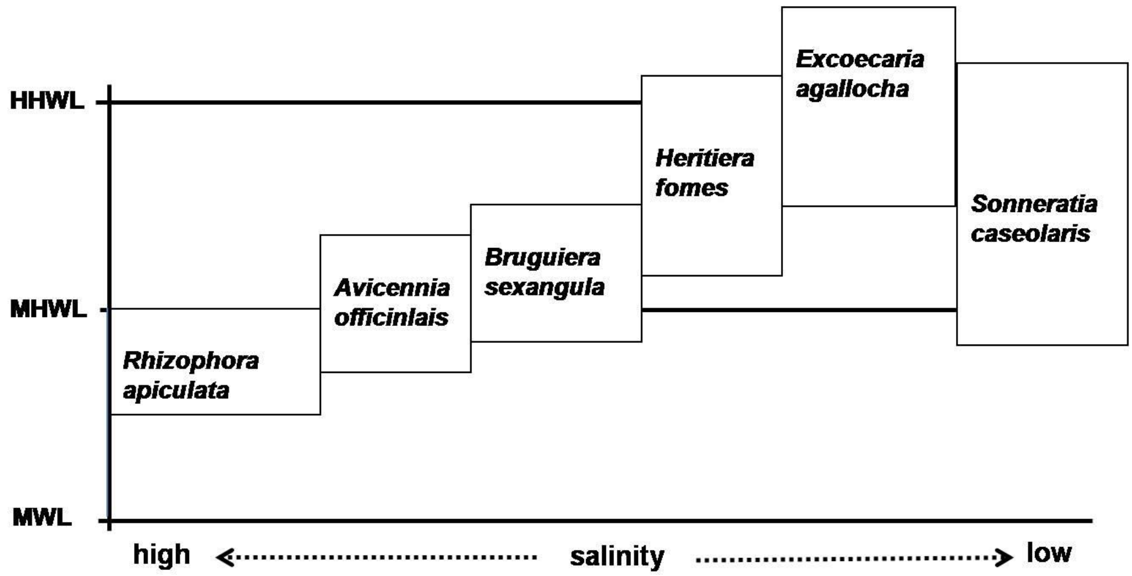


Figure 2. 2 Six selected mangrove communities, their habitats over tidal and salinity ranges: HHWL, highest high water level; MHWL, mean high water level; MWL; mean water level. (Sources: Mochida *et al.* 1998 and Than 2006)

2.2.3 Analytical tools

Analysis involved examining the significant levels in sprouting ability among the species, using the non-parametric Kruskal Wallis H test (p<0.001). After this test, groupings were determined through the Tukey's HSD test (α=0.05). The dissimilarities between compositions of pre-cyclone and post-cyclone species for the six community types were performed with non-metric multidimensional scaling (NMDS). This is the most generally effective ordination method for ecological community data and should be the method of choice, unless a specific analytical goal demands another method (McCune & Grace 2002). Clarke (1993) describes the advantages and uses of this method as being that it avoids the assumption of linear relationships among variables and that because of its use of ranked distances tends to linearize the relationship between distances measured in both species and environmental spaces. This also avoids the "zero-truncation problem," which plagues all ordinations of heterogeneous community data sets.

In order to predict the long-term population growth rate and to compare the six communities, the populations of six mangrove species were modelled by using a stage-classified projection matrix that was originally proposed by Lefkovitch (1965) and developed by Casewell (1989, 2001). This model has proven to be useful for studies of tropical plants in both disturbed and undisturbed environments (Boucher & Mallona 1997), and this type of model, showing how a population behaves, is needed in order to understand how the fundamental demographic processes of birth, death, immigration and emigration contribute to changes (or to stability) in population size (Silvertown 1987). The method for calculating the sizes of the populations for each life history stage at time t+1 can be given as follows:

$$n_1(t+1) = P_{1,1}\, n_1(t) + \sum_{i=1}^{k} F_i\, n_i(t)$$

where F_i indicates the number of young that are produced per stage 1 in year t. The total number of individuals counted in stage 1 in year t+1 is simply the fertility rate of each age class multiplied by the number of individuals in that size class at time t, plus any individuals that remained in the first size class from one time-step to the next ($P_{1,1}$). Generally speaking, once we know the fertility and survivorship coefficients for each stage class, we can calculate the number of individuals in each age at time t+1, given the number of individuals in each class at time t (Gotelli 2001). This assumption or trend projected from the stage-structured model can be true only if the total number of births in the population is the same; that is, if λ is near 1 and survival rates are constant from year to year. Such assumptions are rarely met in natural populations, but they are frequently made in order to get at least some information about a critical population (Vandermeer & Goldverg 2003). Clearly, the best way to predict the trends for population growth is to wait a few 100 years to see what happens. However, to undertake management intervention, we need an answer sooner than that. Therefore, the best approach for us was to develop a projection matrix and predict the future population numerically. We studied the population trends for the six mangrove species in this study, in order to predict their trajectories in population growth rate, by using this stage-structure population model. Our goal was at least to be able to support information about whether or not the population of each species is likely to persist or to become extinct.

This stage-based model was also extended to analyse sensitivity and elasticity for each model parameter. These analyses help to indicate how population size and stable distribution might change as we alter the probability values of fecundities and survival within the matrix. It is often useful to look at both sensitivity and elasticity when interpreting population figures (Vandermeer & Goldberg 2003). Their equations are as follows:

The sensitivity (S_{ij}) of an element in the matrix (a_{ij}) is given by

$$S_{ij} = \frac{v_i \; u_i}{<w,v>}$$

where v_i is the i^{th} element of the reproductive value vector, w_j is the j^{th} element of the stable stage vector, and <w,v> is the product of the w and v vectors.

Elasticity, the proportional sensitivity of the population growth (λ) is

$$E_{ij} = \frac{a_{ij} \; s_{ij}}{\lambda}$$

where e_{ij} is the product of the sensitivity of a matrix element (S_{ij}) and the matrix element itself (a_{ij}), divided by λ. If clearly stated, sensitivity determines the absolute contribution each demographic parameter makes to population growth rate, and elasticity analysis determines the relative contribution each demographic parameter makes to population growth rate.

In this study, the recovery index was also formulated in order to evaluate the comparable recovery potential of six mangrove species, by applying a simple calculation tool. Two key factors considered are the recovery factor and the risk factor. The recovery factor defines the increasing potential for the population size and the risk factor identifies environmental stresses that cause population growth to decrease. We have considered recruitment, release and re-sprouting as recovery factors, while repression and retreat (erosion) are taken into account as risk factors. If more risk factors are observed, they can be added as retreat factors that represent erosion and sedimentation. Sedimentation was not observed to any significant degree in the present study plots and was therefore neglected in the calculation. The proposed calculation is as follows:

Recovery Index = ∑Number of recovery factors/∑Number of Risk factors

The four mechanisms of release, re-sprouting, recruitment and repression used in this calculation are proposed by Everham & Brokaw (1996), and this simple structured formula is expected to be capable of making immediate, possibly even on-the-spot, predictions for vegetation dynamics following disturbance.

2.3 Results

2.3.1 Damage and vegetative responses

Structural and compositional damage

Before exploring the vegetation dynamics among the disturbed mangroves, it is important to understand the patterns of that damage that was caused by cyclones in the sites selected for this study. Figure 2.3 (a) shows that the number of stems with snapped branches and boles (III-a and III-b) was considerably higher than the categories for other damage patterns; indeed, more than 70 % of the stems had broken boles. The most serious disturbance (root damage, IV) and the least serious (no obvious damage, I) were rarely found. Consequently, as illustrated in Figure 2.3 (b), the mean height of each dominant mangrove species was reduced considerably, because most of their stems had broken and snapped (III-a and III-b). For example, the mean heights of *S. caseolaris*, *Sonneratia apetala*, *A. officinalis*, *R. apiculata* and *B. sexangula*, after the cyclone, had decreased to about half of their pre-cyclone measurements. The mean heights of the other species were also considerably lower after the cyclone. These results indicate that almost all species within the eye of the cyclone path, particularly the sites in the current study, were significantly affected. Following our revisit to the area one year after the cyclone had disturbed it, the study focused on mortality among six species, as shown in Figure 2.3 (c). More than 90 % of the *B. sexangula* and *R. apiculata* individuals had died, while other species had undergone less than 20 % mortality. It is important to note that there is no obvious difference in the mortality rates of all of these species, between the exposure and inside plots of each community type. Figure 2.3(d) shows the image of cyclone disturbance, and additional pre-cyclone and post-cyclone mangroves are attached in Appendix II.

Species-specific vegetation response

As Table 2.2 shows, more than 90 % of the stems of *H. fomes* and *E. agallocha* were able to produce vegetative sprouts. Other species, such as *Kandelia candel*, *A. officinalis*, *S. apetala*, *S. caseolaris*, *Aegieras corniculatum*, *Avicennia marina* and *Ceriops decandra*, had re-sprouted on more than 50 % of their stems. However, fewer than 50 % of the *Lumnitzera racemosa* species had stems with sprouts, and barely 1.13 % of the *B. sexangula* stems had sprouted. None of the stems among the *Rhizophora mucronata* or *R. apiculata* species had vegetative sprouts.

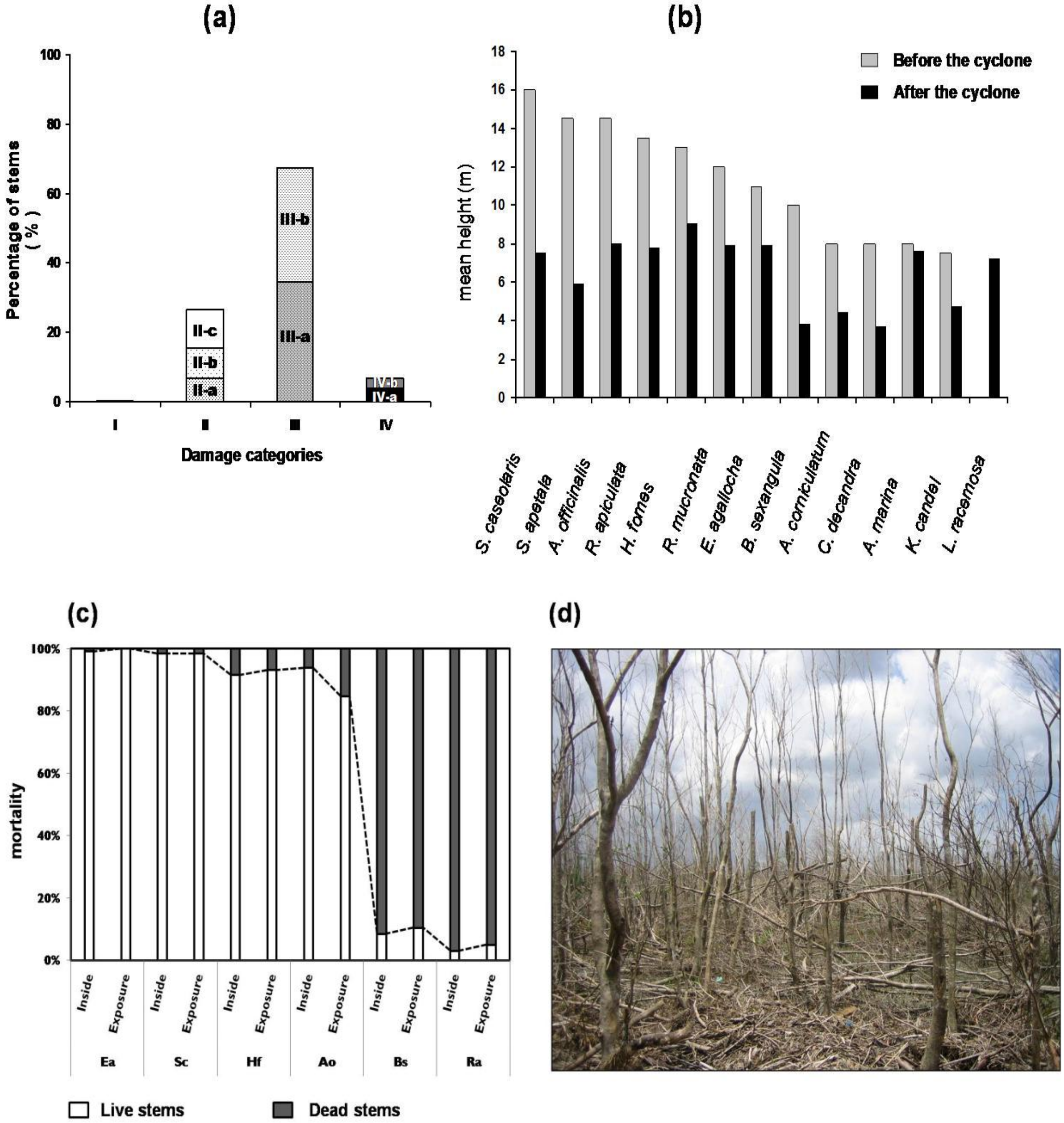


Figure 2. 3 (a) Percentage of the structural damage for 13 mangrove species; (b) Pre-cyclone and post-cyclone mean heights of the 13 mangrove species (Note: Pre-cyclone data adapted from Aung 2004, and Than 2006, and no pre-cyclone data available for *Lumnitzera racemosa*); (c) Percentage of the compositional damage of adults in six dominant mangrove species, one year after cyclone disturbance in the core zone of the cyclone path; and (d) Photo taken immediately after the catastrophic 2008 cyclone impact on plots dominated by *Avicennia officinalis* (Courtesy to Zaw Min Htun)

The number of sprouts per stem differed significantly among the 13 mangrove species

(Kruskal Wallis H= 821.15, P<0.001). Pairwise comparisons were conducted among the species and the grading of the sprouting was ranked using the Tukey's HSD test. For all species with vegetative sprouts, the mean number of sprouts/stem ranged from (49.92 ± 3.14) to (6.97±0.60), and these species were ranked as different grades, based on their levels of sprouting ability. *A. officinalis* was ranked as Grade 1, with the most abundant sprouts/stem (49.92 ±3.14) in comparison to the other species. *S. apetala*, *H. fomes*, *S. caseolaris* and *A. corniculatum* were ranked Grade 2 (spouts/stem measurements ranging from 20.80 ± 1.35 to 18.95 ± 1.64). Grade 3 included *K. candel*, *A. marina*, *E. agallocha* and *C. decandra* (ranging from 16.37 ± 1.57 to 13.53 ± 0.92). Finally, *L. racemosa* represented Grade 4 with the fewest sprouts (6.97 ± 0.60). This indicates that the responses to the impact of the cyclone, in terms of vegetative sprouts, are relatively different among these dominant mangrove species.

Table 2. 2 Sprouting ability, by number, for 13 dominant mangrove species

species	N	Ns	frequency of stems with sprouts (%)	ns	mean number (±SE) ns/N
Heritiera fomes	107	104	97.20	1989	19.31 (±1.68)
Excoecaria agallocha	122	112	91.80	1588	14.31 (±1.14)
Kandelia candel	129	110	85.27	1768	16.37 (±1.57)
Avicennia officinalis	106	88	83.02	4393	49.92 (± 3.14)
Sonneratia apetala	118	95	80.51	1976	20.8 (±1.35)
Sonneratia caseolaris	123	99	80.49	1885	19.04 (±1.32)
Aegieras corniculatum	112	80	71.43	1516	18.95 (±1.64)
Avicennia marina	125	71	56.80	1146	16.14 (±1.47)
Ceriops decandra	134	70	52.24	947	13.53 (±0.92)
Lumnitzera racemosa	145	46	31.72	321	6.97 (±0.60)
Bruguiera sexangula	153	2	1.31	3	0.02
Rhizophora apiculata	151	0	0.00	0	0.00
Rhizophora mucronata	137	0	0.00	0	0.00

Note: N for Number of sample individuals; Ns for Number of sample individuals that reproduced vegetative sprouts; and ns for Number of sprouts.

2.3.2 Community shift

In order to explore the dynamics of mangroves after natural disturbance, six selected communities have been assessed on a yearly basis. As seen in Figure 2.4 (a), the pre-cyclone patterns show clear distinctions between the communities, with a total of 25 species among them. However, Figure 2.4(b) shows most of the communities shifting to the centre of the axis and becoming closer to each other. Their patterns then become more similar and more mixed, with a total of 46 species recorded for all the communities. The dissimilarities between the communities before and after the cyclone are shown in Figure 2.4 (c), the dotted arrows pointing out the differences in the species composition that resulted from NMDS, from 2008 to 2012. Among them, the communities that were dominated by *R. apiculata* and *B. sexangula* illustrated the greatest shift, followed by those where *E. agallocha* was dominant. The two communities with *A. officinalis* and *H. fomes* showed the smallest relative differences. The community that was dominated by *S. caseolaris* was the only one that showed no dissimilarity between the pre-cyclone and post-cyclone compositions.

2.3.3 Patterns of recovery pathways

Trajectories of population

The previous section discussed the changing patterns of species composition in the different communities. This section attempts to project the pathways of the six species. The Leftkovit matrix population model has been used to make these long-term predictions for the recovery trends of the mangroves. Table 2.3 shows the stage-structured population matrices of six dominant mangrove species: *A. officinalis*, *B. sexangula*, *E. agallocha*, *H. fomes*, *R. apiculata* and *S. caseolaris*. Projections for the intrinsic rate of population growth are based on these geometric and matrix tables. It is important to note that the purpose of applying this

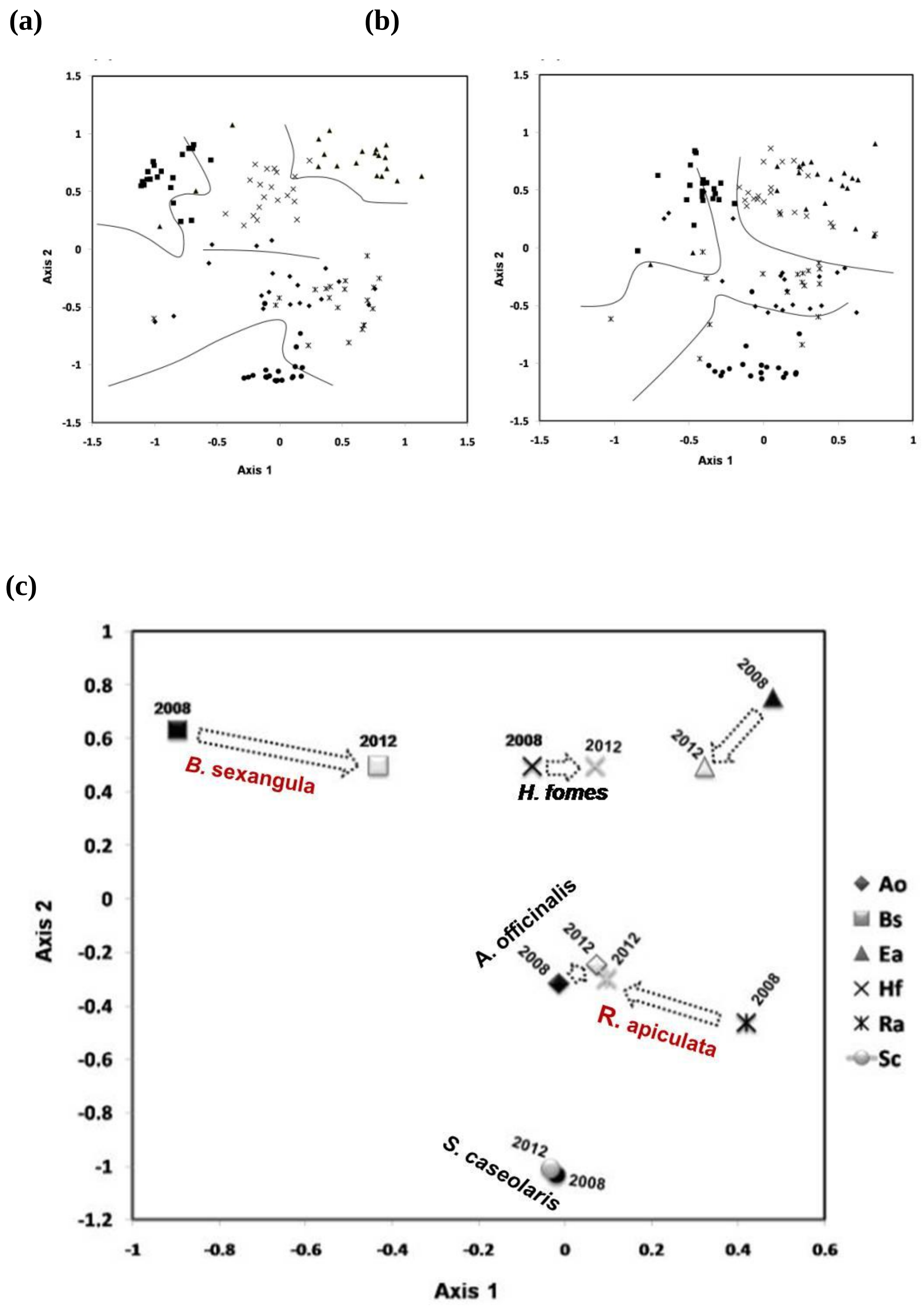


Figure 2. 4 NMDS results showing patterns of community shift for six dominant mangrove communities, in terms of pre-cyclone to post-cyclone species composition: (a) 2008 pre-cyclone species composition, from the data collected immediately after the cyclone, by considering dead individuals as alive; (b) 2012; and (c) dissimilarities from 2008 to 2012.

model was simply to recognize whether the trajectories of their population growth have shown increase, decrease or stability. The results shown in Figure 2.5 clarify the following population growth rates (λ): *A. officinalis* was 1.108, *B. sexangula* was 1.065, *E. agallocha* was 1, *H. fomes* was 0.971, *R. apiculata* was 0.980 and *S. caseolaris* was 1.203. The trends for *A. officinalis*, *B. sexangula* and *S. caseolaris* reveal increases in their recovery pathways, while those for *H. fomes* and *R. apiculata* illustrate decline in their populations. Also, *E. agallocha* is the only species to maintain a stable growth rate λ=1 without showing any increasing or decreasing trends. In case the same intensity of cyclone like the Cyclone Nargis occurs once every decade in future, the *A. officinalis* and *S. caseolaris* species have still shown increasing trends so that they can be supposed to be more persistent compared with other species.

Sensitivity and Elasticity

Following the trajectories for each species population, it is useful to look at their sensitivity and elasticity for use in extended analysis, in order to consider the absolute and relative contributions of each life history stage within the species, for conservation and management purposes. For example, should we focus our efforts on seed reproduction? Should we focus our efforts on increasing survival of seedlings, saplings or adults? Since finances and resources are always limited in undertaking such efforts for conservation and management, it is unlikely that we will be able to do all things at once. In terms of analysing sensitivity and elasticity, only very small changes in the population of each life history stage will affect the population growth when other elements are held constant. Figure 2.6 shows the analysis for both sensitivity and elasticity for five life history stages of the study’s six species. The results reveal that most of the species had a higher elasticity for adult survival, except that *R. apiculata* showed more in the large sapling stage.

2.3.4 Recovery index

Everham & Brokaw (1996) have proposed that the patterns of recruitment, release, re-sprouting, and repression are important mechanisms for vegetation recovery. First, in terms of recruitment or reproduction, phenology began two years after the cyclone impact in *A. officinalis, S. caseolaris* and *B. sexangula*, although reproduction among the other species was delayed until 2012. Also, the number of seedlings as release, perhaps r-strategists, that existed even before the cyclone disturbance was very high among the *A. officinalis, B. sexangula* and *H. fomes* communities, while only limited numbers were observed in the other three communities. In addition, the study uses quantitative data shown in Table 2.4 to rank the six species in terms of the re-sprouting of vegetation. *R. apiculata* and *B. sexangula* require special mention; they belong to the *Rhizophoraceae* group and have limited capacity to produce vegetation sprouts after cyclone impact. Sprouting among *A. officinalis*, on the other hand, is extremely high compared to other species. In terms of repression, then, the composition of herbaceous species was adopted from the cover and abundance values based on phytosociological survey methods. All parameters were consistently simplified into five ranks. Based on these values, a simple calculation was developed for the study, to come up with a tool to use as the index for short-term predictions of the potential of these species for recovery. This calculation is expected to be able to apply immediately even in the field.

Table 2. 3 Stage-structured population matrices of six dominant mangrove species and initial population vectors representing the number of individuals per 100 sqm

***Avicennia officinalis* dominated communities**						
	Young seedling	Large seedling	Young sapling	Large sapling	Adult	Initial population vector
Young seedling	0.3	0	0	0	21	184
Large seedling	0.33	0.38	0	0	0	55
Young sapling	0	0.51	0.89	0	0	9
Large sapling	0	0	0.03	0.99	0	1
Adult	0	0	0	0.01	0.99	15

Bruguiera sexangula dominated communities						
	Young seedling	Large seedling	Young sapling	Large sapling	Adult	Initial population vector
Young seedling	0.35	0	0	0	23	118
Large seedling	0.42	0.29	0	0	0	59
Young sapling	0	0.54	0.69	0	0	10
Large sapling	0	0	0.18	0.98	0	2
Adult	0	0	0	0	1	3

Excoecaria agallocha dominated communities						
	Young seedling	Large seedling	Young sapling	Large sapling	Adult	Initial population vector
Young seedling	0	0	0	0	0	0
Large seedling	0	1	0	0	0	2
Young sapling	0	0	0.5	0	0	2
Large sapling	0	0	0.5	1	0	2
Adult	0	0	0	0	1	13

Heritiera fomes dominated communities						
	Young seedling	Large seedling	Young sapling	Large sapling	Adult	Initial population vector
Young seedling	0.49	0	0	0	0	145
Large seedling	0.33	0.46	0	0	0	96
Young sapling	0	0.24	0.86	0	0	4
Large sapling	0	0	0.13	0.99	0	2
Adult	0	0	0	0.01	0.99	13

Rhizophora apiculata dominated communities						
	Young seedling	Large seedling	Young sapling	Large sapling	Adult	Initial population vector
Young seedling	0.25	0	0	0	0	16.4
Large seedling	0.57	0.24	0	0	0	10.9
Young sapling	0	0.65	0.42	0	0	3.7
Large sapling	0	0	0.55	0.98	0	1
Adult	0	0	0	0.01	0.99	0.4

Sonneratia caseolaris dominated communites					
	Young seedling	Large seedling	Yount sapling	Adult	Initial population vector
Young seedling	0.25	0	0	1	8
Large seedling	0.44	0.35	0	0	14
Yount sapling	0	0.37	0.78	0	16
Large sapling	0	0	0.16	0	11
Adult	0	0	0	1	15

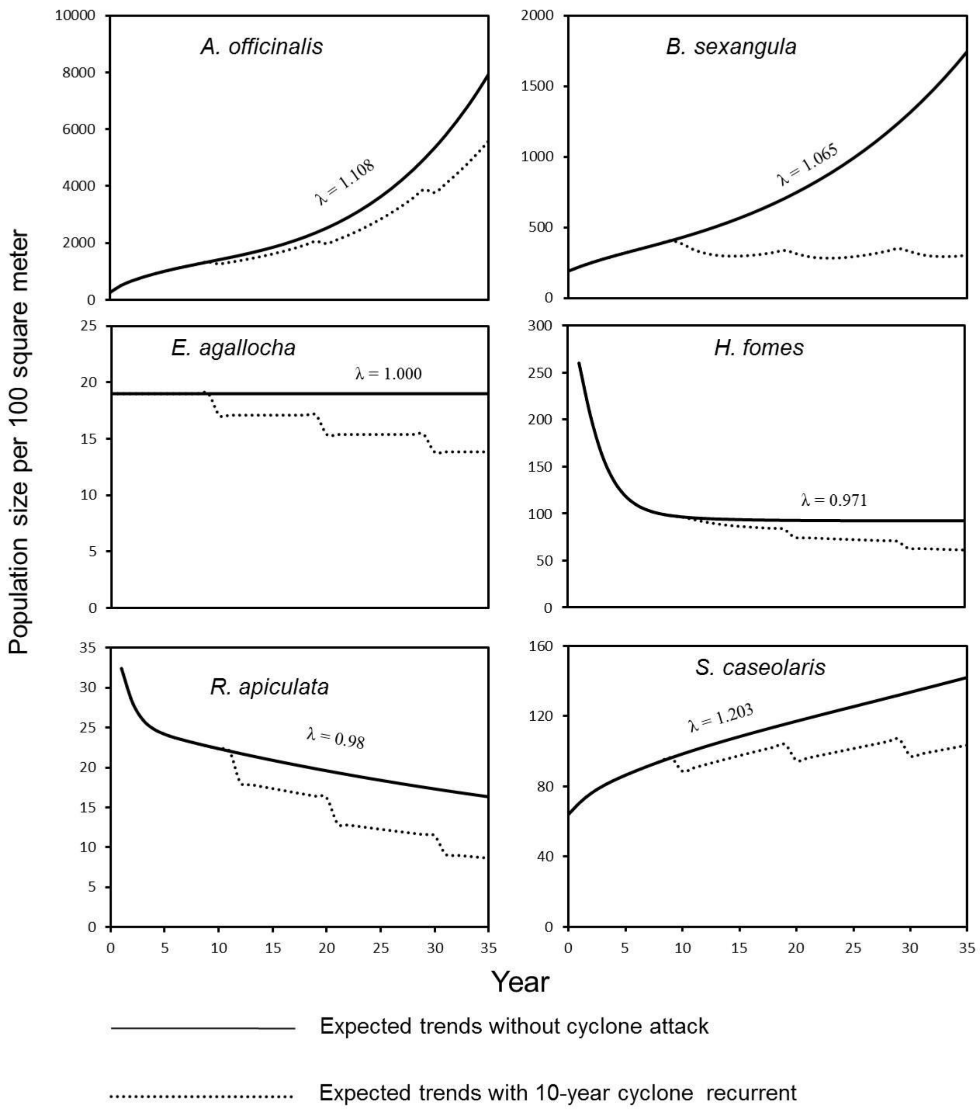


Figure 2. 5 Trajectories of six mangrove species for a span of 35 years, simulated by using a stage-structured population model.

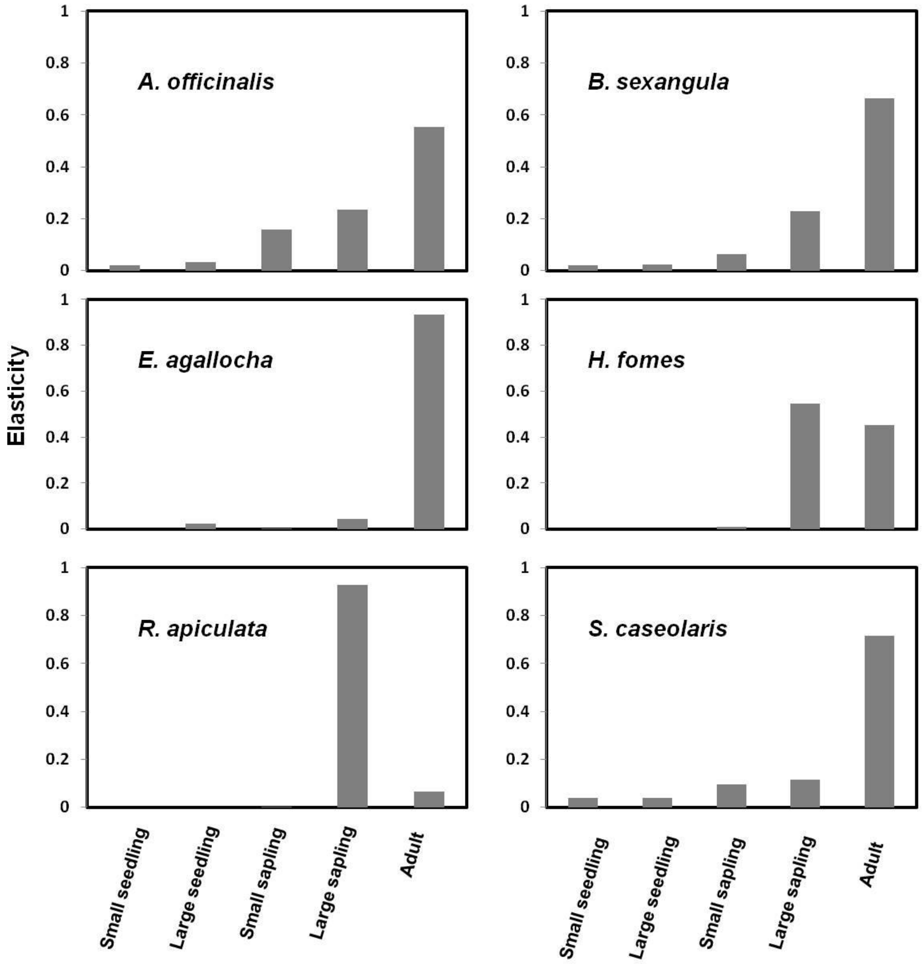


Figure 2. 6 Analysis of elasticity for six mangrove species.

Erosion that occurred inside the plots is qualitatively categorized as being consistent with other factors. Table (2.4) shows erosion as a retreat as well as a repression risk factor. The results showed that *A. officinalis* had the most rapid net recovery, followed by *H. fomes, S. caseolaris, B. sexangula* and *E. agallocha*, in that order, and the only delay was found in *R. apiculata*. The outcomes that resulted in the table (2.4) can also be ascertained by comparing the closed canopies that have recovered during the four-year period following the catastrophic disturbance, as shown in Figure 2.7. With respect to the canopy openness of the species in the present study, it can be assumed that their openness shortly after the cyclone impact was almost 100 %, and pre-cyclone can be assumed to have been 90 % of closed canopy. If the recovery of mangroves merely by canopy closure is considered, the values of recovered canopies for all selected communities can be taken average. In this respect, the recovery rate of the cyclone-affected mangroves for a period of three years and eight months later after Cyclone Nargis are observed 61.06 %.

Table 2. 4 Recovery index based on four factors (Everham & Brokaw 1996) and one added factor with environmental risk (erosion in this study)

Community	Recovery factors			Risk factors		Recovery Index	
	Recruitment	Release	Resprouting	Repression	Retreat		
A. officinalis	5	4	5	3	1	3.50	+++++
B. sexangula	5	3	0	5	0	1.60	++
E. agallocha	0	1	3	4	0	1.00	+
H. fomes	0	3	4	3	0	2.33	++
R. apiclata	0	1	0	3	3	0.17	?
S.caseolaris	1	1	4	1	2	2.00	++

Note: 0 for no recovery, and the higher the values the more rapid the recovery of each community

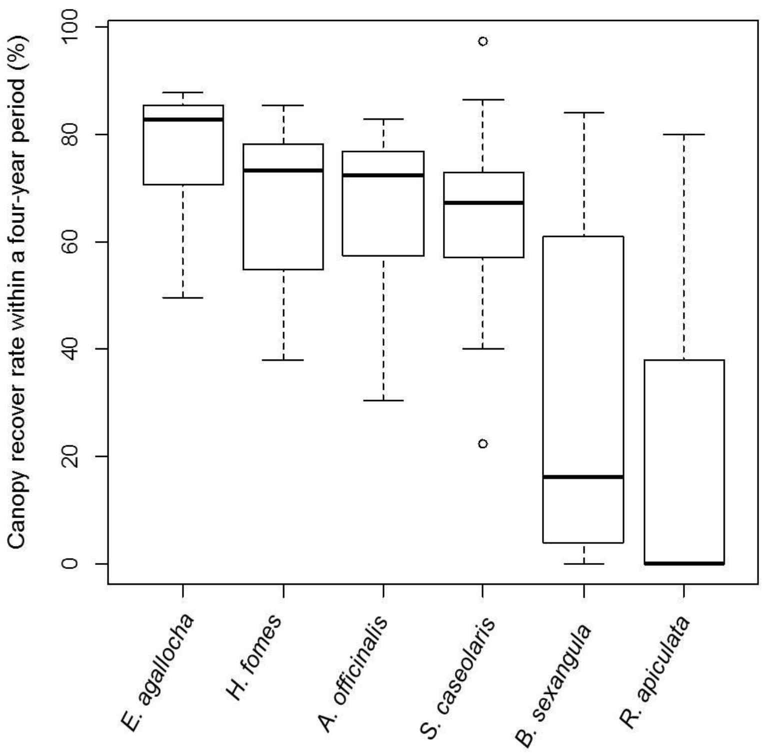


Figure 2. 7 Canopy recovered for a period of three years and eight months later after Cyclone Nargis

2.3.5 Harvesting tolerance

Anthropogenic disturbance plays a critical role in the fate of population sizes. Therefore, after considering the population trends for the mangroves, human intervention to the mangroves in most of the developing regions should be taken into account, and the impact of such intervention may have had more effect than any kind of natural impact. Harvesting or cutting tolerance, therefore, should be included in analysing the trajectories of each population size. In addition, this intervention may also provide valuable information for forest managers and an incentive to implement integrated and wise use of mangroves, by reducing illegal activities and over-exploitation. Harvesting tolerance refers to the potential persistence of each species or community of mangrove for use by local people for their subsistent needs, such as construction materials, fishing tools and firewood. It may also be viewed as a coefficient of density-dependence or an indication of self-thinning processes. This analysis considers only the species that had an increasing and stable population, neglecting those with decreasing population trends. In this case, the initial population sizes at the time directly following the disturbance were taken into account as the threshold levels for cutting tolerance, even though the tolerance may, in reality, be more flexible. As shown in Figure (2.8), for *A. officinalis*, a 25 % cut levelled off with the current population trend, and the population went down below the threshold level in a short time, to a 50 % cut. Although a 25 % cut was adjacent to the threshold level for *B. sexangula*, this would go below the level during the first five years. For *E. agallocha*, it is clear that all levels are decreasing if cutting or harvesting is considered from the level of the stable stage population rate of $\lambda = 1$.

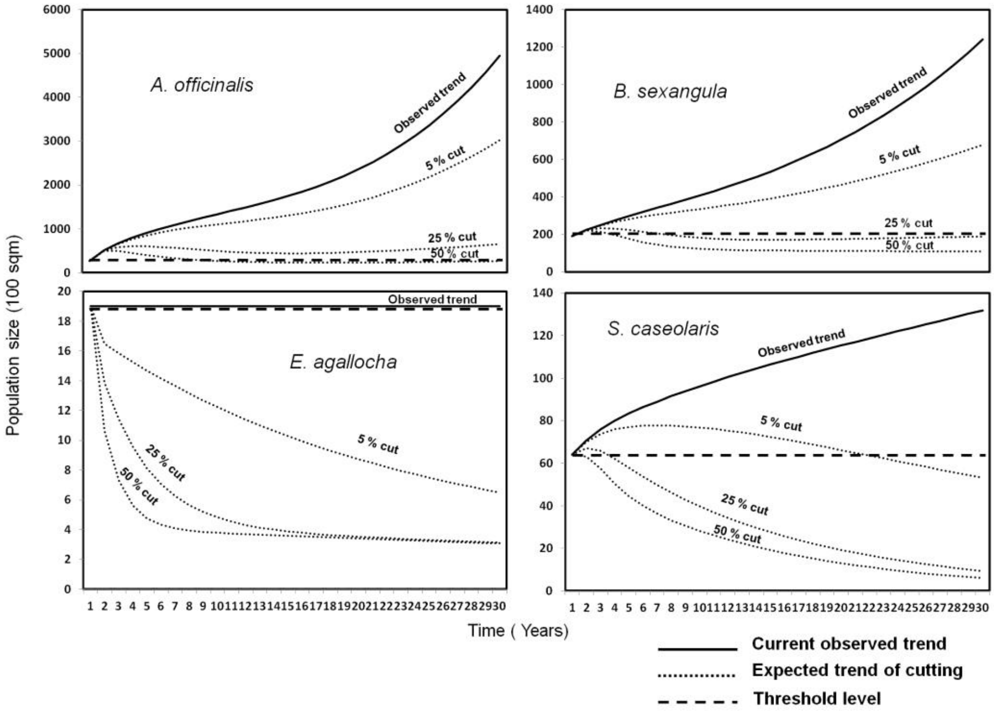


Figure 2. 8 Harvesting tolerance of 5 % to 50 % of adults for those four species that haven't shown the decreasing trends in population sizes.

2.4 Discussion

2.4.1 Cyclone impacts and mangrove responses

The mechanisms of storm and hurricane damage are related to a variety of factors, such as wind fields, wave energy, water levels, sediment dynamics and chenier formation, all of which may affect the characteristics of mangrove sensitivity to a greater or lesser extent (Paling *et al.* 2008; Cahoon & Hensel 2002). Because the present study is focused on the cyclone that happened in the mega delta of Myanmar, wind should be suggested as a key driver. Moreover, similar damage patterns also occurred among all species; more than 70 % of the adult individuals had broken stems rather than being uprooted, which was far less common. Storm surge was reported approximately 3.6 m in the study area, so the tidal flooding in the study area might have covered seedlings, saplings and certain higher levels of adult individuals as well. Indeed, this may be one of the reasons why there were as few uprooted trees. Another possible reason is the distinct architecture of mangrove roots. As mentioned in our previous study (Aung *et al.* 2009), the taller trees received more damage than the smaller ones. Also, Herbert *et al.* (1999) describe a similar case following Hurricane Iniki, in which stem damage largely involved branch removal, with some stems partially uprooted or decapitated, and large trees damaged with greater frequency than the small ones. Cyclones are wind-induced, unlike tsunamis that primarily bring waves and perhaps cause more uprooting of adult trees. In the location for the present study, therefore, it is highly likely that patterns of damage result from wind-induced impact, rather than from waves.

In terms of the sensitivity of the species to disturbance, other research reports both similar and contradictory results to those of our study. However, this is comparable only for the genus level; species-level comparison is limited. In terms of wind damage, the sensitivity of species in the *Rhizophoraceae* and the resilience of those in the *Avicenniaceae* have also been noted in Australian mangroves that were subjected to cyclones (Woodroffe & Grime 1999). By contrast, Paling *et al.* (2008) finds that there were differential survival patterns between the two dominant species, *A. marina* and *Rhizophora stylosa*. In almost all locations, mature *R. stylosa* were in good condition and had apparently survived the cyclone, while the surrounding *A. marina* had all died. In addition, dense areas of mature *R. stylosa* in very exposed locations had remained in good condition. The results of the present study are similar to those of Woodroffe & Grime (1999), but contrary to Paling *et al.* (2008), since our study found the *Rhizophoraceae* group of *B. sexangula* and *R. apiculata* had more than 90 % compositional damage, while other species had less than 20 %. The studies that contradict ours mention that the mortality of *A. marina* was due to the gradual deposition of sedimentation resulting from the cyclone impact. In our study, there was limited evidence of sedimentation, and the high mortality of *Rhizophoraceae* must have been due to the homogenous stands of adults that were easily broken by the strong wind in Cyclone Nargis, so that the broken boles and braches, with loss of crown or complete defoliation, had no ability to reproduce vegetative sprouts. Under this condition, without epicormic sprouts, the survival option for this species was to disappear, further illustrating the high vulnerability to attack by winds. It is important to note that *Rhizophora* individuals that retain only one branch with one bud, can have a chance to survive, even after wind disturbance. Smith & Duke (1987) also claim that there are very few *Rhizophoraceae* in the Sunderbans and that this may be because the adjacent Bay of Bengal receives 30-40 typhoons a year.

In assessing immediate vegetative response to cyclone impacts, mangroves, depending on the species, have the ability to sprout from broken stems and even from a trunk that has lost its canopy (Lewis III 2005). Similar results in the present study show that there are highly significant differences in the numbers of sprouts/stems among the 13 dominant mangrove species. *A. officinalis* had the greatest ability to produce vegetative sprouts, as measured by number/stem, whereas most *Rhizophoraceae* species had few, if any, vegetative sprouts. The study on sprouts/stump by human impact (Ono & Fujiwara 2004) also states that *A. officinalis* had more sprouts than did other species. According to Tomlinson (1986), mangrove Rhizophoraceae are distinctive because they lose the ability early to produce reserve meristems, whereas most other common genera (e.g, *Avicennia*, *Laguncularia* & *Sonneratia*) retain reserve meristems and develop epicormic sprouts when damaged. This study also observed that *R. apiculata* and *R. mucronata* had no ability to reproduce vegetative sprouts after the cyclone, but that *B. sexangula* (also *Rhizophoraceae*) did have a few sprouts. In spite of the fact that *B. sexangula* had sprouts, their potential was extremely low at 0.02 sprouts/stem. A study in Thailand and Malaysia (Tsuda & Ajima 1999) found no sprouts in *B. sexangula* and *C. decandra*. By contrast, this study observed that these two species had sprouts, although they were rare in *B. sexangula*. This might be due to the different locations or habitats. It also seems probable that pioneer mangrove species, the light demanders, have the ability to produce abundant sprouts after natural disturbance. Aside from most *Rhizophoraceae*, most other species were also observed to have a considerable ability to produce vegetative shoots, although sprouting ability was not as high as in *A. officinalis*.

2.4.2 Recovery pathways

The measures to conserve, restore and manage mangroves after cyclone disturbance require understanding about their trajectories in population sizes. Two communities of *B. sexangula* and *R. apiculata* have shifted considerably farther from their pre-cyclone origins in ordinated space, compared to the others. A possible reason for this is that after opening up the canopies of mangrove communities, the herbaceous species and survival stems of other species have invaded and taken the opportunities in the light gap. Baldwin *et al.* (2001) indicate that moderately damaged mangroves were leading to single-species stands, and in severely damaged ones led to mixed-species stands. Rashid *et al.* (2009) also reports on the invasion of non-mangrove species after catastrophic disturbance. The years following the impact of a cyclone are challenging for mangrove species, as they compete with a number of herbaceous invaders and other opportunists. Therefore, species that are fast growing and demand a lot of light appear to have higher potential for competing successfully with invader species. The community shift of *B. sexangula*, then, may turn over for a considerable period of time, and current patterns of dissimilarities are supposed to be under oscillation processes. However, for the *R. apiculata* species, it may take more time to leap back to its initial state. In this case, forest managers rather than ecologists may need management intervention in order to facilitate the development of true mangrove species in the face of herbaceous species like eradication of undesirable species.

A stage-structure population model for the recovery pathways of mangroves has been predicted for a long time. A recovery index for the current situation was also developed with a newly structured formula, based on mechanisms proposed by Everham and Brokaw (1996) and adding erosion in this study as one more risk factor, and sedimentation was neglected here. Making predictions through the stage-structured model used here is clearly impossible. This unreasonable forecasting is based on an assumption of continued density-independent growth, without any changes in the parameters of the transition matrix. This, essentially, means an unchanging relationship between the population and its environment, as forest regeneration proceeds (Boucher & Mallona 1997). Nonetheless, the primary purpose for the present study that applied this model is to recognize whether the population sizes have been increasing or not. This model is very useful for such cases of projection. In the sites where there are a couple of limitations to carry out long-term monitoring, the newly structured formula might be relatively appropriate for assessing the potential recovery pathways of all other forests or communities, by one-shot inventory. The result derived from the stage-structured model claims high recovery potential for *A. officinalis*, *B. sexangula*, *E. agallocha* and *S. caseolaris*. As for *H. fomes*, its recovery pathway has shown delay in the projection trends through the stage-structured model. This was due to delayed reproduction after catastrophic disturbance. However, it has other mechanisms, such as a carpet of seedling reserves as release and vegetative sprouts, so the newly structured formula in the present study performs like a crosscheck tool to produce different results for its potential in resiliency. The recovery of mangrove forests from hurricane impacts, relying primarily on seedling recruitments has also been noted by Smith *et al.* (1994) and Cahoon & Hensel (2002). Mangroves, therefore, affirm their resiliency and have an ability to absorb natural disturbance, with the exception of the *R. apiculata* communities, which are liable to erosion, as the mass mortality of these trees without epicormic sprouts has resulted in an inability to hold sediments, soil and the pre-cyclone advanced seedlings and post-cyclone recruited seedlings on the mud flats at the riverbank. Furthermore, the delay in post-cyclone propagule reproduction also hinders recovery potential of this *Rhizophora* sp. Cahoon & Hensel (2003) also reveal a similar case in mass tree mortality that caused elevation loss. While established mangrove communities assist in stabilizing coastlines, then, seedlings are susceptible to wave, current and wind energy, and this limits the habitats that they can successfully colonize (Boizard & Mitchell 2011). With respect to the reason for recovery delay, Milbrandt (2006) states that delays in forest recovery are possible in severely impacted areas if either the delivery of propagules or the production of seedlings is reduced by habitat fragmentation. Fujioka *et al.* (2008) also report that although the mangrove community recovers quickly after tsunami impacts, in highly disturbed areas where thick sand has accumulated at the bottom of the mangrove forest recovery appears to be difficult because the composition and depth of the sediment has altered. Therefore, rather than having a direct impact, indirect post-cyclone consequences present major obstacles and delay the recovery process, in spite of the acknowledged resilience of the mangroves.

Alongi (2008) thoroughly reviews the variety of key features that contribute to the resilience that mangroves have against disturbances. Among these features are the large reservoirs of nutrients that lie underground, the rapid rates of change among these nutrients and the microbial decomposition, as well as the complex and highly efficient biotic controls, self-design and redundancy of the keystone species. The current study agrees with its underlying theory of mangrove resilience, although the focus of this study is just on the flora, rather than fauna. Cahoon & Hensel (2002) and Paling *et al.* (2008) affirm the recover ability mangroves from large impacts. Also, while natural short-term impacts, such as hurricanes, may temporarily destroy the trees, mangrove forests are readily re-established through seedling recruitment and/or epicormic sprouting by local species (Baldwin *et al.* 1995; Moore

2004). In addition, there are threats to the long-term integrity and functional values of these coastal wetlands, from anthropogenic impacts such as oil spills, eutrophication, the over-harvesting of trees for wood products, clear-cutting for development, changes in hydrology, conversion to agriculture and unsustainable aquaculture (Lugo 1990; Ellison & Farnsworth 1996). Most of the catatrophic disturbances have occurred neither by massive die-offs nor by parasitic infections; the real chronic ecological degradation have been proven when humans mismanage the systems and allow irreversible environmental changes from which recovery is almost impossible. It can be concluded, then, that mangroves can recover from catastrophic cyclone impact within a short period of time, with the exception of the *Rhizophora* genus, which the current study found to have been affected by intense winds. Regarding engineering resilience that is introduced by Walker & Salt (2006), an attempt here is to describe canopy recover rate for a span of five years later after Cyclone Nargis. As is shown in the canopy recovery details in Figure 2.7, if the pre-cyclone canopy cover of each is considered to be almost 90 %, the recovery rate of *A. officinalis* within a three-year and eight-month period is 60 %, *B. sexangula* is 20 %, *E. agallocha* is 40 %, *H. fomes* is 50 %, *S. caseolaris* 55 % and *R. apiculata* is 15 %, and on the average for all species is more than half 61.06 %. Appendix II also clearly shows the images of recovered mangroves. The processes for the mangrove ecosystem, perhaps, differ from those of other forest types. Cahoon & Hensel (2002) concluded that dry forest recovery from hurricane disturbance might be delayed by the cumulative effect of other chronic disturbances such as drought.

2.4.3 Management implication

Coppice is a forest crop raised from shoots produced from the cut stumps (called stools) of the previous crop, and coppicing describes the operation of regenerating crops in this way. Coppicing can usually be repeated many times over and is a useful means of regenerating broadleaved trees within short time intervals (less than 30 years), to produce small round wood. It is the main process used for managing underwood and has been employed widely in the management of small woods for centuries (Evans 1992). Therefore, it is expected that this traditional method will be used for depleted mangrove forests, especially in community-based management. Some of the species that demonstrated an ability to sprout should be tested as plantation models for beginning coppicing operations in community-based forest management programs. This would aim to provide a surplus and the quick return of mangroves in the densely populated region, to meet the subsistence needs of local people. For example, *A. officinalis*, *H. fomes*, *S. caseolaris* and *E. agallocha* have good potential for coppice management practices in community-based projects. Ono *et al.* (2004) have also stated that *H. fomes* is appropriate for coppice management. However, some of the *Rhizophoraceae* species should not be recommended for coppicing management operations.

Determining whether management intervention is needed for post-cyclone mangroves is important for both foresters and ecologists. Mangroves have shown considerable recovery potential. However, as long as the particular species and site-specific conditions are considered, the different impacts and recovery pathways can be observed. Such as *R. apiculata*, which grow mainly along the riverbanks might need to be restored with the appropriate species before erosion happens. Rashid *et al.* (2009) made the general conclusion that, instead of relying solely on natural regeneration, forest managers should actively consider planting mangrove species in the larger canopy gaps that are created after catastrophic disturbances. The reason for this is that, following such disturbances, the persistence of non-mangrove species, mangrove associate species and invasive species, rather than true mangroves species, could lead to critical ecological degradation and biological invasion. In addition to erosion, then, it is important to eradicate non-mangrove species in order to facilitate the development of mangroves. Also, post-cyclone intervention can lead to mismanagement, by totally clearing mangrove habitats for restoration and replacing them with alien, non-mangrove species in order to make the forests grow faster. Great care should be taken to prevent such clearances on cyclone-disturbed mangroves, in order to make plantations. Figure 2.6 shows the results of the present study's elasticity analysis. These show that mother trees play a crucial role in maintaining the population of each species and that they should be strictly maintained under a set of guidelines and instruction. Taking into consideration the cost-benefits of restoring degraded mangroves, then, gap planting might be preferable and, in some cases, eradication might even be enough to release seedlings that already existed in as understory before the disturbance. The present study points out that most of the mangrove species have such patterns of release and wait for the canopies to open, after they incur certain kinds of crown damage either from natural disturbances, self-thinning or proper harvesting.

Cutting tolerance is proposed, therefore, in order to support proper management decisions for forest managers, local people and all of the stakeholders. Clearly, this theory does not apply in the region where mangroves should be set aside for conservation purposes alone, such as for bio-shields in the transition zone between sea and land. In this analysis, harvesting appears to be permissible for species such as *A. officinalis*, which have a high harvesting tolerance, where the subsistence use by local people has little effect on the population size of the species. However, caution must be taken to avoid over-exploitation and disturbance to the understory release layer. In the past, the cutting tolerance of mangroves might have played a crucial role in mangrove management, since their use by local people has not been the main source of their degradation. Mangrove deforestation was a result of the clear cutting, to convert the land for other uses of agriculture and aquaculture.

Of greater importance, however, as mentioned above, is that the stage-structured model was clearly impossible because of its density-independence. An attempt to cut an acceptable number of individuals, then, might also be a factor for density-dependent cases and produce an artificial thinning process instead of self-thinning ones. The number of individuals that were able to consider for harvesting or cutting was smaller for some species, such as *S. caseolaris*, *E. agallocha* and *H. fomes*, than for others. If that is the case, harvesting more than 50 % of the trees should be totally prohibited, in order to maintain a population composed of all life histories. Therefore, the cutting threshold should be kept at 5 - 10 % harvesting for local use. Although Pinzon (2003) did not focus on population size, it was compared the regeneration conditions in both natural and anthropogenic gaps among the mangroves in Micronesia, and pointed out that current harvesting practices do not seem to alter the richness of the species. In addition, Imai *et al.* (2006) state that having many large gaps may help seedlings and saplings of *Sonneratia alba* and *Avicennia alba*, which need sunny conditions for their growth. Overall, these expectations are based not only on theory but also on reviews of practical action that was taken in the past. In particular, consideration should be given to the sites where the very sensitive *Rhizophora* species are disturbed so that they can be restored more rapidly, before it is too late to maintain soil erosion. Kumara *et al.* (2010) recommended restoration in high density that the relatively high accretion and high elevation change, coupled with greater plant survival, suggest the potential to develop mangrove plantations to help protect coastal regions. Mangroves certainly demonstrate self-help specific strategies for ecological resilience and their resilience may help in developing innovative integrated management, rather than having to rely on conventional methods that may have excluded the social needs of local stakeholders in some regions.

2.5 Conclusion

The present study confirms that the species-specific levels show different recovery pathways, although mangroves are generally highly resilient. *B. sexangula* and *R. apiculata*, which belong to the *Rhizophoraceae* group, were found to be more sensitive to natural disturbance, presumably wind-induced impact, while the other species showed more resilience. In the *Rhizophora*-dominated community, it is the indirect rather than the direct consequences of cyclones that slow the recovery process of this species-dominated sites. Management intervention in the cyclone-sensitive communities might be necessary in order to mitigate the adverse effects of catastrophic disturbances such as erosion and invasion by herbaceous species. The species observed highly persistent to cyclone impacts should be paid attention in implementing plantations as the life-protecting function to local people for storm protection in future. In general, the recovery rate of mangroves based on the six communities in the present study was observed 61.06 % by three years and eight months later after Cyclone Nargis. Sustainable management and the restoration of mangroves should not neglect anthropogenic disturbances, which are inevitable in the current study region where most of the local people rely, either directly or indirectly, on mangrove products. Based on this framework, a theoretical harvesting tolerance is developed in which *A. officinalis* represents the highest tolerance. After proper opening of the canopy, a number of recruited seedlings can be facilitated to graduate to the next stages. However, practical and long-term research is needed to determine whether this is indeed feasible or not and also how much threshold should be kept for local harvesting in real situations. This does not necessarily mean that harvesting should be totally allowed in this region and, in terms of forest management in densely populated regions of the developing world, a wise-use scenario in mangrove management should be carefully considered by thinking about the basic needs of local people. To summarise, most mangrove species rely strategically on natural recovery processes and patterns, for great conservation purposes, attention should be paid to some sensitive communities suffering indirect, negative consequences following cyclone impact.

Chapter III

Assessment of Actual Vegetation and Environmental Risks in the Mangroves Disturbed by Anthropogenic Activities

Abstract

Human activities have continuously threatened mangroves worldwide. In Myanmar, rice fields and shrimp ponds have encroached into mangrove forests. On the landscapes affected by these agriculture and aquaculture impacts, understanding actual living vegetation recovered naturally is required for drawing strategy to meet the goal of mangrove sustainability. While conversion to rice fields has had a long history, conversion to shrimp ponds has become a growing concern in recent decades. First, vegetation censuses by using line transect and a phytosociological survey method were conducted. In the rice field affected sites, a total of 44 species were recorded in the young fallow lands and 52 species in the mature fallow lands. The only one true mangrove species, *Sonneratia caseolaris*, has been observed in the community types classified for both lands. Similar methods were used on the shrimp ponds affected sites. A total of 36 species was recorded. True mangrove species that most frequently occurred as tree life forms were *Ceriops decandra, Avicennia marina*, *Heritiera fomes*, *Avicennia officinalis*, and *Excoecaria agallocha*. At these human affected sites, the occurrence of herbaceous species outweighed that of mangrove ones. For recovery process at the clearly-cut mangrove sites, the patterns of vegetation succession, in general, can be proposed as four main phases; 1) short grasses initially start growing in the barren areas, 2) tall grasses mixed with herbaceous species invade, 3) pioneer mangrove species establish again, and 4) eventually climax species are supposed to return to mangrove forests again. In these natural self-help recovery processes, the rice field affected sites witnessed to take a long time to return to mangrove forests because this agricultural practices almost cut mangroves clearly. On other words, it would need restoration by artificial means. Similar patterns have occurred at the shrimp farming sites with cleared mangroves. In order to address the current growing issue, the present study proceeded to investigate potential risks in the aquaculture affected mangroves. In the result, the community-managed mangrove forests without shrimp farming and the abandoned shrimp farming with mangroves have shown more preferrable status. Despite certain appreciable levels of biomass and soil properties on the active shrimp ponds with mangroves, the prominent finding on the activation of acid sulfate soil at these sites and its consequences can cause adverse environmental and ecological impacts. In case mangrove-friendly aquaculture is considered as one of the restoration strategies, it is urgently required to improve systematic pond design and management to comply with local regular hydrology.

Keywords: mangroves, anthropogenic impacts, shrimp ponds, rice fields, actual living vegetation, environmental risk assessment

3.1 Introduction

Mangroves are remarkable transitional ecosystems between marine and terrestrial environments, and the term “mangroves” refers to both the plants that occur in tidal forests and the community itself (Tomlinson 1986; Wightman 1989). In some parts of the world, these invaluable wetlands had been considered as wasteland. For instance, Aypa & Baconguis (2000) points out that the mangroves in the Philippines were once considered the vast tracts of wasteland that could be developed into other land uses. The economic “advantages” associated with such exploitation were considered socially “valuable” to human communities, and so mangroves were cleared to give way to developments or when its presence was considered unsightly. Since the past decade, new research from around the world has shown that mangroves have higher levels of primary productivity than most other tropical or temperate forests. Moreover, mangrove soils have considerable storage of organic carbon. Hence, mangroves, despite their small global presence, may be important in managing global carbon budgets and in mitigating climate change (Spalding *et al.*, 2010). Furthermore, in terms of economic value, mangrove forests currently occupy 14,650,000 ha of coastline globally (Wilkie & Fortuna, 2003), with an average monetary value estimated at US $10,000 ha^{-1} $year^{-1}$ (Costanza *et al.* 1997). More importantly, regardless of this monetary value, mangrove ecosystems are important habitats, especially in developing countries. They play a key role in human sustainability and livelihoods (Alongi 2002), being heavily used traditionally for food, timber, fuel, and medicine (Saenger 2002).

Despite the above-mentioned values of mangroves, they have been decreasing rapidly worldwide. According to the *World Atlas of Mangroves* (Spalding *et al.* 2010), one quarter of the original mangrove cover has been lost as a result of human actions. While rates of loss decreased from 1.04% per year in the 1980s to 0.66% per year in five years to 2005, these rates are still five times greater than the overall rates of global forest loss. The prominent impacts are conversion to agriculture and aquaculture mainly due to the increasing density of population around mangroves.

Among the threats to mangroves by human activities, there has still limited information regarding mangroves converted to agriculture, in particular rice fields. However, the Ayeyarwady mega-delta mangroves have continuously been converted into rice fields approximately since the 1960s. This has happened far prior to the brackish aquaculture extensively practices in this mega-delta region since 2002. Giri *et al.* (2008) states that 98 % mangrove deforestation in Myanmar was due to rice fields and other 2 % was due to shrimp cultures. The Ayeyarwady mangroves are delta-based formation, and this makes more favorable to convert mangroves to rice fields compared with the mangroves in other parts of the world.

Unlike the conversion of mangroves to rice fields, unlimited information is available regarding the conversion of mangroves to shrimp farming, but merely about intensive farming rather than about extensive one. This aquaculture issue has become the predominant cause of mangrove loss in recent decades, representing one of the major threats to mangrove-dominated coastal and delta areas worldwide. For instance, due to mangrove conversion to aquaculture, Honduras lost 22% of its mangroves between 1973 and 1992 (De Walt *et al.* 1969). Of the 203,765 ha of mangroves lost in Thailand in 1961–1993, 32% were converted into shrimp farms (Menasveta 1997). Approximately 25%–30% of mangroves in Vietnam were lost for shrimp farm development from 1985 to 1988 (Thuoc 1995). From 1967 to 1988, 973 ha of 7500 ha of mangroves were converted into shrimp cultures in Chakaria Sundarbans, Bangladesh (Choudhury *et al.* 1994). From 1983 to 1994, 2000 ha of 3650 ha of mangroves were converted into shrimp cultures in Puttlam District, Sri Lanka (Liyanage 1995).

The mangroves in the Ayeyarwady Mega Delta of Myanmar have also been lost due to shrimp farming practices to some extent. Despite limited data currently available, FAO (2003) reports that the total shrimp farming area in 2002 across Myanmar was estimated to be 193,265 acres (over 70,000 ha), and the largest area of shrimp farming was 155,533 acres in the Rakhine State, followed by 33,373 acres in the Ayeyarwady Delta, 7394 acres in Yangon, and smaller areas in Bago, Kayin, Mon, and Tanintharyi. It is estimated that of 193,265 acres (over 70,000 ha), over 85% (around 60,000 ha) is under extensive culture techniques. Approximately 5180 acres is under more intensive culture, and another 22,768 acres is under improved extensive (extensive plus) culture. In the present study area alone, the shrimp cultures are reported to be 3140 acres by the Forest Department (unpublished data, 2010). However, this extent would have been underestimated because of a difficulty in clearly classifying extensive aquacultures and mangrove areas.

Seventy-five percent of these cultured shrimps worldwide are said to come from Asia, with Thailand, Indonesia, China, and Vietnam among the top producers (Rosenberry 1996). The commercialization of these shrimp cultures has been driven by lucrative profits from export markets and has been fuelled by government support, private sector investment, and external assistance (Primavera 1998a). In the past, the loss of mangroves in the tropics had been caused even by the international economic assistance, given the high level of financing from the World Bank, Asian Development Bank (ADB), and other development agencies (Siddall *et al.* 1985) involving the large-scale development of mangrove swamps into small shrimp/fish pond holdings (ADB 1978) as mentioned above, perhaps with less knowledge about their ecological values.

In shrimp farming practices, there are three main grow-out systems of shrimp farming noted by Primavera (1998a), such as extensive characterized by natural food and tidal flushing, semi-intensive indicating supplemental feeds and occasional pumping of water, and intensive with complete dependence on formulated feeds, water pumping, and circulation/aeration. In these ponds, the main target of production in high marketed demands is the giant tiger prawn (*Penaeus monodon*), whereas the smaller species are stocked at greater numbers. Takashima (2000) states that silvo-fishery was initially developed by the government of Myanmar about 50 years ago to make artificial forests with low operation costs; the farmers used the land by contract, obligating them to plant trees. Under the government's shrimp culture expansion, a three-year plan from 2000 to 2002, traditional shrimp farms were upgraded to improve extensive culture systems (FAO 2003). Consequently, the remarkable effects of the extensive shrimp aquaculture to the Ayeyarwady mega-delta mangroves have started since 2002. Before that time, Win (2000) also reported that neither intensive nor semi-intensive shrimp farming had developed, and Myanmar was then fortunate to have learned from the mistakes of shrimp-producing countries, such as Thailand and the Philippines. However, there were plans to develop 40,000 ha of ponds into semi-intensive shrimp cultures because the government considered shrimp a potentially large generator of foreign exchange (US $400–500 million).

Many challenges associated with shrimp farming have been documented (Macintosh & Phillips 1992; Landesmann 1994; Pullin 1993; Phillips 1995a,1995b), and the most common problems reported were mangrove deforestation, reduction of habitat, reductions in shoreline protection, increased coastal erosion, coastal water pollution, eutrophication, depletion of wild prawn and fish larvae stocks, land subsidence, salinisation of soils, agricultural land, and ground water, activation of acid sulfate soils, loss of agricultural lands, introduction of exotic species, and the discharge of undesirable chemicals (Stevenson 1995). More importantly, disused ponds are likely to be unstable, leading to a risk to neighboring habitats. Unless proper management is implemented, it would become progressively more difficult to rehabilitate and restore degraded mangroves. Some means of evaluation, therefore, should be developed to facilitate the identification of “best-use” scenarios for disused ponds.

This mangrove-friendly aquaculture is not a new one. It has had a long history and a system of traditional farming practices: Gei Wai are traditional ponds for extensive shrimp cultures established by the local people in Mai Po at the edge of Deep Bay in Hong Kong (Cha *et al.* 1997) with at least 100-year history in the Bay, and the beginnings of brackish-water pond culture in Asia might be traced to Madura or East Java in Indonesia (Schuster 1952). Implementing and initiating this so-called sustainable mangrove-friendly farming practices have a number of challenges that need to be addressed, and most of the attention is on social, environmental, and economic impacts. Until now, little attention has been paid on the recovery of mangrove vegetation on both disused ponds and currently-used extensive ponds. Also, not much attention has been paid about which mangrove species are appropriate for shrimp farming practices. The paucity of information about the suitability of species in the mangrove-friendly aquaculture has also been discussed (Takashima 2000).

In this framework mentioned above, understanding the recovery of vegetation communities on the landscapes affected by major human activities of rice fields and shrimp ponds in mangroves is the main purpose of this study, and this would provide the needs for rehabilitation and restoration of degraded mangroves. In addition, an assessment on the impact of shrimp farming practices on mangroves can help us understand the opportunities and threats of mangrove-friendly aquaculture initiatives as one of the restoration measures. The term of actual vegetation or actual living communities used in the present study is referred to different plant communities over a landscape, especially a fragmented, human-modified, landscape (Miyawaki & Box 2006), and a number of restoration terms has been described in Chapter I.

3.2 Materials and methods

3.2.1 Study site

The study region was located in the eastern part of Ayeyarwady Mega Delta (Figure 3.1), which is between latitudes 15°42´ and 16°12´ north and longitudes 95°05´ and 95°35´ east, surrounded by the Andaman Sea to the south. To explore the actual vegetation at the agriculture-affected sites, particularly rice fields, the fallow lands classifying young and old ones mainly over the Kadonkani Reserved Forest were explored. To investigate the actual vegetation at the aquaculture affected sites, the study focused on the seaward side of the reserved forest named Pyindaye Reserved Forest, where the encroachment of shrimp farming has extensively covered the region since 2002.

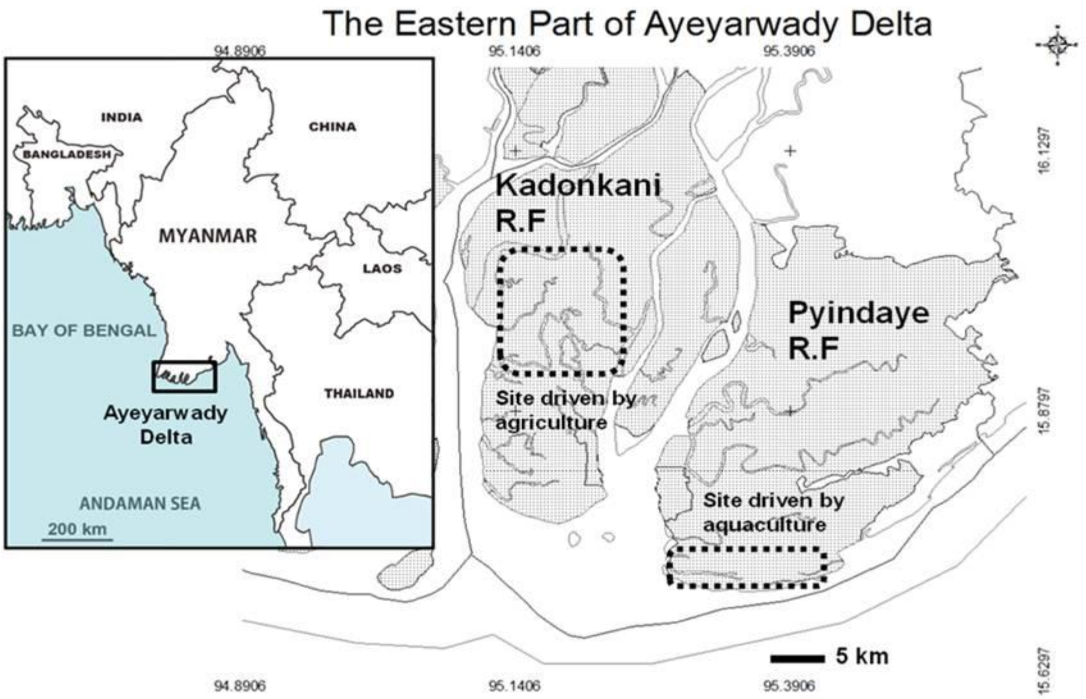


Figure 3. 1 Map showing the location of the study site driven by brackish water shrimp ponds (aquaculture) in Pyindaye Reserved Forest, and the site driven by rice fields (agriculture) in Kandonkani Reserved Forest

3.2.2 Sampling techniques

Vegetation censuses were conducted by using belt transects and a phytosociologial survey method (Braun-Blanquet 1964; Fujiwara 1987). Plots were randomly chosen on every distinct vegetation change on the belt transects from river sides to landward sides to explore the actual vegetation naturally grown on mangrove areas disturbed by the two major impacts of human activities to mangroves, rice fields and shrimp ponds. Each plot size ranged from 1 to 100 m^2 based on the vegetation types and was placed randomly over the forest to meet the objectives of the survey method applied. For the sites affected by agriculture, the plots collected were 188 on the young fallow lands and 288 on the mature fallow lands. A total of plots in the agriculture affected sites were 476. The young fallow lands are approximately 5–8 years old after abandoning rice fields, which were previously converted from clearing mangrove forests, and the mature fallow lands are more than 10 years old. For the aquaculture affected sites, 250 plots were collected for data analysis.

After surveying the mangrove sites affected by the agriculture and aquaculture practices, the occurrence of *Avicennia marina* at the active and abandoned shrimp pond sites was prominent during the field visit. Based on this observation, more in-depth investigation was followed at the aquaculture-driven sites to better understand the level of environmental risks of the currently growing concerns about practicing the brackish shrimp farming. To ensure site consistency as much as possible, five categories or sites mostly dominated by *A. marina* species were selected as follows: (A-I) active shrimp farming with mangroves, (A-II) active shrimp farming with cleared mangroves, (B-I) abandoned shrimp farming with mangroves, (B-II) abandoned shrimp farming with cleared mangroves and (C) community-managed mangrove forests without shrimp farming practices or control sites that can also represent natural sites. There was no absolute intact natural site in the study area. The tidal range of the surveyed plots dominated by *A. marina* was suggested to fall under a similar range because the sites dominated by *A. marina* are intentionally selected. They can be taken into account as tidal inundation class 2 by Watson (1928), flooded by medium high tide 45~59 times per month (Mochida *et al.* 1999; Aung *et al.* 2004). In each category, 10 sample plots, each measuring 25 m^2, were temporarily set up to assess differences in biomass, floral diversity, and chemical and physical properties of soil. Diameters and tree heights $\geqq$ 3 cm in diameter at breast height were measured, and counting was done for smaller individuals < 3 cm. In case of some herbaceous species that were not available to be counted, the cover and abundance values by Braun-Blanquet (1964) and Fujiwara (1987) were used. Furthermore, in order to understand the responses of species to shrimp farming, *A. marina* (diameter sizes ranging from 4 to 5 cm) pneumatophores per square meter around the base of the tree were counted, and 20 of them were measured by their lengths using randomly pinpoint methods to clarify pneumatophores' responses to shrimp farming practices. Soil samples were collected from the surface layer of 5 cm in depth at five places of each plot to assess some soil quality indicators.

3.2.3 Analytical tools

To explore a species group or an association of actual vegetation at the mangrove sites affected by extensive shrimp farming practices and rice fields, cluster analysis was conducted by using PC.ord version 4, ecological analytical software. Other statistical analyses were determined with R version 2.14.0.

First, to define groups and the dominant species in actual vegetation, hierarchical agglomerative method was considered with the cover and abundance data collected by following the phytosociological survey method. The clustering technique used in this study is a useful tool in seeking groups from multivariate ecological data, provided they can be represented by a distance matrix (McCune and Grace 2002), and has long been in use in ecology (Goodall 1973). Most common is the clustering of sample units based on species abundance or presence-absence. For this study, the cover and abundance values were used for analysis. In this hierarchical agglomerative analysis, Ward's method of clustering based on a Euclidean distance matrix was used. Following this, to prune the resulting dendrogram scaled by Wishart's objective function, the criteria considered both quantitatively and qualitatively are the following: (1) at least 25% remaining information, (2) avoiding to cut the dendrogram into a large number and a very small number of groups, (3) trying to seek "natural" break point, (4) chi-square test for picking the most ecologically meaningful point, in which the most dominant species were sought by the relative frequency combined with the relative abundance. For analyzing floral diversity, the following methods and equation were performed (Panwar & Bhardwaj 2005).

$$\textbf{Shanon Wiener Diversity Index H' (e}^{\textbf{H'}}\textbf{)} = -\sum Pi \log_n Pi$$

where,

Pi = Number of individual of one species/ Total number of all individual (one community only)

$$\textbf{Species richness} = \frac{(S-1)}{LogN}$$

where,

S= total number of species; N= total number of individual of all species

$$\textbf{Similarities} = \frac{2C}{A+B}$$

Where,

A= number of species in community A

B= number of species in community B

C= number of species common in both A & B

Then, the number and length of *A. marina* pneumatorphores in the active shrimp farming practices with other sites were determined with the nonparametric Kruskal–Wallis test to avoid the assumption of normal distribution. Following this nonparametric test, pairwise or multiple comparisons were done with Tukey's test. Electrical conductivity and pH were determined using a field tester on a 1:5 soil: water suspension by weight. Then, to understand the contents of moisture, total organic carbon, total nitrogen, phosphate, and sulfate properties, samples were analyzed with the support of land-use section in Myanmar Agricultural Services (MAS), and tested by Hygroscopic methods, Walkley-Black, Kjeldahl, Bray and Kurtz methods, and EDTA titration methods, respectively,

3.3 Results

3.3.1 Actual vegetation in the human-disturbed mangrove areas

Agriculture-driven regime

This study emphasized primarily on the two main regimes affected by agriculture (rice fields) and aquaculture (brackish water farming). Firstly, the agriculture affected sites were explored. At these sites, two categories were analysed as the young and mature fallow lands. In the young fallow lands, a total of 44 species including one unidentified species, were recorded in the 188 plots, in which eight species were true mangrove species. Out of these eight species, six are tree life forms and others are understory species, including shrubs, herbs, climbers, ferns, and palms (Table 3.1). For all 44 species, the presence of understory or herbaceous species outweighed that of canopy trees. Relative frequency, combined with relative abundance, was considered for the observed species, and the ten species with the highest values in rank were *Leptochola filiformis* (0.36), *D. trifoliata* (0.25), *A. illicifolius* (0.18), *Cyperus malacensis* (0.17), *Acrostichum aureum* (0.16), *Eupatorium odoratum* (0.11), *D. spinosa* (0.10), *Phoenix paludosa* (0.07), *Pluchea indica* (0.07), and *Sonneratia caseolaris* (0.05). Among them, the only true mangrove species observed as a tree life form is *S. caseolaris*. Hierarchical clustering methods and chi-squared statistical tests in the agriculture-driven areas were performed for classifying the vegetation in the young fallow lands, in which five groups were classified, as shown in Figure (3.2a). Group I, the *P. paludosa–L. filiformis* association, included 38 sample plots. Group II, the *C. malacensis–Delbergia spinosa* association, included 45 sample plots. Group III, the *A. illicifolius–L. filiformis* association, included 28 plots. Group IV, the *L. filiformis–S. caseolaris* association, included 44 plots. Group V, the *A. aureum–L. filiformis* association, included 33 plots.

Second, in the mature fallow land, 52 species including one unidentified species, were recorded in 288 plots, in which 14 species were true mangroves. Out of these 14 species, 8 are tree life forms and others are understory species including shrubs, herbs, climbers, ferns, and palms (Table 3.1). Similar to the young fallow lands above, the presence of understory species outweighed that of canopy trees. Relative frequency, combined with relative abundance, was considered for the observed species, and the ten species with the highest values in rank were *L. filiformis* (0.28), *A. illicifolius* (0.28), *D. trifoliata* (0.27), *C. malacensis* (0.19), *A. aureum* (0.16), *S. caseolaris* (0.10), *F. maritima* (0.08), *P. paludosa* (0.07), *E. odoratum* (0.07), and *Agiceras corniculatum* (0.04). Similar to the above young fallow land, the only one canopy mangrove species observed as a tree life form is *S. caseolaris*. Through similar clustering methods mentioned above, five groups were classified, as shown in Figure (3.2b). Group I, the *S. caseolaris–A. illicifolius* association having maximum height of 8 m and maximum diameter at breast height of 46 cm included 43 sample plots. Group II, the *C. malacensis–L. filiformis* association, included 27 sample plots. Group III, the *L. filiformis–D. trifoliata* association, included 128 plots. Group IV, the *A. aureum–D. trifoliata* association, included 40 plots. Group V, *A. illicifolius–D. trifoliata* association, included 50 plots.

In the young fallow lands, all communities classified in this study were composed of Graminaceae. In the mature fallow lands, two out of four communities included Graminaceae. These findings have illustrated that the Graminaceae represents the onset of vegetation recovery processes at these sites, and gradually become to be replaced by the invasion of herbaceous species, primarily *Acanthus* spp, *D. trifoliata* and *A. aureum*. The relative frequency combined with relative abundance of canopy mangrove species *S. caseolaris* was also more dominant in the mature fallow lands than in the young fallow lands. The number of mangrove species was also more abundant on the mature fallow lands than in the young fallow lands.

Aquaculture-driven regime

A total of 36 species were recorded by 250 plots in the aquaculture-driven sites, in which 16 species were true mangrove species. Similar to the agriculture affected sites, the presence of understory species outweighed that of canopy trees. Relative frequency, combined with relative abundance, was considered for the observed species, and the 10 species with the highest values in rank were *Derris trifoliata* (0.34), *Acanthus illicifolius* (0.22), *Dalbergia spinosa* (0.20), *Ceriops decandra* (0.18), *Avicennia marina* (0.14), *Heritiera fomes* (0.13), *Agelalitis rotundifolia* (0.12), *Finlaysonia maritima* (0.10), *Avicennia officinalis* (0.09), and *Excoecaria agallocha* (0.08). Among them, five true mangrove species as tree life forms are *C. decandra*, *A. marina*, *H. fomes*, *A. officinalis*, and *E. agallocha*. The same clustering method mentioned above classified the 250 plots into four groups. The resulting groups were presented in Figure (3.2c). Group I, the *C. decandra–A. rotundifolia* association with maximum height of 4.2 m and maximum diameter at breast height of 31 cm included 67 sample plots, and they occurred mainly in the higher parts of the ground level at the active farming sites. Group II, the *D. spinosa–A. marina* association with maximum height of 6 m and maximum d.b.h. of 40 cm included 55 sample plots, and they were located mostly at the lower ground level and water-logged active farming sites. Group III, the *S. portulacastrum–L. filiformis* association, included 37 plots, and they commonly occurred after abandoning the farming sites where mangroves were clearly cut. Group IV, the *D. trifoliata- H. fomes* with maximum height of 7 m and maximum d.b.h. of 42 cm association, included 91 plots, and this type was observed mostly in the unused or suspended farming sites on the less frequent tidal inundated sites or the higher part of the ground level.

It should also be noteworthy that the last one, *D. trifoliata–H. fomes*, can be rarely found in the active shrimp ponds with frequent tidal flushes. According to the field observation, *D. trifoliata* are very sensitive to prolonged flooding sites. One more thing to note is that in both agriculture and aquaculture affected sites, the occurrence of *Rhizophora* and *Bruguiera* species belonging to the *Rhizophoraceae* were rarely occurred. This finding is, to much extent, linked to that in Chapter II, in which these species have shown very sensitive to the catastrophic cyclone disturbance.

3.3.2 Assessment on the aquaculture-driven mangroves

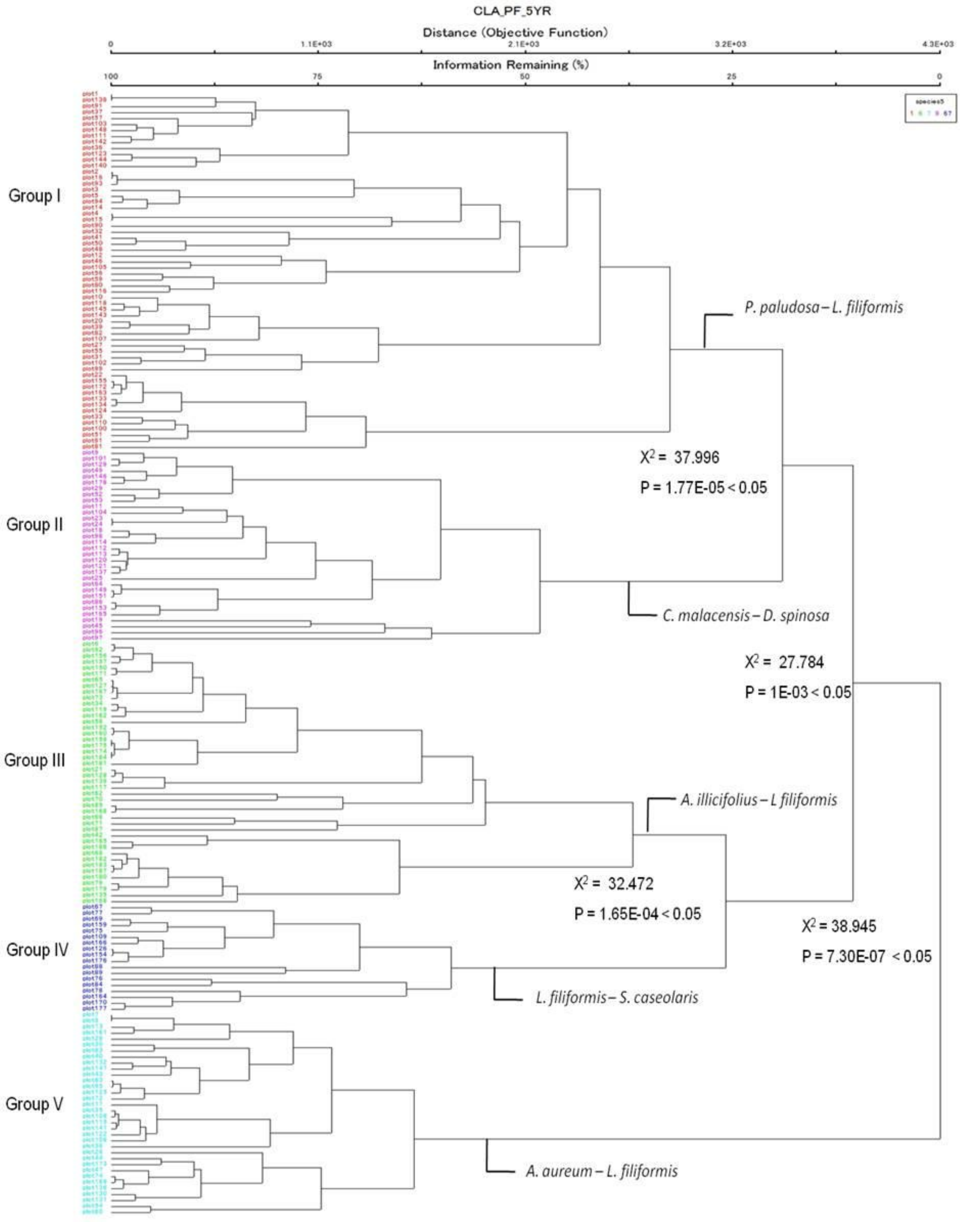
Biomass and floral diversity

Following the censuses on the actual living vegetation of the human-disturbed sites, the study proceeded to assess the aquaculture-driven sites in order to be able to address the current growing issues of brackish water aquaculture extension to the mangrove forests. The biomass productivity is shown in Figure (3.3a). The active shrimp ponds with mangroves had 69.59 m^3/ha, representing the highest values, followed by community-owned mangroves having 54.69 m^3/ha. After these, the abandoned shrimp farming with mangroves had 18.02 m^3/ha of biomass productivity. Other two areas did not show any appreciable amount of biomass because of being clear-cut practices. In terms of diversity index, the two clear-cut mangrove areas (A-II) and (B-II) had 3.98 and 3.88 showing greater in number, other two sites with mangroves (A-I) and (B-I) had 2.91 and 3.04. (C) sites representing natural ones had the lowest number 2.65 (Figure 3.3b). Accordingly, there was the most species richness 1.55 and 2.47 for the two categories with cleared mangroves (A-II) and (B-II), 1.11 and 1.43 for the two categories with mangroves A-I and B-I, and the least species richness 0.92 for category C or natural sites (Figure 3.3c). This has shown evidence that natural mangroves can be homogeneity rather than heterogeneity. In order to highlight the invasion of herbaceous species, the proportions of true canopy mangrove species by herbaceous species are illustrated in Figure (3.3d). The corresponding values at A-I, A-II, B-I, B-II and C were 4, 0.67, 0.83, 0.67, and 1.67. These facts also confirm that the more impacts the sites receive the higher the more the invasion of herbaceous species occurs. In other words, natural mangroves do not necessarily mean including the heterogeneity of species. In that so, the similarity of species composition at the four disturbed sites with the natural control sites were meaningful to look at. Their corresponding similarity indices with control sites or no shrimp farming sites category-C were 0.62 for A-I, 0.67 for A-II, 0.74 for B-I and 0.43 for B-II, respectively (Figure 3.4). The species composition of the abandoned shrimp farming with mangroves is most similar to natural sites without shrimp farming.

Pneumatophores' responses to aquaculture practices

True mangrove species possess the following plant traits: (i) occurring only in mangrove environments and not extending into terrestrial communities, (ii) morphological specialisation (aerial roots and vivipary), (iii) physiological mechanism for salt exclusion and/or salt excretion, (iv) taxonomic isolation from terrestrial relatives (Tomlinson 1986; Wang *et al.* 2010). In this study, regarding special root traits of mangroves, different growth patterns of *A. marina* pneumatophores were recognised in different sites during field visits. In all three ponds with the presence of mangroves, the *A. marina* pneumatophores were compared to understand their survival strategy under the impacts of shrimp farming practices. The results (Figure 3.5) show that the average numbers of penumatophores per square meter in the active shrimp farming with mangroves, the abandoned shrimp farming with mangroves , and the community-managed mangroves were 391±69, 345±105, and 240±88 (Kruskal–Wallis chi-squared = 7.2111, df = 2, p-value = 0.02717). Correspondingly, the average heights of pneumatophores in these three categories were 30.5±5.09, 23.72±5.54, and 16.58±3.93 (Kruskal–Wallis chi-squared = 352.7807, df = 2, p-value = 2.2e-16), respectively. For both the length and the number of pneumatophores, the active shrimp farming with mangroves demonstrated the highest values, followed by the abandoned shrimp farming with of mangroves and then by the community-owned mangroves, natural sites without shrimp farming. The significant difference between the farming sites and the non-farming sites was observed.

(a)



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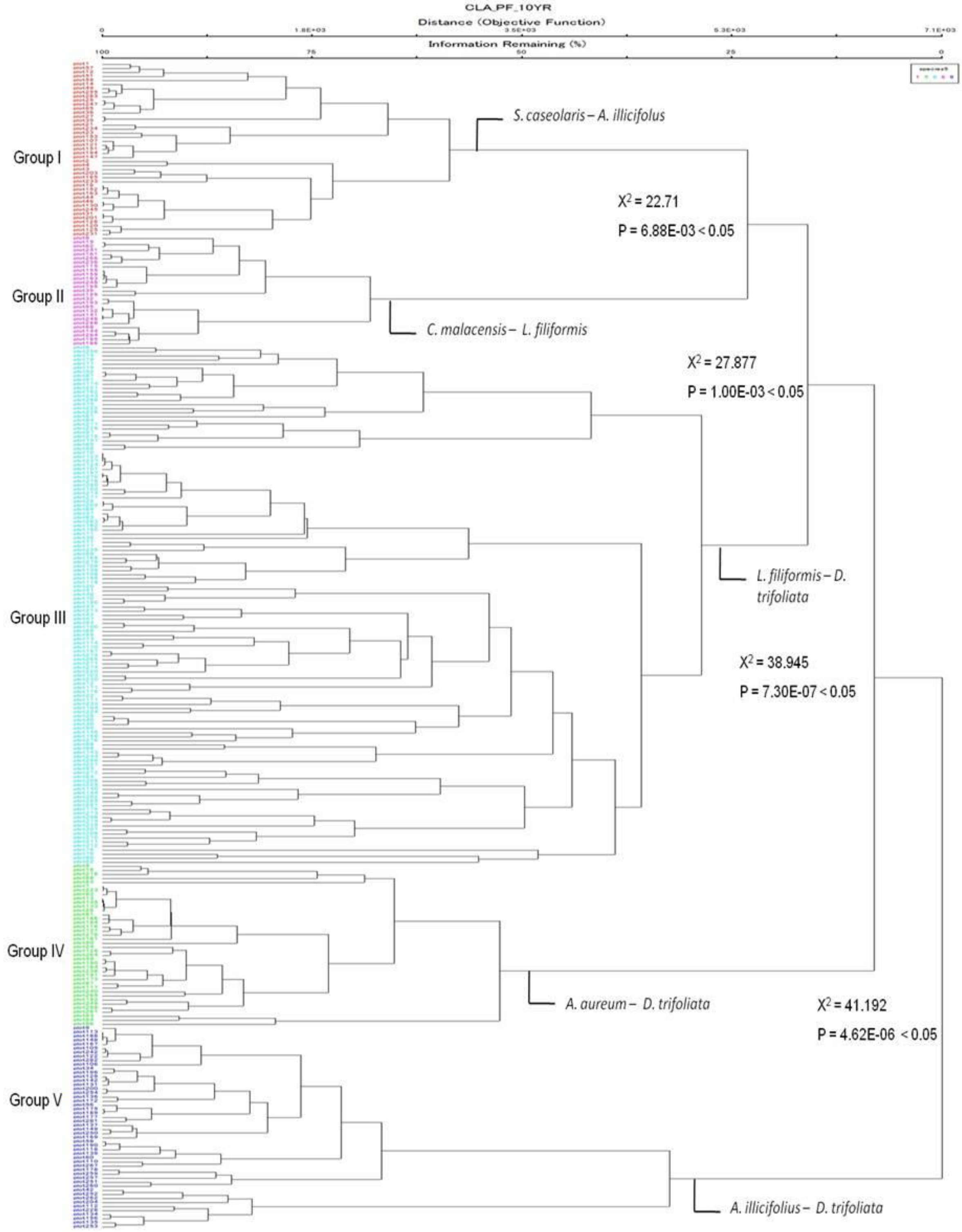


CLA_PF_10YR
Distance (Objective Function)
Information Remaining (%)
Group I
Group II
Group III
Group IV
Group V
S. caseolaris – A. illicifolus
X2 = 22.71
P = 6.88E-03 < 0.05
C. malacensis – L. filiformis
X2 = 27.877
P = 1.00E-03 < 0.05
L. filiformis – D. trifoliata
X2 = 38.945
P = 7.30E-07 < 0.05
A. aureum – D. trifoliata
X2 = 41.192
P = 4.62E-06 < 0.05
A. illicifolius – D. trifoliata

(c)

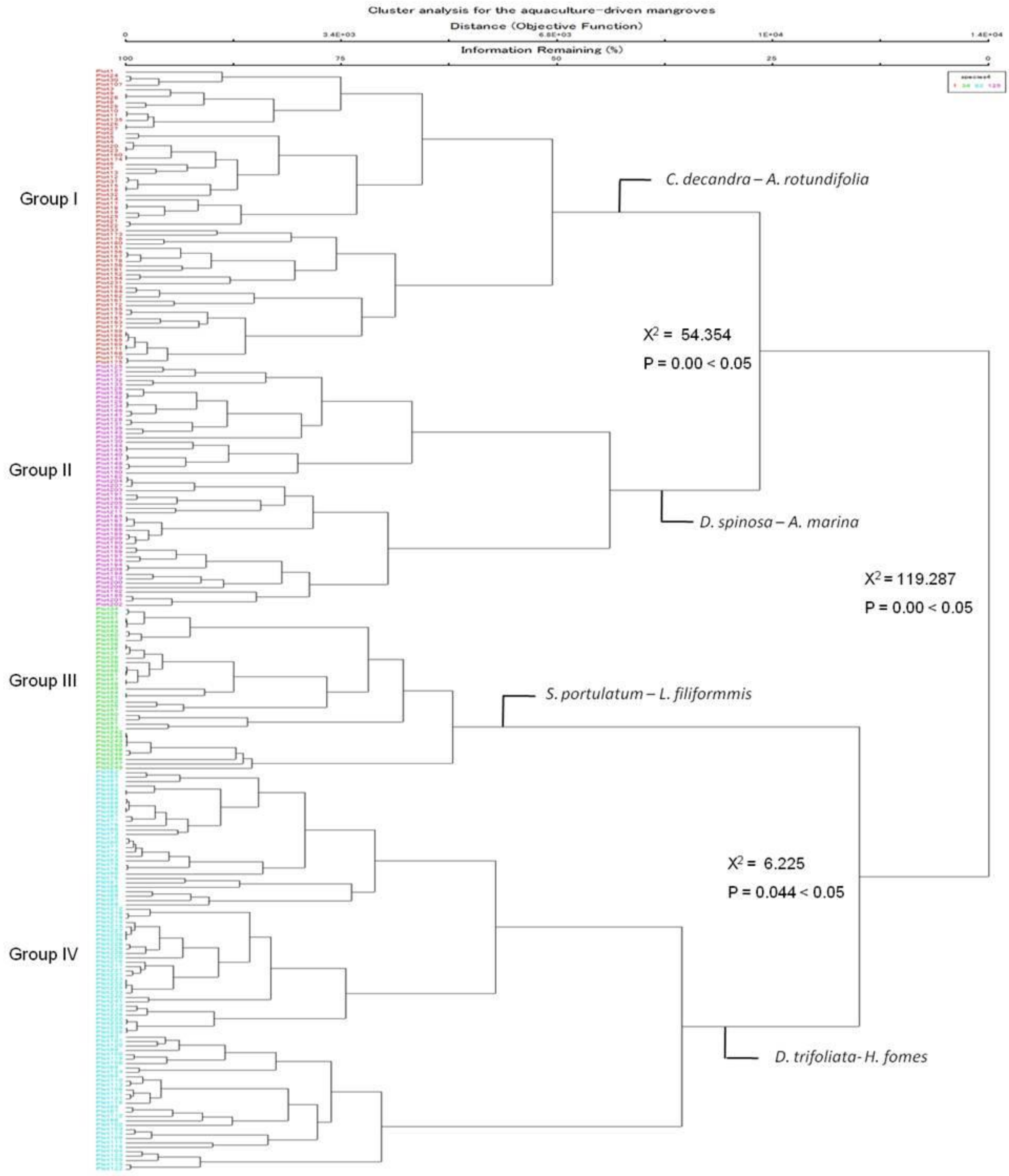


Figure 3. 2 Dendrogram showing the different groups identified by hierarchical agglomerative cluster analysis based on the cover and abundance values of phytosociological survey methods: (a) on the agriculture-driven regime, young fallow lands, and (b) on the agriculture-driven regime, mature fallow lands, (c) on the aquaculture-driven regime

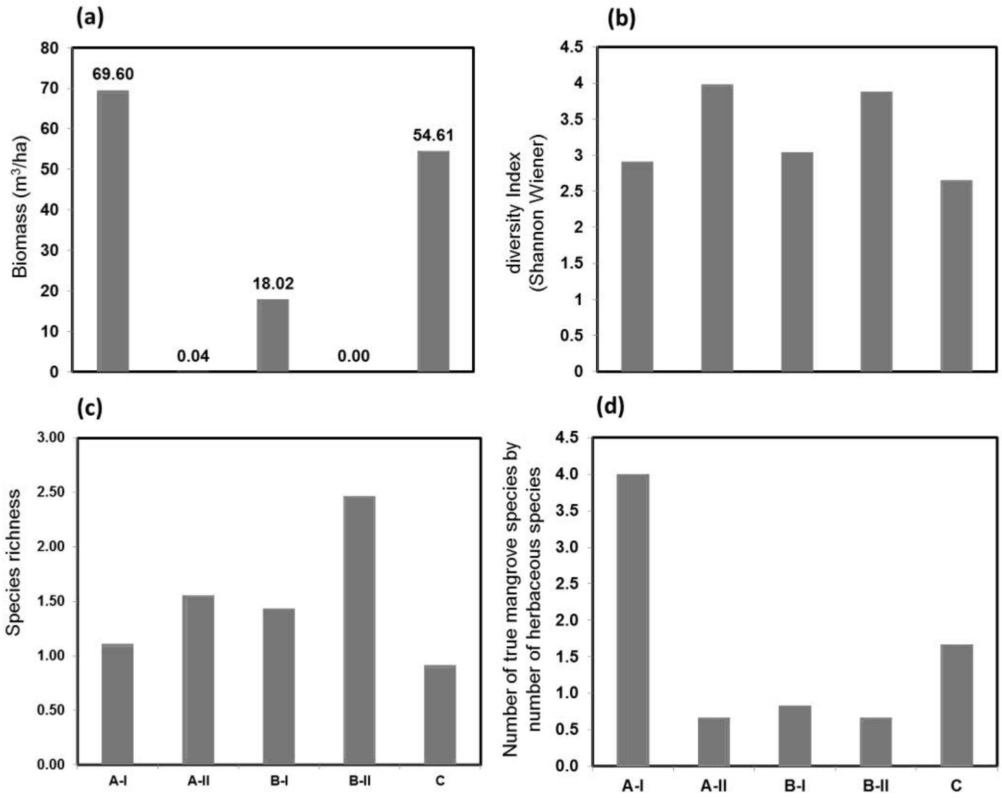


Figure 3. 3 (a) Biomass productivity for individuals > 3 cm in d.b.h, (b) Shanon Wiener diversity Index ($e^{H'}$), (c) Species richness and (d) the proportion of true tree mangrove species by herbaceous species or invaders. Five categories classified are (A-I) active shrimp farming with mangroves, (A-II) active shrimp farming with cleared mangroves, (B-I) abandoned shrimp farming with mangroves, (B-II) abandoned shrimp farming with cleared mangroves and (C) community-managed mangrove forests without shrimp farming practices as control sites

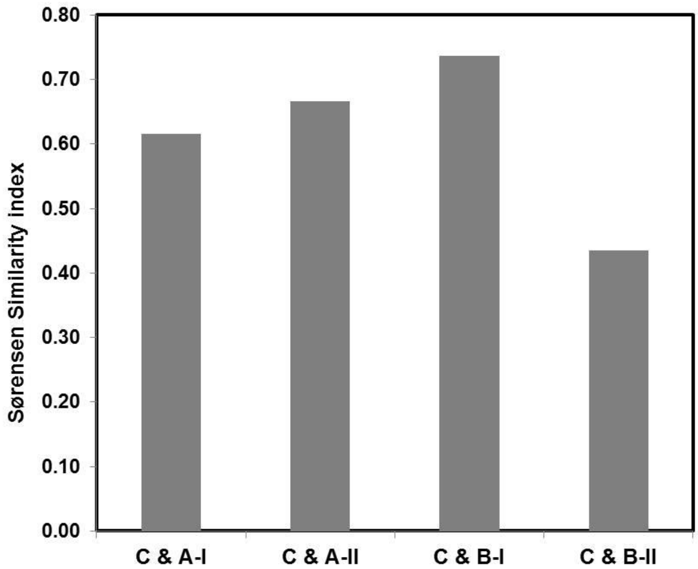


Figure 3. 4. Similarities of four shrimp farming sites with control ones in natural sites by Sørensen index (See figure 3.3 for five categories)

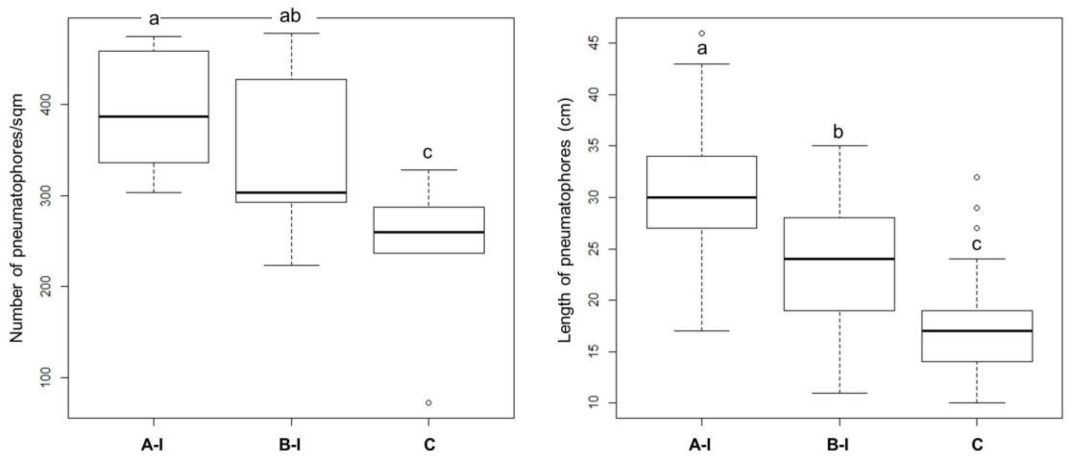


Figure 3. 5 Number and length of *Avicennia* pneumatophores in three different study sites (See figure 3.3 three categories)

Indicators of soil risk

Table 3.2 shows the chemical and physical properties of soil in five management categories in the present study. Generally, the highest appreciable levels of chemical and physical properties can be observed at category C, community-managed mangroves, followed by the active shrimp farming sites with mangroves. For instance, soil moistures on A-I sites were the nearest values to C sites. Compared to C-sites, however, A-I sites had still shown slightly lower in the contents of C, N, P. The EC is higher in wet condition on A-I sties. In wet conditions, the pH level in A-I sties was only slightly acidic compared to all other categories; but in dry conditions, the pH of this site became extremely acidic. The result provides evidence that there is the activation of potential acid sulfate soil (PASS) in this (A-I) site. Although other three disturbed sites are lower in the contents of C, N, P, and silt compared to A-I sites, there was no evidence of acidic occurrence in both wet and dry condition. Despite the fact that most of the physical and chemical properties seem to be appreciable level at A-I sites, there have shown evidence of the actual ASS that can cause ecological and environmental impacts.

Table 3. 1 Species recorded at the sites by the anthropogenic impacts in the Ayeyarwady Mega Delta.

No	Scientific name	Family	True mangrove	Life form	AGRI-Young	AGRI-Mature	AQUA	Local name	Remark
1	*Acanthus ebracteatus* Vahl	Acanthaceae	M	h		+		Kayar-phyu	
2	*Acanthus ilicifolius* L.	Acanthaceae	M	h	+	+	+	Kayar-kayan	
3	*Acanthus volubilis* Wall.	Acanthaceae	M	h		+	+	Kayar-nwe	
4	*Acrostichum aureum* Linne	Pteridaceae	M	f	+	+	+	Hnget-gyi-daung-aywet_gyi	
5	*Acrostichum speciosum* Willd.	Pteridaceae	M	f		+		Hnat-gyi-daung-aywet_thay	
6	*Aegialitis rotundifolia* Roxb.	Plumbaginaceae	M	s			+	Sar-thar	
7	*Aegiceras corniculatum* (L.) Blanco	Myrsinaceae	M	t		+		Ye-ka-yar	
8	*Aglaia cucullata* (Roxb.) Pellegrin	Meliaceae		t		+	+	Pan-tha-ka	
9	*Allophylus cobbe* (L.) Raeusch.	Sapindaceae		t		+		Moe-hman	
10	*Avicennia alba* Blume	Avicenniaceae	M	t			+	Tha-me-kyat-tet	
11	*Avicennia marina* (Forssk.) Vierh.	Avicenniaceae	M	t			+	Tha-me-phyu	
12	*Avicennia officinalis* L.	Avicenniaceae	M	t	+	+	+	Tha-me-kyi	
13	*Barringtonia racemosa* (L.) Spreng.	Lecythidaceae		t		+		Ye-kyee	
14	*Brownlowia tersa* (L.) Kosterm	Tiliaceae	M	s	+	+	+	Ye-tha-man	
15	*Bruguiera parviflora* (Roxb.) W. & A. ex Griff	Rhizophoraceae	M	t			+	Byuu-wa-kyeik-lein	
16	*Bruguiera sexangula* (Lour.) Poir.	Rhizophoraceae	M	t		+	+	Byuu-shwe-wa	
17	*Canavalia maritima* Thouars	Leguminosae		h	+	+		Taw-pe-nyunt	**?**
18	*Cayratia trifolia* (L.) Domin.	Vitaceae		c	+	+		Yin-hnaung-nwe	
19	*Cerbera odollam* Gaertn.	Apocynaceae		t	+			Za-latt	
20	*Ceriops decandra* (Griff.) Ding Hou	Rhizophoraceae	M	t		+	+	Ma-da-ma	
21	*Clerodendrum inerme* (L.) Gaertn	Verbenaceae		s	+	+		Taw-kyaung-pan	
22	*Crinum asiaticum* L.	Amaryllidaceae		h			+	Koyan-gyi	
23	*Cryptocoryne ciliata* (Roxb.) Fisch. Ex Schott	Araceae		h		+		Nga-dan-pein	

24	*Cymnometra ramiflora* L.	Leguminoceae		t		+		Myin-ga	
25	*Cyperus compactus* Retz.	Cyperaceae		g	+			Myat-ka-lone	**?**
26	*Cyperus haspan* L.	Cyperaceae		g	+	+		Wet-lar-myet	**?**
27	*Cyperus malaccensis* Lamk.	Cyperaceae		g	+	+		Thone-daung-myet	**?**
28	*Dalbergia spinosa* Roxb.	Leguminosaceae		c	+	+	+	Byeik-su	
29	*Dalbergia volubilis* Roxburgh	Leguminosaceae		s	+	+		Ye-gyin-nga	
30	*Derris pinnata* (Lour.) Prain	Leguminosaceae		c	+	+		Ye-ma-gyi-nwe	
31	*Derris scandens* (Aubl.) Pittier	Leguminosceae		c		+		Nwe-phyu	
32	*Derris trifoliate* Lour.	Leguminosceae		c	+	+	+	Nwe-net	
33	*Dioscorea globosa* Roxb.	Dioscoreaceae		c	+	+		Myauk-nwe	**?**
34	*Dolichandrone spathacea* (l.f.) K.Schum.	Bignoniaceae		t	+	+		Tha-khut	
35	*Eupatorium cannabinum* L.	Asteraceae		h	+			Kway-thay-pan	
36	*Eupatorium odoratum* L.	Asteraceae		h	+	+	+	Beezat	**?**
37	*Excoecaria agallocha* L.	Euphorbiaceae	M	t	+	+	+	Tha-yaw	
38	*Finlaysonia obovata* Wall.	Asclepiadaceae		c	+	+	+	Byauk-nwe	
39	*Flagellaria indica* L.	Flagellariaceae		c	+	+		Myauk-kyein	
40	*Heritiera fomes* Buch. Ham.	Sterculiaceae	M	t	+	+	+	Kanaso-ywet-gyi	
41	*Heritiera littoralis* Dryand.	Sterculiaceae	M	t			+	Kanaso-ywet-thay	
42	*Hibiscus tiliaceus* L.	Malvaceae		s			+	Thin-ban	
43	*Hygrophila obovata* Wight	Acanthaceae		h	+	+	+	Pinle-hnan	
44	*Hygrophila spinosa* T. Anders	Acanthaceae		h	+			Lepadu	
45	*Imperata cylindrica* (L.) P. Beauv.	Poaceae		g		+	+	Thekke	
46	*Intsia bijuga* (Colebr.) Kuntze	Leguminosae		t	+	+		Saka-lun	
47	*Ipomoea maxima* (L.f) Don *ex* Sweet	Convolvulaceae		c			+	Taw-kazon	
48	*Ipomoea pes-caprae* (L.) Sweet	Convolvulaceae		c			+	Pinle-kazon	
49	*Ipomoea tuba* Schlechtend	Convolvulaceae		c	+			Bon-sein-nwe	
50	*Kandelia candel* (L.) Druce	Rhizophoraceae	M	t	+			Byu-baik-daunt	

51	*Leptochloa filiformis* (Lam.) P. Beauv	Poaceae		g	+	+	+	Myet-khar	
52	*Melastoma malabathricum* L.	Melastomataceae		s		+		Oae poke	**?**
53	*Merope angulata* (Willd.) Swingle	Rutaceae		s	+	+	+	Taw-shauk	
54	*Nypa fruticans* Wurmb.	Palmae		p	+	+	+	Dani	
55	*Oryza meyeriana* Nees & Arn. ex Watt	Poaceae		g	+	+		Daung-sapa	
56	Oxystelma carnosum R. Br.	Asclepiadaceae		c	+	+	+	Shoke-htwe-nwe	
57	*Pandanus tectorius* Sol.	Pandanceae		p		+		Tha-baw	
58	*Phoenix paludosa* Roxb.	Arecaceae		p	+	+	+	Thing-baung	
59	*Phragmites karka* (Retz.) Trin. ex Steud.	Poaceae		g	+	+		Kyu	
60	*Pluchea indica* (L.) Less.	Asteraceae		s	+	+	+	Kayu	
61	*Rhynchosia minima* (L.) DC.	Fabaceae		c	+	+		Taw-pe-thi-nwe	**?**
62	*Rorippa indica* (L.) Hiern	Brassicaceae		h	+			Taw-mon-la	**?**
63	*Salix tetrasperma* Roxb.	Salicaceae		t		+		Moe-ma-kha	
64	*Sarcolobus carinatus* Wall.	Asclepiadaceae		c	+	+	+	Swut-kamon-nwe	
65	*Sarcolobus globosus* Wall.	Asclepiadaceae		c	+	+	+	Kyee-ka-lain	**?**
66	*Sesuvium portulacastrum* (L.) L.	Aizoaceae		h	+		+	Daye-shar	
67	*Sonneratia caseolaris* (L.) Engl.	Sonneratiaceae	M	t	+	+		Lamu	
68	*Sonneratia griffithii* Kurz.	Sonneratiaceae	M	t	+	+		Laba	
69	*Xylocarpus granatum* Koen.	Meliaceae	M	t			+	Pinle-ohn	
70	*Xylocarpus moluccensis (Lamk)* M.Roem.	Meliaceae	M	t			+	Kya-na	
71	Unknown-1	Unidentified		h		+		Ga-doo	
72	Unknown-2	Unidentified		h	+			Myae-pe-htwe	
	Total number of species		**72**		**44**	**52**	**36**		
	True Mangrove species		**22**		**8**	**14**	***16***		

Note: trees (t), shrubs (s), ground herbs (h), palms and palm-like species (p), ferns (f), grasses & grass-like herbs (g); AGRI-Y for young fallow lands after abandoning rice fields, AGRI-M for mature fallow lands after abandoning rice fields, AQUA for the sites driven by brackish water aquaculture practices; (?) in remarks means those species are needed to be identified more by experts or taxonomists

(1) A plant ecological study on restored and natural communities of mangroves in Myanmar, Ph.D dissertation, Yokohama National University (Than 2006)

(2) Mangrove guidebook for Southeast Asia, FAO (Giesen *et al.* 2006)

(3) A checklist of the trees, shrubs, herbs and climbers of Myanmar (Kress *et al.* 2003)

(4) World atlas of mangroves (Spalding *et al.* 2010)

Table 3. 2 Analytical results of physical and chemical properties of four categories with aquaculture-driven mangroves and one category with natural mangroves.

Wet condition	A-I	A-II	B-I	B-II	C
pH	**6.991±0.19 ***	7.45±0.11	7.18±0.05	7.337±0.07	7.393±0.29
EC (ms/cm)	0.587±0.05	0.284±0.05	0.361±0.02	0.244±0.01	0.467±0.04
Moisture %	9.26±0.77	7.17±0.54	7.72±1.37	7.35±0.26	11.32±1.29
Organic carbon %	2.312±0.75	1.178±0.14	1.682±0.46	1.518±0.31	2.888±0.49
Total N %	0.246±0.05	0.226±0.05	0.222±0.01	0.233±0.02	0.316±0.04
Dry condition					
pH	**3.9 ***	6.64	6.52	6.06	6.31
EC (ms/cm)	1.524	1.674	1.736	1.623	2.59
Moisture %	4.367	2.269	3.258	2.977	6.881
SO4 (me/100g)	**1.25±0.83 ***	0.75±0.22	0.86±0.56	0.5±0.11	**2.5±0.01 ***
P2O4 (ppm)	8.0±0.2	9.2±0.81	10.4±0.4	8.0±0.2	14.0±0.4
Sand %	1.35	1	1.5	2	1.1
Silt %	50.5	35.7	35.6	23.5	54.2
Clay %	46.1	62.1	61.2	72.1	42.5

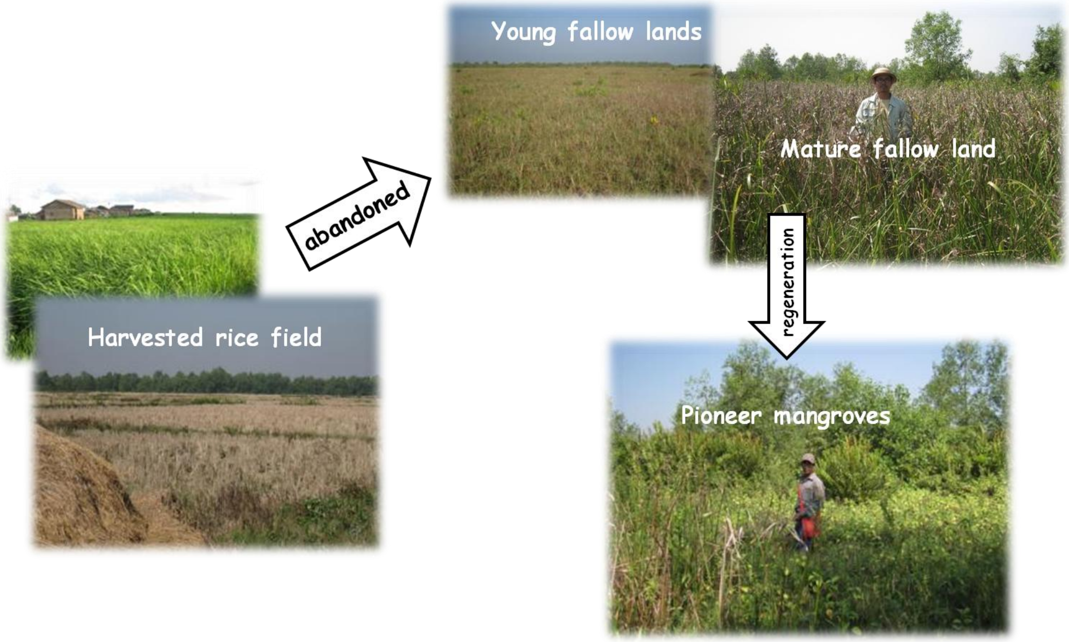
Note: Significant data are marked with asterisks (*). Data without standard deviation were tested once by mixing samples to reduce time and cost.

3.4 Discussion

3.4.1 Patterns of actual living communities in the human-disturbed landscapes

The actual living communities naturally recovered at the mangrove sites driven by rice fields (agriculture) and extensive shrimp farming (aquaculture) were explored in this study. The agriculture-driven sites are relatively far from the sea and located in the inland part of the Ayeyarwady Mega Delta. The salinity measurement during field visits in dry seasons was rarely more than 1%. Among five community groups in the agriculture-driven sites, the only true mangrove species, *Sonneratia caseolaris* community was found both on young and fallow lands. On the contrary, three out of four communities classified under the aquaculture-driven sites include true tree species. This species is low in salinity tolerance.

Even on the mature fallow lands, representing at least 10 years after being abandoned, most of the actual living communities that were classified in this study are still covered with herbaceous species and only one true mangrove species included. This finding affirms that the recovery processes take a long time to return to mangrove forests. In terms of vegetation observed in the extensive aquacultures, most of the mangroves are moderate to high salinity-tolerant species, such as *C. decandra* and *A. marina*. The explainable reason is that these aquaculture-driven sites are close to the sea, showing the salinity ranging from 2 % - 2.7 % in dry season. If attempt is made to look at the agriculture affected sites in the young fallow lands, all classified communities are dominated by *Graminaceae,* specifically short grass. Gradually, in the mature fallow lands, the only two communities out of four include the *Graminaceae*. Instead, herbaceous communities are dominant. The relative frequency and abundance of *S. caseolaris,* that are observed the only one true mangrove species both on the young and fallow lands, are higher on the mature fallow lands than on the young fallow lands, and more true mangrove species are recorded on the mature fallow lands. This provides strong evidence of vegetation succession returning to mangrove forests. Generally, four phases of vegetation succession can be recognized; 1) the initial process of vegetation succession has been shown with the *Graminaceae*, mostly short grasses; 2) long grasses and other shrubs, herbs, climbers, ferns and palms follow; 3) together with these invaders, pioneer species of *Sonneratia caserolaris* start to establish in these fallow lands, and this mangrove species try to compete with the *Graminaceae* and other herbaceous communities, and; 4) Eventually, after these sites become stable by pioneer character species, the recovery processes can return to its pre-existing mangroves with some climax character species as close as possible. This pattern mostly happen at the agriculture affected sites because of the practices of cutting mangroves clearly. It should be also noteworthy here that continuous disturbances perhaps hinder the re-establishment of *Rhizophora* and *Bruguiera* species belonging to the *Rhizophoraceae* family that rarely occurs in these human-disturbed sites, both by the agriculture and aquaculture. This finding is similar in the natural disturbed sites discovered in Chapter II.



Photos: Recovered vegetation on the fallow lands after abandoning rice fields

As mentioned above, this recovery processes at the agriculture affected sites could take a couple of decade because the dispersal of mangrove species to these fallow lands might have been restricted by clear-cut and over-fragmented mangrove landscapes. Similar to the species association in the agriculture-driven regimes, there is one group dominated by the Graminaceae—*L. filiformis* in the aquaculture-driven mangroves which represents the patterns of abandoned shrimp ponds by clear-cutting mangroves. Unlike the agriculture-disturbed mangroves, instead of *S. caseolaris*, higher salt-tolerant species like *A. marina* mostly start to occur like pioneer species in the abandoned ponds with cleared mangroves. In the aquaculture-driven, mangrove vegetation is still maintained in most parts of the active and abandoned sites. Therefore, rather than at shrimp farming sites, restoration on most of the fallow lands after abandoning rice fields are indispensable by artificial means.

In the case of the abandoned rice fields and the abandoned shrimp farming sites with clear-cut mangroves, the onset of recovery with the *Graminaceae* and herbaceous species starts as mentioned above, can improve chemical and physical properties of disturbed sites in the processes of returning to true mangrove vegetation, e.g., maintaining soil moisture. Similar findings have been done by McKee *et al.* (2007) how facilitation by herbaceous vegetation improved forest restoration after disturbance, and they revealed a number of mechanisms on mangroves afforded by herbaceous species: (1) trapping of dispersing propagules, (2) structural support of the seedling, and (3) promotion of the survival and growth through amelioration of soil conditions (temperature and aeration). On the contrary, Biwas *et al.* (2007) described that some of the herbaceous species were considered highly invasive species threatening local species after natural disturbances. Some herbaceous vegetation, therefore, should be thoroughly considered whether they are invasive species representing negative effects or providing multiple positive effects for the process of mangrove resilience. As mentioned above, the following section proceeds to discuss about the silvo-aquaculture practices that have currently became a growing global concern.

3.4.2 Opportunities and threats of the extensive aquaculture practices

Species suitability

The results show that there are 16 true mangrove species observed as tree life forms in the brackish aquaculture-driven mangrove areas. Five of these frequently occur, showing evidence that some mangrove species are still capable of surviving and persisting in the areas affected by extensive shrimp farming practices. These frequently and naturally grown species can be fittest ones in these sites once restoration and rehabilitation are considered. In case of species choice in establishing extensive shrimp framings, it relies on the site of the ponds, the shrimp and fish species cultures, and the species persistent to the shrimp farming practices and the ones with high potential for local use, such as food, fuel wood, and fodder. In some parts of the world, *Rhizophora* spp seemed to be mostly introduced, for instance, in the pilot project at Segara Anakan in Cilacap, West Java, facing the Indian Ocean (Takashima 2000). However, potential toxicity of tannin from this mangrove species was reported as a problem (Primavera 2000), meaning little possibility to use the *Rhizophoraceae* groups having contents of tannin. The communities and species in the aquaculture-driven sites observed in this study also rarely include the *Rhizophora* species.

Based on a personal communication with traditional small-scale farm owners in the study area, *E. agallocha* is also less preferred in the ponds because of the inclusion of white sap in the bark and leaves of this species that are said to expel cultured shrimps and fish. Then, in terms of *Avicennia* species, a clear example of pneumatophores adaptable to the acceptable level of flooding or inundation in the ponds was observed. This finding may also be applicable to other similar species having pencil-like pneumatophores, such as the genus of *Avicennia* and *Sonneratia*. Rönnbäck (2002) also reports that fish community prefers the pneumatophore (*Avicennia*) microhabitats to the prop root (*Rhizophora*)**.** Hence, based on the present study and reviews from other literatures, *A. marina* and perhaps other species in the same genus with similar root architectures illustrate high potential to grow in the mangrove-friendly aquaculture.

One more option to note in the study area is *Nipa fruitcans* observed in the abandoned ponds with the clearance of mangroves that was used instead of mangrove trees because of its higher economic potential in the area as well as its ecological role. Aypa & Baconguis (2000) demonstrated a model of agri-nipa-aquaculture farms in Puerto Galera, Mindoro and its roles in utilisation are in terms of erosion control, coastal protection and stablilisation, and provision of sanctuaries for some marine species. Its leaves are used in making nipa shingles, native bags, coarse baskets, hats, mats, brooms, and raincoats. Nipa sap can also be extracted and processed into alcohol, wine, sugar, and vinegar. Thet (2009) also studied how local people in the present study area were dependent primarily on nipa plantations as one of the non-wood forest product services. If that is so, the nipa model may also be beneficial to nipa habitats where *A. marina* was rare.

Therefore, practicing aquaculture mixed with mangroves is potential to be implemented, and indeed there is already a long history of traditional shrimp farming in mangroves. For instance, the dominant mangrove species in gei wei, which is a traditional aquaculture in Hong Kong, are *A. marina*, *Kandelia candel*, and *Aegiceras corniculatum* (Primavera 2000). In a tambak system in Indonesia, the primary species of mangroves planted on dikes are *A. marina* and *Rhizophora mucronata*, followed by *Excoecaria agallocha* and *Xylocalpus moluccensis* (Davie & Sumardja 1997; Inoue *et al.* 1999). In particular, if specific species is considered for this study, *Avicennia* sp seems to be the one potentially persistent in aquaculture practices. Furthermore, similar to the present study area, *A. marina* is harvested by cutting the lateral branches for fuel wood using leaves as green manure (preferred that they lack tannin, unlike *Rhizophora*) and allowed to coppice to regenerate after a few seasons, as described by Primavera (2000) and Aung *et al.* (2009). In arid regions, this species is also extraordinarily useful for camel fodder (Field 1995).

Potential risks

In order to address the current growing conflict on the brackish water aquaculture practices inside mangrove forests, some basic soil properties were assessed in this study. Generally, most of the physical and chemical properties were not under serious risks. Those in the active shrimp ponds with mangroves closely followed the values of natural sites. In addition, the critical limit of organic matter accumulation can also be compared with the resulting values in natural sites (C) as control ones, and all other values lower than those of natural sites. Like common problems occurred in most of the intensive farming practices, there was no excess amount of mineral accumulation occurred in the study sites. For most of the properties, the lower limit is also still above the critical points by Boyd & Fast (1992). Their evaluation on the problems with toxic metabolites in extensive and semi-intensive states that the critical value of total carbon is less than 1%, and that of total nitrogen is 0.15 %; the pH of dry soil water ranges from 7 to 8. They concluded that there was no evidence to show the toxic levels in extensive shrimp farming practices. This agrees with the findings of this study. Unlike the extensive farming, in the intensive shrimp ponds worldwide, problems with excessive organic matter accumulations that occurred from uneaten feeds, shrimp feces, and dead plankton (Boyd 1995) are common. Funge-Smith & Griggs (1994) also report that slightly higher values for organic content of the accumulated sediment occur in intensive shrimp ponds in Thailand (5.54%–8.54%). Furthermore, in two experimental shrimp ponds operated without water exchange, the organic matters of the accumulating sediment were 26.2% and 37.1% (Hopkins *et al.* 1994).

Despite most of the properties showing within the limits, the high acidity in dry condition due to the air exposure of potential acid sulfate soil (PASS) has been confirmed on the active shrimp farming with mangroves in the present study. The irregular flushing of brackish water with alternative prolonged flooding and drought may have lowered the pH values. Boyd (2000) reports that most samples with $pH < 6$ represent sulfur concentration greater than 0.3%. Therefore, pH values may also be assumed as an alternative indicator of the concentration of sulfur in these sites. In the present study, natural mangroves and active shrimp ponds with mangroves have proved the higher contents of sulfur greater than 0.3%. In terms of natural mangrove sties, there is no barrier for regular flow of tidal water. Even though the contents of SO4 at the natural sites (C) are more or less similar to the active shrimp farming with mangroves, limited acidity was detected at the natural sites (C). Not only the natural sites, acidity was also not found on all other sites apart from the active shrimp ponds with mangroves. These may be already leached out with rain water or water drainage on the other sites. As for the active shrimp ponds with mangroves, the ponds have been with the irregular inundation of alternative flooding and soil exposure a year. Once there is no shrimp production in dry season, the flushing of brackish water flowing into the ponds is suspended and out of control without management. This must have caused to become lower in pH values in the active shrimp farm with mangroves. According to the report from the Department of Environment and Resources management in Australia, the potential environmental impacts of acid sulfate soils can kill fish, crustaceans, annelid worms, shellfish and oysters, cause fish diseases, and change aquatic communities. Furthermore, the main ecological effects of potential acid sulfate soils are habitat degradation and poor plant productivity. In addition, when acid sulfate soils are exposed to air due to drainage or disturbance, these soils produce sulfuric acid (battery acid), often releasing toxic quantities of iron, aluminum, and other heavy metals. The release of acid and metals can cause significant harm to the environment, engineering structures and even human health (DERM 2011).

For managing these acid sulfate soils, preferred management strategies are avoidance, minisation of disturbance, and neutralization (DERM 2011). Liming is also a typical treatment. Pond bottoms were often treated between crops with 1000–2000 kg/ha of agricultural limestone Boyd (2000), however, there was still lack of information doing so in the extensive farming practices.

Shrimp Yields

Regarding shrimp yields, though any of the data in the study is not available to present here, by reviewing the previous literature, extensive farming witnessed less production compared to others; the stocking densities are 1–3 no/m for extensive, 3–10 for semi-intensive, and 10–50 for intensive (Poernomo 1990; Primavera 1993, 1998b). According to personal interviews with shrimp pond owners, shrimps produced from the ponds mixed with mangroves mostly become smaller in size, and then decline in production, finally the ponds are abandoned. Typically, the average utilisation of extensive shrimp farming in this area was said to be from 5 to 8 years, except that the active shrimp ponds with mangroves (A-I) have been continuously practicing since 2002 up to now. Macintosh *et al.* (2002) report that shrimp yields decrease when mangroves within the pond reach 8–10 years of age because of a lack of light through the shading of the canals by forest canopy. A similar case was expressed by the shrimp pond operators in the study area, where shrimp sizes and yields deceased due to the shade of mangrove canopy. So, it is necessary to consider the density of mangroves once the mangrove-friendly aquacultures are considered. Even under the current condition some of the shrimp pond owners do thinning the braches of *A. marina* to get light energy for shrimps based on their traditional knowledge.

Considerations for Mangrove-friendly aquaculture initiatives in restoration

The preferred site category with less risks in the study is undoubtedly category C, community-managed mangroves without shrimp farming practices. Except this category C, there are more favourable points of the abandoned shrimp farming sites with mangroves, 1) most similarities with natural sites by species composition 2) no acidity observed. The active shrimp farming with mangroves is less recommendable because of 1) less similarity to natural site 2) highly acidic in dry condition although highest biomass productivity and more appreciable levels of physical and chemical properties occurred. A key important finding from the present study is that the active shrimp ponds with mangroves have shown the evidence of activating potential acid sulfate soil condition. In case it is considered to initiate the mangrove-friendly aquaculture, the modification and systematic control of ponds in accord with local tidal hydrology and layouts of mangrove species are indispensable to develop an aquaculture model. The present study does not emphasize fauna perspectives, the survivorship of other faunal communities should also be learned to affirm the status of mangrove-friendly aquacultures.

Alongi *et al.* (2000) suggest some changes to present management practices that may shift the autotrophic-heterotrophic balance sufficiently to improve shrimp production: (1) A more controlled flow of tidal water would improve the net tidal exchange. (2) A reduction in the high suspended solid loads using settling ponds would improve water clarity and primary production and would lower bacterioplankton abundance and production. (3) More effective harvesting techniques would minimise post-larvae losses (Johnston *et al.* 2000). (4) A better design of the levees would minimise erosion and slumping, resulting in less accumulation of sediments. Overall, this study might be a way to support floral information in rehabilitation and restoration measures in the human-disturbed sites, focusing more on the aquaculture-driven sites. To sum up, the most preferred sites are community-managed mangrove sites, followed by the abandoned ponds with mangroves. However, in case the mangroves-friendly aquaculture or small-scale farm forestry are considered as one of the restoration strategies, to provide reliable scientific information, and to thoroughly assess potential risks are indispensable in order to achieve the integrity of mangrove ecosystems through effective restoration and rehabilitation measures.

3.5 Conclusion

The present study explored the actual living vegetation in the mangroves on the human affected landscapes. The major human impacts considered were rice fields and shrimp ponds. In these human-disturbed sites, the number of herbaceous/understory species outweighed that of true canopy mangrove species. Whereas the communities with more mangrove species were observed in the aquaculture-driven sites, those with the only one true mangrove species dominated the agriculture-driven sites. The former practices did not cut all mangroves clearly, but the latter did clearly. Patterns of vegetation recovery processes in the clearly-cut mangrove sites can be generally classified into four phases; first, *Graminaceae*, specifically short grasses, starts encroaching into the barren areas after abandoning rice cultivation and cleared-mangorves shrimp ponds. Second, a mix of tall grasses with shrubs, herbs, climbers, ferns and palms such as *Acanthus*, *Derris* and *Acrostichum* spp gradually follow, and as third phase pioneer character mangrove species start to recover again. Eventually, as four phase after taking a considerable time, the recovery process is supposed to return to the pre-existing mangroves as close as possible. Generally, in the third phase, the current study has shown evidence that recovered true mangrove species that are dominant in the agriculture-driven sites was *Sonneratia caseolaris*, and those in the aquaculture-driven sites were *Ceriops decandra* and *Avicennia marina*. In these self-help recovery processes, the abandoned agriculture-driven sites witnessed to take a long time to return to mangrove forests because of the clearly-cut practices to mangroves whereas certain parts of mangrove vegetation were still maintained in the aquaculture-driven sties. Therefore, restoration by artificial means is necessary to facilitate the recovery processes at the agriculture affected sites. The naturally observed actual living mangroves in these human-disturbed landscapes can be fittest species under the human-modified fragmented landscapes, and they can be more preferable species in the restoration measures on their corresponding sites. The study proceeded to make assessment on the aquaculture-driven sites. The tests have shown that there was highly acidic in the active shrimp ponds with mangroves representing the activation of potential acid sulfate soil. It ensures that environmental and ecological impacts can occur due to the unsystematic practices of extensive brackish water shrimp ponds. In case the small-scale and extensive shrimp farming practices are considered to implement in restoration processes, how to keep pace with local regular hydrology should be developed through well-evaluated mangroves-friendly aquaculture models.

Chapter IV

Temporal and Spatial Dynamics of Vegetation Health in the Mangroves of the Eastern Ayeyarwady Mega Delta

Abstract

Two decades of mangrove dynamics have been examined using time-series Landsat data from 1990 to 2010. If attempt is made to look back over the long history of the study area from before 1990, the region must have been covered with more than 90 % of dense mangroves due to the region having been delineated as reserved forests since 1924. During the two decades of the present observation, from 1990 to 2010, 30 % of dense mangroves have been disturbed and cleared, and an overall deforestation rate has shown 0.7 % per year. Agriculture, particularly rice fields, has led to the majority of the mangrove clearance. Four main regimes were selected based on the types of management and disturbance: totally protected mangroves – wildlife sanctuary; mangroves with frequent access by local people for their local utilization; mangroves disturbed by extensive shrimp-farming practices; and mangroves disturbed by rice fields. Each exclusive regime was extracted via a 25-km^2 sub-scene, where the normalized difference vegetation index (NDVI) was intended to be analyzed. The transition between pre-cyclone and post-cyclone mangroves was also taken into account, as the 2008 Cyclone Nargis devastated this region. The results showed that although the pre-cyclone vegetation indices continuously decreased due to highly human-disturbed regimes, the post-cyclone vegetation indices were relatively increasing. The possible reasons for the increasing vegetation indices after the cyclone impact are assumed to be due to the suspension of farming work on rice fields and shrimp ponds after the cyclone impact and to the newly sprouted leaves showing a higher spectral response than the pre-cyclone matured leaves. However, these upward trends could be temporary, as they are thought to be rapidly reversible once human intervention starts again, as was usual before the cyclone impact. The present study highlights how the mega-delta mangroves are decreasing at an alarming rate and the patterns of vegetation health and recovery across different management and disturbance regimes can support the thinking on best-use management scenarios. Restoration and rehabilitation, therefore, should be accelerated urgently to mitigate potential disastrous events in the future such as the deadly Cyclone Nargis of 2008.

Keywords: mangroves, Landsat images, deforestation, management and disturbance regimes, NDVI, cyclone impact

4.1 Introduction

Mangroves represent a specific ecosystem found in the intertidal zone along tropical and subtropical coastlines, and are often located near estuaries and deltas (Spalding *et al.* 1997). In addition to their great ecological importance in shoreline stabilization, reduction of coastal erosion, sediment and nutrient retention, storm protection, flood and flow control, and water quality (Dahdouh-Guebas *et al.* 2005; Giri *et al.* 2007), they are also of crucial importance in terms of socio-economics (Alongi 2008; Walters *et al.* 2008). However, these mangroves have been affected by over-exploitation because densely populated areas in the coastal and delta regions place pressure on the mangroves due to the demand for food, fuel wood, construction materials and human settlement. It has been estimated that there may be a 60 % loss of the mangroves by 2030 (Valiela *et al.* 2001; Alongi 2002; UNEP-WCMC 2006). The spatial-temporal patterns of dynamics in the mangrove vegetation need to be monitored and highlighted in order to revise the present conservation and management measures, allowing for decision-making based on scientific evidence.

Satellite remote sensing is a useful source of information as it provides timely and complete coverage of the study area, complementing field surveys containing higher information content. The objectives of the studies differ according to what can be expected from the different types of remote-sensing data (Satyanarayana *et al.* 2001). For example, mapping mangroves at the species level can be attempted with high-resolution aerial photography, whereas mapping the landscape-level environmental indicators of a coastal area can generally be carried out using optical satellite images from sensors such as Landsat TM, SPOT, HRV or IRS LISS (Klemas 2001, Ramachandran *et al.* 1998). In remote-sensing analysis, the NDVI is used to determine the aboveground biomass, primary productivity level and vegetation health (Seto *et al.* 2004, Walters *et al.* 2008).

Although Myanmar possesses the eighth largest extent of mangrove cover worldwide (FAO 2007), and the seventh largest one by Spalding *et al.* (2010), studies on mangrove forests remain limited in the scientific literature. In the Ayeyarwady Mega Delta of Myanmar, mapping mangroves, and GIS- and RS-related studies have been carried out by some researchers (Oo 2004; Giri 2008). Blasco *et al.* (2001) also points out that the ecological studies were still scant in Myanmar and that the exact extent of the mangroves in Myanmar was unknown at the time of their survey. They demonstrated the magnitude of the on-going deforestation in Myanmar by using remote-sensing techniques. The total extent of mangroves throughout Myanmar in their study was 6900 km^2, although there is a considerable difference in the area description by the World Mangrove Atlas (Spalding *et al.* 2010), with a figure of 5029.11 km^2. Consequently, there are a variety of descriptions based on the different tools and methods used.

After the deadliest cyclone impact in May 2008, the crucial role that mangrove forests play as a critical bio-shield that protects vulnerable coastal communities has been highlighted (Thant *et al.* 2010). Similar findings in the previous literature have confirmed that mangrove forests attenuated the tsunami waves and protected coastal communities in Indonesia, Thailand, India and Sri Lanka during the Indian Ocean tsunami impact in December 2004 (Danielsen *et al.* 2005; Kathiresan & Rajendran 2005). It has been suggested that mangrove deforestation due to over-exploitation along the tropical coastline – including Myanmar – has largely reduced the protective capacity of mangrove forests and their ability to rebound from natural disasters (Dahdouh-Guebas *et al.* 2005; Nigel 2005; Weiner 2005; Giri *et al.* 2008). Based on such a framework, more supporting information is required to better understand mangrove deforestation dynamics, forest fragmentation, vegetation health and the provision of ecosystem services and goods, and until now such documents are poorly recorded in developing countries. Kovacs *et al.* (2001) state that in developing countries, where the majority of large-scale losses are occurring, funds are not commonly available for such endeavours and, hence, these regions remain of great concern for wetland conservationists, and the limitations should soon be overcome as governments take on the responsibility of maintaining continuous records of their mangrove forests by coordinating with other government and non-government agencies. Giri *et al.* (2008) selected the Ayeyarwady mega-delta region as one of their study regions including Indonesia, Malaysia, Thailand, Bangladesh, India and Sri Lanka based on four reasons: 1) this area was the most devastated during the Indian Ocean tsunami of December 2004 – as a result, many national governments and international organizations are now implementing ambitious conservation and rehabilitation programmes; 2) the region contains approximately 10 % of the total mangrove forests of the world, including the largest contiguous mangrove forest in the world; 3) strong demographic pressure and diverse climatic conditions in the region have created a mosaic of mangrove diversity that is changing constantly; and 4) the region is the epicentre of mangrove biodiversity and consists of many existing and planned national parks, biosphere reserves and world heritage sites. Most importantly, one added important fact that determined the selection of this area in the present study is that Cyclone Nargis hit this region, devastated mangroves, caused massive destruction of property and a death toll of at least 134,000 people (TCG 2008).

Based on the frameworks of this dissertation about mangrove dynamics and recovery perspectives in the previous two chapters, an attempt has been made in this part to generate a deeper understanding of vegetation recovery after natural and human impacts on the landscape scale, and, additionally, to deal with the lack of scientific records in this region. In this part, therefore, the study seeks to address the following points: what is the extent of the dense mangrove change during the two-decade period under consideration? How were the patterns shown by vegetation indices differentiated by a variety of management and disturbance regimes? In addition, how did catastrophic disturbance in 2008 affect mangrove vegetative indices? It is hoped that in understanding the trends of deforestation and the proportion of vegetation distribution in different management regimes, the requirements to properly consider the current mangrove management and conservation measures in the region can be better understood.

4.2 Materials and methods

4.2.1 Study site

The whole landscape of the eastern part of the Ayeyarwady Mega Delta in the present study is focused on (Figure 4.1).

4.2.2 Image acquisition

Time-series Landsat TM satellite images are used for 1990 to 2010, in which 2007 and 2010 images were analysed to focus mainly on the pre-cyclone and post-cyclone vegetation dynamics in regards to the catastrophic cyclone impact, called Cyclone Nagris, in 2008. The 1995 and 2010 images were purchased from the US Geological Survey, and the acquisition of the 1990 and 2007 images was supported by the Planning and Statistics Division of the Forest Department, Myanmar. All these scenes were taken in the same opening season in January and February during rice-harvesting time, thus making the classification more convenient in terms of determining the spectral response of mangroves and other cultivated crops. These collections of time-series Landsat images are almost cloud-free as they were taken during the dry season with limited rainfall.

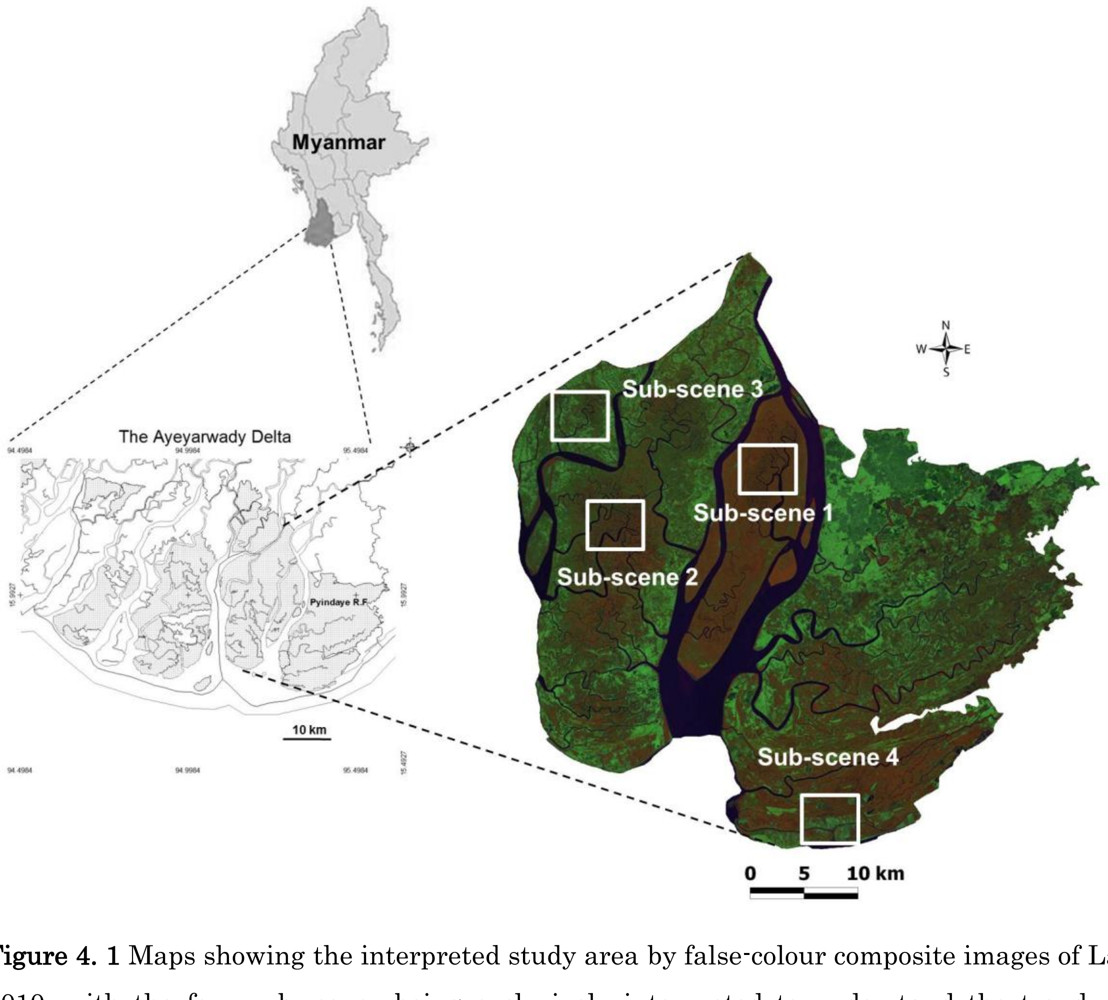


Figure 4. 1 Maps showing the interpreted study area by false-colour composite images of Landsat 2010, with the four sub-scenes being exclusively interpreted to understand the trends in the normalized difference vegetation indices – NDVIs: sub-scene (1) stands for totally protected mangroves demarcated as wildlife sanctuary; sub-scene (2) for frequent access of local subsistence utilization, Kadonkani Reserved Forest; sub-scene (3) for mangroves affected by rice

cultivation, Kadonkani Reserved Forest; and sub-scene (4) for shrimp-farming affected sites, Pyindaye Reserved Forest.

4.2.3 Ground data collection

The training data used in the present study was acquired during yearly field visits in the period 2008–2011. At least 125 validation points were used for supervised classification. The interpretation for the earlier years was based on the current data, interviews with the Forest Department's staff, local key informants, long-settlement residents in the nearby villages and the forest cover maps produced by the Forest Department. In-depth and detailed classification was not performed in the present study because of time constraints and interpretation was merely based on the moderate-resolution Landsat images. If a deeper ecological study were done, high-resolution data would have been required. The five classes in Table (4.1) were categorized by following and modifying the class definitions of Blasco *et al.* (2001) and Giri *et al.* (2008). Then, four main different management regimes were exclusively categorized and analysed when the NDVIs for each were considered. These categorized management regions are 1) totally protected mangroves with less human intervention inside Meinmahla Wildlife Sanctuary; 2) the mangrove site that is mostly exploited for local subsistence needs inside Kadonkani Reserved Forest; 3) the mangrove site that is affected by rice cultivation, inside the Kadonkani Reserved Forest; and 4) the mangrove site that is affected by brackish water shrimp-farming practices inside Pyindaye Reserved Forest. Field visits were undertaken to check these four management regimes thoroughly in order to avoid a mix of different land uses in each block of 25 km^2 in the analysis. The study did not follow the standard classification rules of forests because the spatial distribution of mangrove trees and shrubs under human interventions occur as randomly intermingled distributions and they remain almost totally unexplained. Paddy fields in this data-collection season are examined after the harvesting periods, and being devoid of crops, produce a similar spectral signature to barren lands. In terms of shrimp ponds, some of the ponds have been clearly cut in the large scale. In this type of pond in the dry season of the data-collection period, they are exposed to air and the soils are dry. Consequently, the interpretation can also be confused with that of a similar spectral response of paddy fields after harvesting and bare lands. In terms of extensive shrimp ponds, it is one of the challenges to classify them alongside dense mangrove vegetation because mangrove vegetation remains dense in some of such extensive ponds. The present study, therefore, attempted to aggregate similar categories in order to reduce misclassification. Ground truth data were gathered with the help of a GPS receiver (Garmin GPSmap 60CSx45) set at an estimated accuracy of 5 m to 10 m resolution and the structure of ground truth points were adopted from the preivous chapters.

Table 4. 1 Classes classified to interpret time-series Landsat images

Classes	Supervised classification class definitions
Dense mangroves	Mangroves remain dense, being tall or low. It can be either a forest or thicket. In this part, there is a clear-cut limit between mangroves, rice fields or open brackish waters. At this level, however, it is impossible to try to go deeper into the analysis to attempt to discriminate mangrove stands according to their floristic composition, the size of trees, or shrubs or their standing biomass. The adult trees ≧ 5 cm in dbh for training sites of this class are; Average density of tree > 5 cm in dbh = 1657/hectare Maximum canopy tree height = 17.8 m Maximum tree diameter at breast height = 107 cm
Degraded mangroves	Mangroves are fragmented. There is no clear-cut limit between mangroves and other land uses. Their surroundings

	are exposed, being devoid of mangrove vegetation. Regardless of the tree heights, some individuals can be > 5 m in this class of degraded mangroves, but these canopy trees are scattered, so no in-depth data was available for this class. The available information on the training sites for this class using field data plus Google earth are; Average density of canopy trees = 27/hectare Maximum canopy tree height = 6 m Maximum tree diameter at breast height = 25 cm
Deforested mangroves	Mangroves have been clearly cut, converted mainly to agriculture, followed by aquaculture and other uncommon land uses. (Agriculture in this study region is mostly rice fields, which are harvested and become exposed without crops in the dry season.)
Fallow lands	After disturbances, especially anthropogenic disturbances, this class is mostly covered with the growth of *Graminaceae* and Herbaceous species on these disturbed sites, and mangrove species mostly occur as seedlings and in sapling stages. In the dry season of the data acquisition, it was clearly ascertained that this class had a low spectral response, unlike the classes with canopy mangrove species.
Water bodies	Areas of open water with no emergent vegetation, e.g. channels and waterways, and inundated sites as well.

Note: The classes are modified from Blasco *et al.* (2001) and Giri *et al.* (2008). For deeper ecological and land-use analysis, further investigation is required by using genuine high-resolution data. The present study is merely "quick look" data to figure out the dynamics of the vegetated and non-vegetated status of the mega-delta mangroves. The in-depth ground data for some training sites is taken from the previous chapters II and III.

4.2.4 Classification

The new images acquired were geo-referenced via UTM projection based on the images available from GIS and the RS section of the Forest Department in order to be able to analyse all images consistently. The RMS (root mean square) error of the transformation was less than 15 m. For image classification, a hybrid unsupervised and supervised classification approach was used. Prior to the field visit, false colour composite images such as in Figure 4.1 were prepared, and an ISODATA clustering algorithm or unsupervised classification by 10 clusters was performed for convenience when collecting ground truth data. After field visits, a maximum likelihood supervised classification was carried out using training areas chosen according to extensive field knowledge. For this analysis, remote-sensing software, MULTISPEC version 3.2, freely given by Purdue University in Canada was used. In determining the NDVIs of the four management regimes, raster calculations of bands 3 and 2 were performed by using the Arc GIS 9.3 desktop application. Twenty-five km^2 of clipped images for each management regime were detected to obtain the minimum, maximum, mean and standard deviation of the NDVI values. Change-detection analysis was not performed in this present study.

4.3 Results

4.3.1 Trends of mangrove deforestation over two decades

The total area in the present study is almost 170,500 hectares including two reserved forests and one wildlife sanctuary. In 2010, almost two years shortly after the cyclone impact, vegetation recovery can be seen. To understand the natural impact of the cyclone, the Meinmahla Wildlife Sanctuary can be taken as a model because mangroves in this sanctuary are less interfered with by human disturbance compared to others. As for the other two reserved mangrove sites, Kadonkani and Pyindaye R.F, they are fragmented and cleared; that is, the sites have been converted to agriculture and aquaculture by clearly cutting mangroves. Figure 4.2 and Table 4.2 illustrate the trends of mangrove degradation and deforestation from

1990 to 2010. From 1990 to 2010, dense mangroves reduced from 45 % to 15 %, fragmented mangroves increased from 26 % to 45 %, cleared mangroves increased from 6 % to 20 %, and fallow lands changed slightly. If the pre-cyclone 2007 and post-cyclone 2010 images are considered, there is a slight increase for dense mangroves, degraded mangroves and fallow land, and then there is a relative decline in deforested mangroves. Overall, the deforestation rate of the present study region is 0.7 % per year during the two-decade period from 1990 to 2010, and 1.5 % of dense mangroves are decreasing every year.

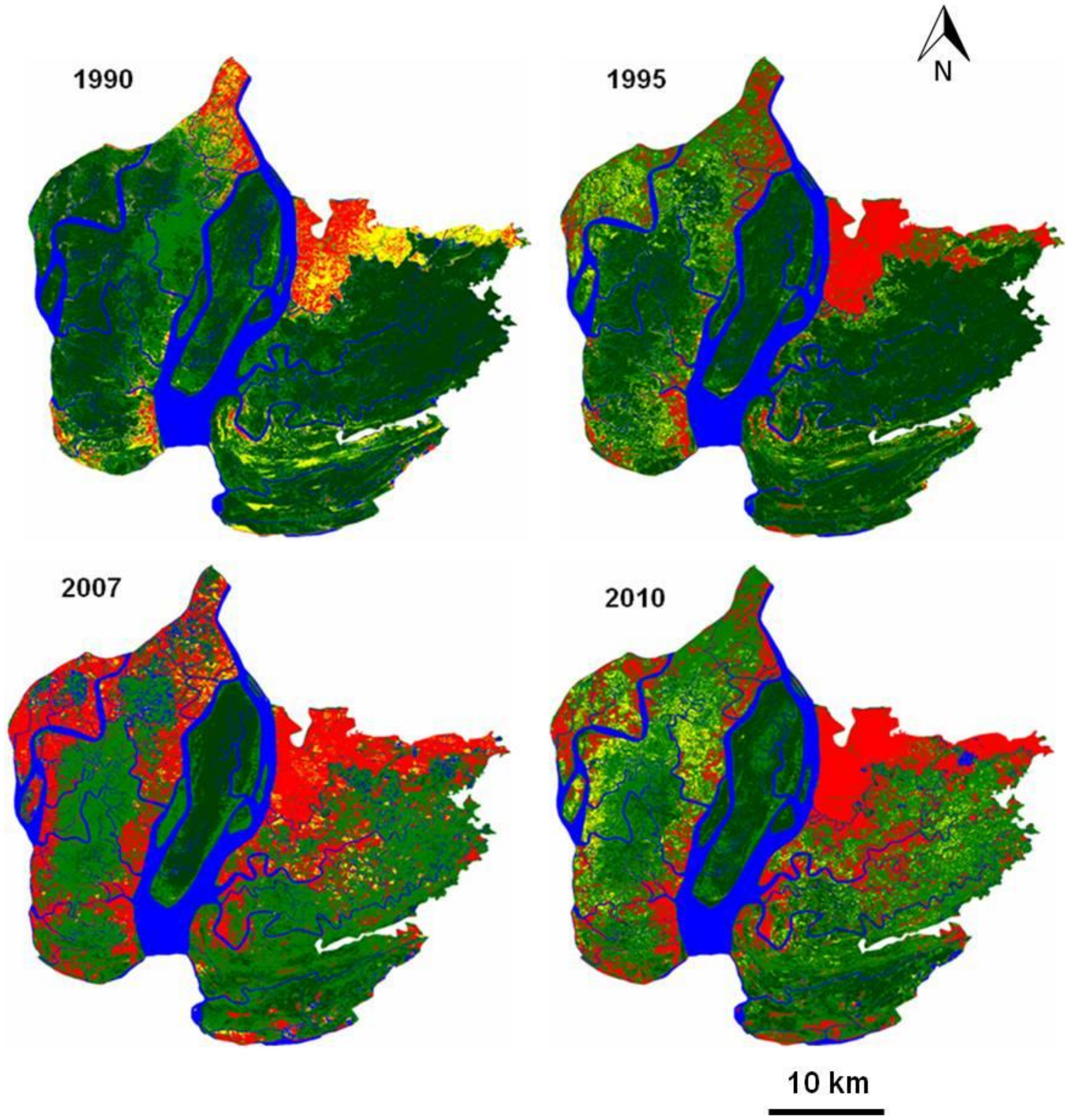


Figure 4. 2 Images of mangrove deforestation over two decades from 1990 to 2010; dark green for dense mangroves, light green for degraded mangroves, red for cleared mangroves, yellow for fallow lands and blue for water bodies.

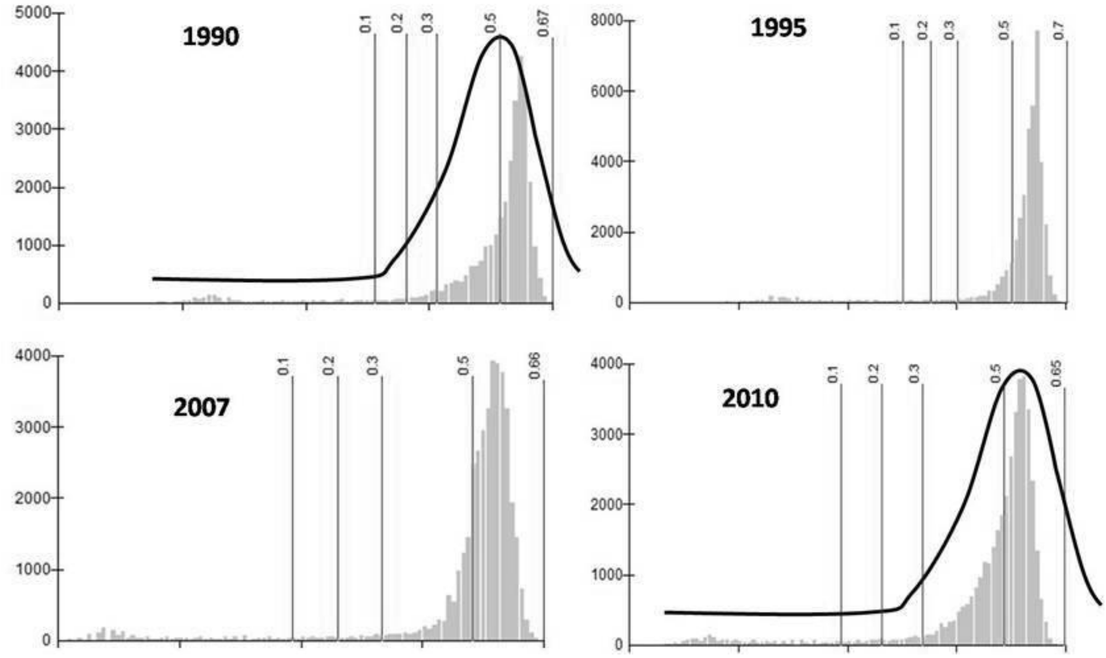
Table 4. 2 Degradation and Deforestation of mangroves over a two-decade period

Years observed	1990	1995	2007	2010
Dense mangroves (hectares)	77,070.61	75,907.92	21,088.37	24,750.82
(%)	45	45	12	15
Degraded mangroves (hectares)	44,819.25	47,646.78	72,705.53	76,754.76
(%)	26	28	43	45
Deforested mangroves (hectares)	9,438.54	18,043.03	42,055.21	34,713.57
(%)	6	11	25	20
Fallow lands (hectares)	12,498.64	7,301.53	4,364.57	9,468.33
(%)	7	4	3	6
Water bodies (hectares)	26,672.95	21,600.73	30,286.32	24,812.52
(%)	16	13	18	15
Average producer`s accuracy (%)	99.00	99.58	98.62	99.38
Average user`s accuracy (%)	98.32	96.72	92.60	99.22
Kappa statistics (%)	99.10	99.50	99.00	99.60
Average likelihood probability (%)	56.10	55.60	54.10	55.40

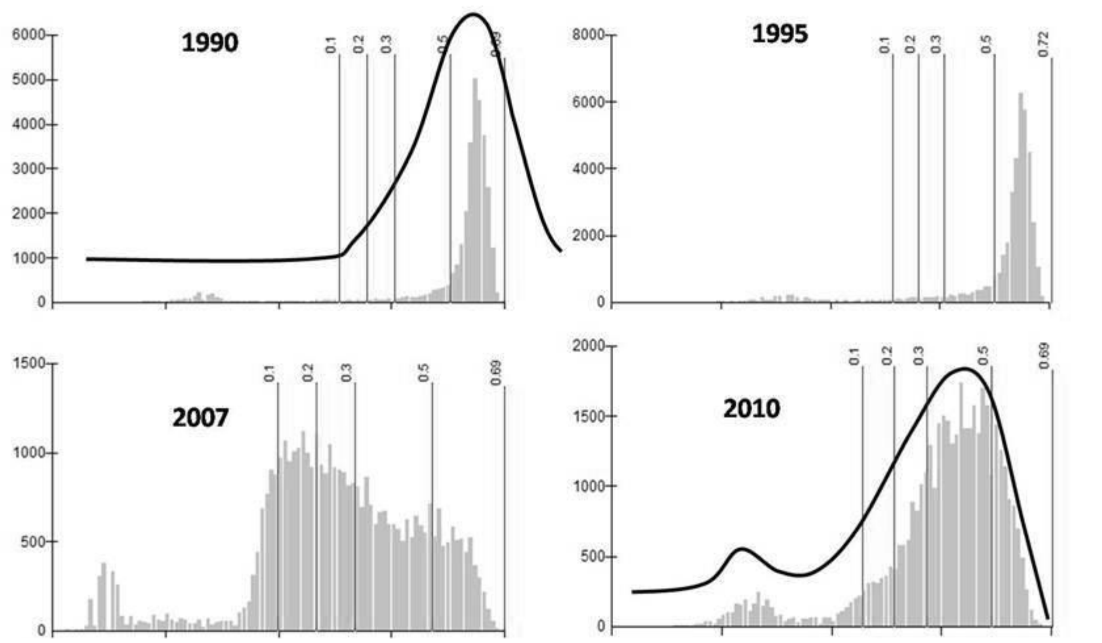
4.3.2 Patterns and trends of NDVI change by management regime

Figure (4.3) shows that there are various patterns of vegetation health indices observed in the study. The natural mangrove area that is totally protected for wildlife – that is, mangroves that are least affected by human disturbance – showed that the distribution of vegetation in the mangroves approached the right end of the scale; that is, the values of the NDVI approach 1 (Figures 4.3a). Following this subplot of the wildlife sanctuary, the Kadokani Reserved Forest, which are frequently accessed by local stakeholders to exploit for fuel woods, construction materials, fishing tools and so on, showed distribution patterns that shifted slightly from the right end to the left, but they seem to still maintain values that are close to those of the wildlife sanctuary (Figure 4.3b). For the mangroves disturbed by paddy fields, the values of the NDVI were almost close to 0, showing almost barren land with a complete lack of vegetation (Figure 4.3c). The most interesting pattern is shown by the places driven by aquaculture (Figure 4.3d). The graph shows bimodal distribution patterns that are significantly different to the other areas; that is, partially healthy vegetation and partially barren lands and water logged parts that witness the extensive aquaculture practices through the partial cutting of mangrove habitats.

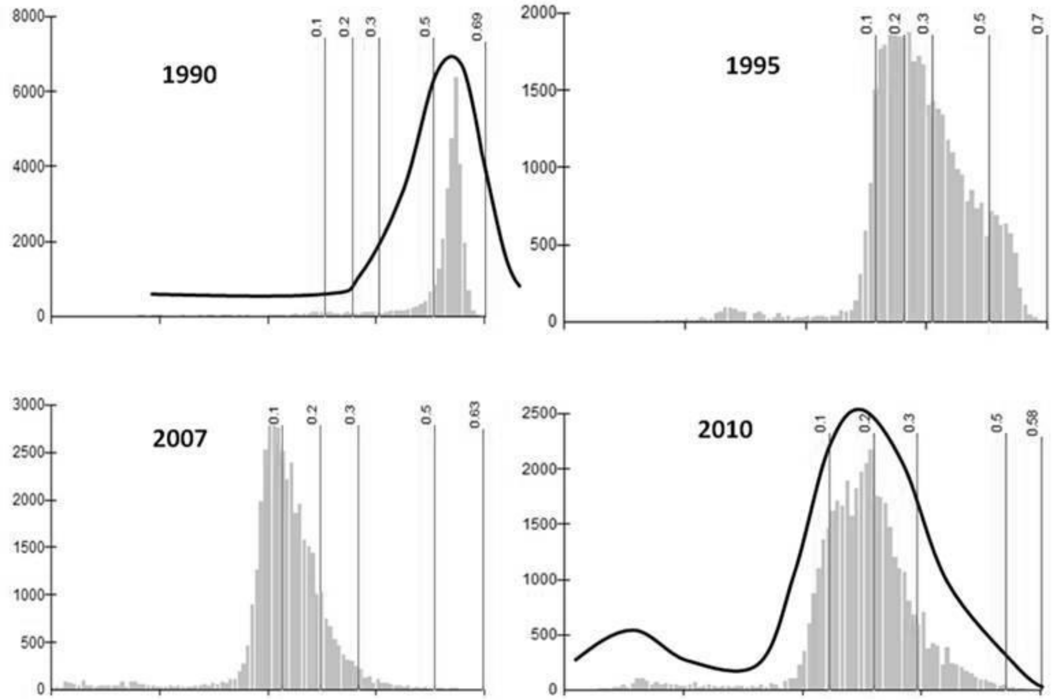
(a) Meinmahla Kyun Wildlife Sanctuary over a two-decade period



(b) Mangroves accessed for local utilization



(c) Mangroves affected by rice cultivation



(d) Mangrove sites affected by shrimp-farming practices

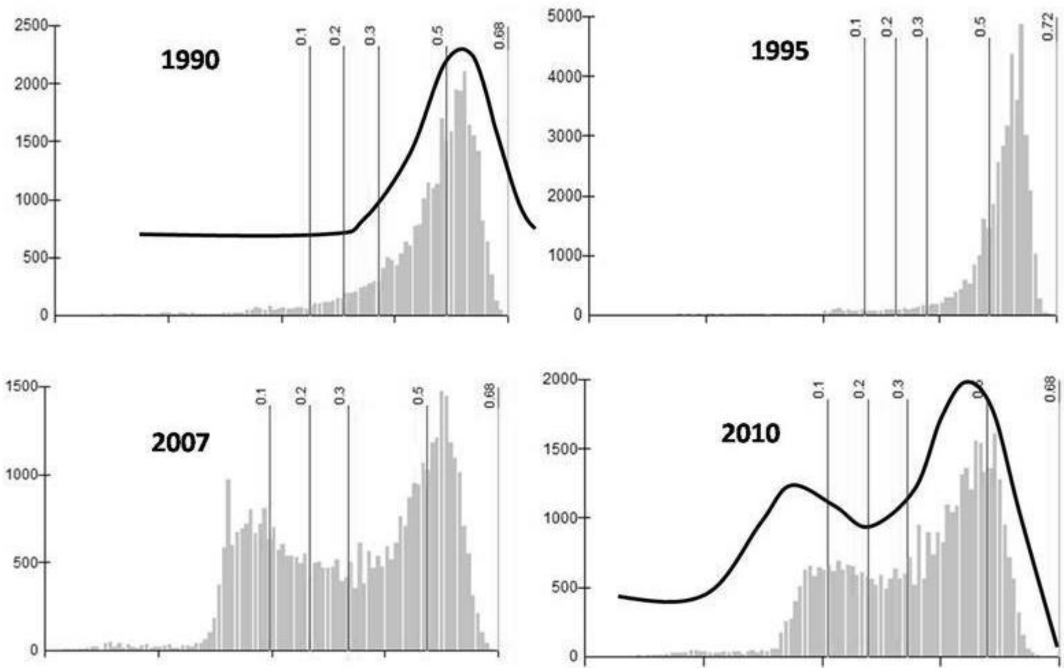


Figure 4. 3 Patterns of vegetation health in four management regimes in mangrove environments (a) Totally protected mangroves, (b) Mangroves under frequent access for local subsistence use, (c) Mangroves affected by rice cultivation; and (d) Mangroves affected by shrimp-farming practices.

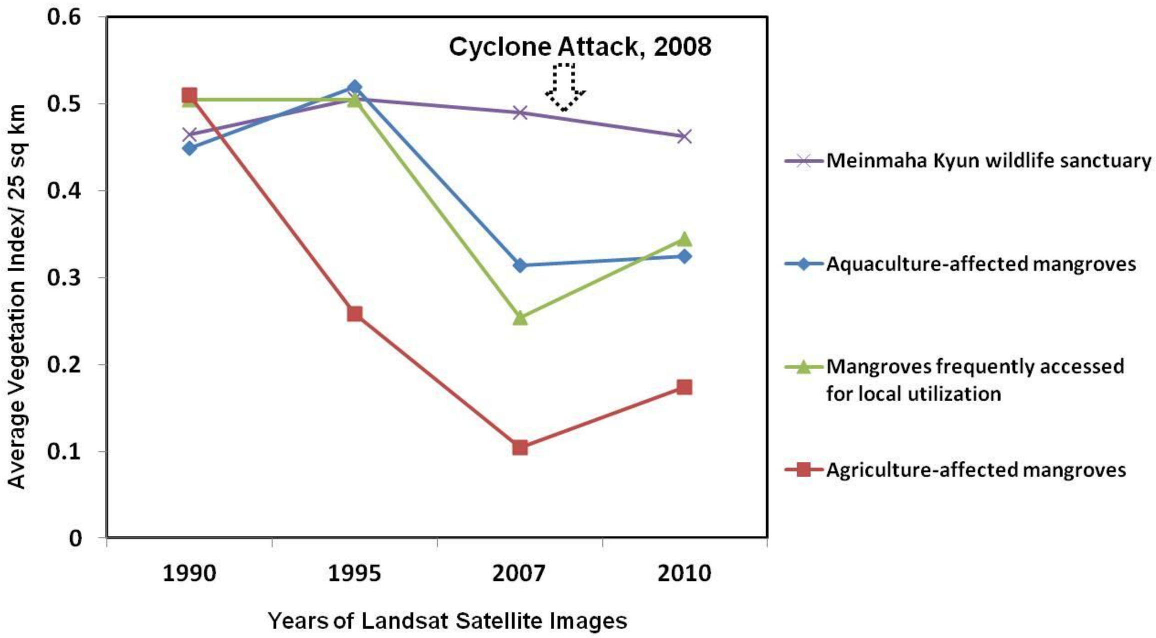


Figure 4. 4 Trends of normalized difference vegetation indices (NDVIs) for four management regimes over a two-decade period.

Then, an attempt was made to recognize the trends of NDVI change from 1990 to 2010 (Figure 4.4). The NDVI values for the initial point of analysis in 1990 of the Meinmahla Wildlife Sanctuary are 0.46±0.22, for the mangroves frequently accessed for local utilization the figure is 0.51±0.25, for the aquaculture-affected mangroves, the value is 0.45±0.16 and for the agriculture-affected sites, it is 0.51±0.18. Then, the comparable NDVI values before the cyclone impact in 2007 and almost two years after the cyclone impact in 2010 are; 0.49±0.17 and 0.46±0.17 for the Meinmahla Wildlife Sanctuary, 0.25±0.21 and 0.34±0.2 for the mangrove frequently accessed for local utilization, 0.31± 0.21 and 0.32±0.18 for the aquaculture-affected mangroves, and 0.10± 0.12 and 0.17±0.12 for the agriculture-affected sites. The values of vegetation indices for the wildlife sanctuary area almost level off throughout the observed period. For the wildlife area, the sites for local use, and the aquaculture-affected mangroves, all these three sites were still almost the same until 1995, while agriculture-affected mangroves started to decline from 1990 onwards. It proves that the clearance of mangrove habitat for rice cultivation started earlier in the history of the area before 1990. If the pre-cyclone 2007 and the post-cyclone 2010 periods are considered, unexpected results are observed. Apart from the wildlife sanctuary, the indices of vegetation health in all the other three sites increased, to even more than those of the NDVI in 2007, one year before the cyclone impact.

4.4 Discussion

4.4.1 Mangrove degradation and deforestation

Giri *et al.* (2008) interpreted time-series Landsat data covering the tsunami-affected coastal areas of Indonesia, Malaysia, Thailand, Myanmar (including the present study region), Bangladesh, India and Sri Lanka in Asia. It is stated that the annual rate of deforestation from 1975–2005 was highest in Myanmar, although the largest percentage of the remaining mangrove forest areas in 2005 is located in Myanmar (551,361 ha), 33 % in this region of Asia. In the present study, dense mangroves have reduced from 45 % in 1990 to 15 % in 2010, illustrating that 30 % of them have been degraded and cleared during the two-decade period, showing that the dense mangroves are degrading by 1.5 % per year. In terms of deforestation, 6 % in 1990 have increased to 20 % in 2010, that is, overall deforestation rate is 0.7 % per year during this two-decade period. The main reason for this rapid deforestation is due to conversion of mangroves to paddy fields, followed by aquaculture, fuel wood cutting and use for construction materials. Giri *et al.* (2008) also estimated that 98 % of mangrove deforestation in Myanmar during the period 1975–2005 was due to agricultural expansion, mainly rice fields, and 2 % was for aquaculture. In the Ayeyarwady Mega Delta, mangroves are also being destroyed or degraded by erosion and sedimentation (Barbier 2006); this mega-delta has the fifth largest sedimentation rate in the world.

Interestingly, there was a slight increase of dense and degraded mangrove after the cyclone impact if the pre-cyclone extent of mangroves in 2007 is compared to the post-cyclone extent of mangroves in 2010. The assessment of vegetation indices in the present study also shows evidence of this slight increase in mangrove vegetation health indices after Cyclone Nargis. There are two possible reasons for this: 1) local stakeholders severely affected by Cyclone Nagris have suspended their work, in particular paddy cultivation and shrimp farming. Thus, during this period, there seems to be less clearance of dense and degraded mangroves; and 2) it might be due to newly-sprouted leaves after the natural disturbance. This second fact is claimed by Satyanarayana et al. (2011) to occur in sites having young/growing and also mature trees with lush green cover, which is reflected in greater NDVI scores (0.40–0.68), implying healthy vegetation, while matured forest under the environmental stress indicated lower NDVIs (0.38–0.47). They also stated that although there is a relatively meaningful relationship between NDVI and density, their notable observation is that mature trees, usually with large stem diameter and height, may not necessarily show greater biomass in the remote-sensing analysis. In this regard, it should also be noted in this study that the increasing trends of mangroves and vegetation indices do not necessarily mean an increasing wood biomass; this is used merely to describe the health of the vegetation. In fact, if commercial or tangible values of wood are considered, they must have been reduced to some extent by natural disturbance. The average reduction in tree height was shown by Aung *et al.* (2011), in which most of the species decreased to almost half of their pre-cyclone tree heights when within the cyclone path. The third reason for an increase in dense mangroves as well as in mangrove vegetation health should also be added – there might have been some extent of classification errors in the process of image analysis through using moderate-resolution satellite scenes.

The first reason relating to the suspension in farming is proved by the double increase of fallow land in 2010 compared to that in 2007. It can, therefore, be seen that before natural disturbance, the cyclone impact, the continuous decline of mangroves at a rapid rate was prominent due to the clearance of mangroves for agriculture and aquaculture. Compared to 2007, post-cyclone mangroves do not show any further decline from their 2007 level. Instead, they show a slight increase in their vegetation indices. Mangroves after the natural disturbance, therefore, have shown their considerable resiliency once human disturbance is suspended. However, once the in-depth analysis is considered in the specific human-disturbed cases, the trends of returning to the initial state would have differed in the intensity, size and frequency of each impact. This progress can also be clearly seen from the figures 4.3 (a) to 4.3 (d) by focusing from 2007 to 2010 on the vegetation indices.

4.4.2 Conceptual model of vegetation health by disturbance

In Figure (4.5), an attempt was made to extract trends from Figure (4.3), and to elucidate conceptual models of how natural and human disturbances cause dispersion in the patterns of healthy vegetation in intact mangroves. The solid lines represent the distribution patterns of initial intact mangroves by analysing the trends in 1990; that is, the mass of the distribution is concentrated on the right with considerable high vegetation indices. The dotted lines represent the distribution patterns of the current state of mangroves after natural and human impacts. Figure 4.5a can be taken as an illustrated model, showing only natural disturbance, because it is the only site with less human disturbance compared to the others. Its distribution patterns may shift slightly during a short period, but they are likely to rebound quickly to their initial patterns of intact mangroves without disturbance. The other three figures show the site that is mostly accessed for local utilization (Figure 4.5b), the one disturbed by paddy cultivation (Figure 4.5c) and the one disturbed by aquaculture (Figure 4.5d). The first one (Figure 4.5b), representing a local-use site, is relatively dispersed to the left, but still maintains its healthy vegetation at an appreciable level; the second one, for the site disturbed by paddy fields, is almost opposite to the trends of initial intact mangroves, and is skewed to the left with relatively few high values for vegetation health; and the third one, for the site disturbed by aquaculture, in particular extensive types of shrimp farming, is interestingly, a bimodal distribution – that is, it is partially maintained by healthy vegetation, and partially exposed to soil and water. Degraded mangrove areas converted to paddy cultivation, therefore, are most challenging and appear to take a longer time for restoration processes, similar to the results found in Chapter III. On the other hand, that the sites already converted to agriculture should be restored is still in question, and it is necessary to review current land-use policy and evaluate which land use is most appropriate with the current socio-economic and ecological approaches. Nevertheless, the existence of mangroves is invaluable, and they play a critical role in supporting human livelihood in terms of goods and services. Dahdouh-Guebas *et al.* (2005) give a general message concerning how humans use, plan and manage their habitats and landscapes: this can have profound and undesirable consequences.

The conversion of mangrove land into shrimp farms, tourist resorts, agriculture or urban land over the past decades, as well as the destruction of coral reefs off the coast, have likely contributed significantly to the catastrophic loss of human lives and settlements during the recent tsunami event. While it may be a good investment to establish early warning systems for the next tsunami, it could be far more effective to restore and protect mangrove forests and other natural defences in parallel. Similarly, the death toll and loss of property during Cyclone Nargis 2008 must have been largely influenced by the extensive conversion of mangroves to other land uses, mainly rice fields. In some locations inside the so-called reserved mangrove forests, there are almost no single mangrove trees left, merely an extensive plain of paddy fields, and this situation of destroying natural barriers in this mega-delta have increased the death toll by Cyclone Nargis, 2008. If there were mangroves covering this region instead of cryptic ecological degradation, not only lives would be safe, but also massive property damage and loss of subsistence livelihoods would be minimized.

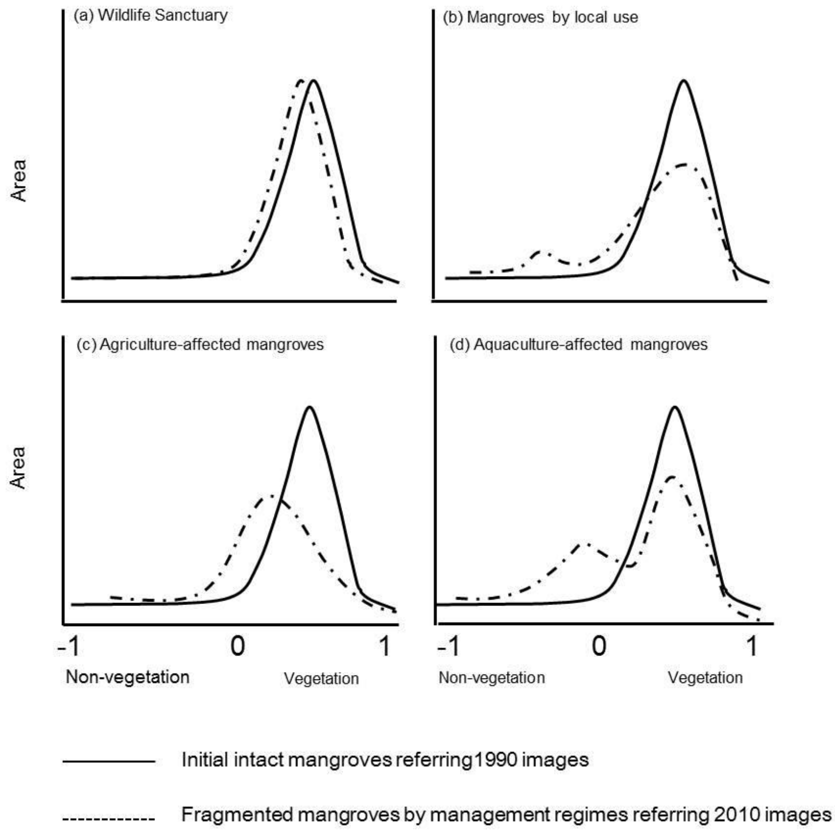


Figure 4. 5 Conceptual models illustrating distribution patterns of mangrove vegetation health by different management regimes, drawn from observed vegetation indices from 1990 to 2010 (a) Meinmahla Wildlife Sanctuary, totally protected area; (b) Mangroves frequently accessed by local people for their subsistence needs within Kadonkani Reserved Forest; (c) Mangroves disturbed by paddy cultivation within Kadondani Reserved Forest; and (d) Mangroves disturbed by shrimp-farming practices within Pyindaye Reserved Forest.

Fortunately, mangroves are extremely resilient (Alongi 2008) and this encourages us to restore mangroves with positive expectations. Consequently, the following Chapter V is about current examples of mangrove restoration measures and local people's perspectives on restoration. When considering mangrove resilience, the second figure (4.5b) may be taken as the best example of the coexistence of local people and mangroves, and it also shows evidence that after a resting period, even during a short span from 2007 to 2010 (4.3b), the vegetation indices of this site have shown recovery, close to the initial intact mangroves. It is hoped that these figures are good examples showing mangrove resilience, and they may follow the underlying resilience assumptions made by Gunderson *et al.* (2010): 1) a system would generally persist in form and function; and 2) a system would recover to its former equilibrium state after disturbances. The word "resilience" was introduced by Holling (1973), describing a measure of a system's persistence and its ability to absorb change and disturbance but still maintain the same relationships among population or state variables. However, the resiliency of mangroves has shown relative difference among the types of disturbance regimes, showing different intensities; therefore, the first regime with the least human disturbance quickly leaps back to its initial values. The second regime could be an excellent model of renewable mangroves with acceptable local unitization. In addition, the fourth regime shows, without doubt, an irreversible shift in the short run, and for the third regime, the debate is on-going as to whether or not mangrove-friendly aquaculture should be developed. To sum up, nature gives us renewable and invaluable mangrove resources, and attention should be paid to treating them with wise-use scenarios.

4.5 Conclusion

The present study highlights the alarming rate of mangrove deforestation in the Ayeyarwady Mega Delta mangroves that are threatened to disappear in the short run. This is particularly due to anthropogenic disturbances, which have cleared a large extent of the Ayeyarwady mangroves. During a two-decade period from 1990 to 2010 for the study area, the deforestation rate was 0.7 % per year and the dense mangroves are rapidly decreasing by 1.5 % per year. The study shows evidence that the recent natural impact does not affect the Ayeyarwady mangroves seriously. Instead, there was a slightly increasing trend in vegetation health indices, which is perhaps due to the temporary suspension of paddy cultivation and shrimp-farming practices shortly after the cyclone impact. In fact, it should be noted that the commercial values of timber might have been reduced, but if the ecosystem scale is considered, it may follow the disturbance theory in explaining that natural disturbance is a kind of ecosystem process. Great attention should be paid to the fact that the recent cyclone in 2008 devastated mangroves and caused a death toll of at least 134,000 people and loss of property. This deadliest impact can be assumed to be largely due to the disappearance of the bio-shield or life-protecting function of mangroves in this mega-delta region. It should be also noted that the protection of mangroves in the mega delta is of crucial importance because the bio-shield function of mangroves is the only mechanism for the security of local people in such a large area. If tsunamis and storms hit this region, there is extremely limited time and limited space to escape from the disasters, because the vast Ayeyarwady Delta is connected to countless larger and smaller river tributaries and its relief capability is also low. Therefore, it is expected that the findings in the present study will highlight the need to urgently restore and rehabilitate the mangroves in this Ayeyarwady Mega Delta based on the current disturbance regimes and the extent of their impacts.

Chapter V

Perspectives of Awareness, Attitudes and Participation of Local Stakeholders in Mangrove Restoration

Abstract

Humans play a crucial role in shaping their surrounding environment, and as such have the ability to either destroy or improve it. With positive input from local stakeholders or critical local social capital, the degraded mangroves in Myanmar can be restored, and the natural remnants of the mangroves can be sustainably conserved. Firstly, in order to observe the awareness, attitudes and participation status of local stakeholders, their geographical location inside and outside of the cyclone path, level of education, gender, and different livelihoods in restoration measures were assessed. The observed stakeholders primarily accessing mangrove resources were fishermen, farmers, casual laborers, shrimp-pond owners, salt-pan owners, and workers. It was anticipated that local stakeholders would be considerably aware of the mangroves and the surrounding environment; however, local stakeholders' participation in mangrove restoration was found to be limited. Although the awareness of mangroves by all local stakeholders has been generally concluded as being high, a slight difference was observed between the mobile and immobile stakeholders. The immobile ones had relatively higher awareness and attitudes than the mobile ones. Their participation is of critical concern to mangrove sustainability, and needs to be thoroughly evaluated and reviewed. Based on interviews with stakeholders, the limitations to their active participation in mangrove restoration processes were due to the hardship of subsistence living, the requirements for their general wellbeing, and a lack of a sense of ownership. Without immediate economic incentives or quick monetary benefits, their further exploitation of mangrove resources will not be arrested. Based on this framework, two management practice

initiatives—community-owned and privately-owned mangrove forests—might be considered opportunities for local stakeholders although they still have several drawbacks. The critical point in the present study, therefore, is that local stakeholders` participation in mangrove restoration is limited, notwithstanding the fact that they recognize the importance of the mangroves. In addition to their concerns regarding the mangroves, local knowledge of different species and their effective utilization was also identified as important. The preferences of local people with respect to species need to be incorporated into the mangrove restoration process. The development of sustainable management strategies should also include the prioritization of the subsistence requirements of local people.

Keywords: local social capital, mangrove environment, awareness, attitude, participation, local knowledge, species utilization

5.1 Introduction

Humans constantly derive benefits from the environment to provide for their needs, and the environment has essentially been used to expand our habitat and improve our quality of life. Humans cannot live just for themselves; instead, they live and support each other, and gather with other species in the ecosystem (Sudarmadi *et al.* 2001). However, they are becoming densely populated and exploit natural resources unwisely, with the net effect that they now have to confront the critical problem of environmental degradation. In recent decades, therefore, we have become increasingly conscious of issues such as famines, droughts, floods, the scarcity of fuel, firewood, and fodder, pollution of the air and water, problems of hazardous chemicals and radiation, depletion of natural resources, extinction of wildlife, and dangers to flora and fauna. As one of our major environmental concerns, mangroves are disappearing at a rate greater than or equal to the adjacent rainforests (Valiela *et al.* 2001), and their deforestation has become critical to be tackled in our time. The causes of the loss have been mainly attributed to anthropogenic activities (FAO 2007; Walters *et al.* 2008), such as conversion to agriculture, aquaculture, urban development, salt pans, transmission lines, and mining (ISME 2004). Humanity is therefore a major force in global change and shapes ecosystem dynamics ranging from local environments to the biosphere as a whole (Redman 1999; Steffen *et al.* 2004; Kirch 2005; Folke 2006).

For most of human history, the natural world has been protected from most disruptive human influences by virtue of our relatively humble technology, local laws, and cultural or religious taboos, all of which have prevented overexploitation. The loss of traditional knowledge about resource use is one of the central problems of our time (McNeely 1993). Local environmental knowledge and awareness can be a powerful mechanism in mangrove restoration and management. Restoration measures in coastal environments cannot displace the surrounding social system, and the integration of indigenous community knowledge into the restoration strategy must be taken into account. Local people retain knowledge of and understand wetland functions in their particular context in a way that is far subtler and sometimes superior to that of outside "experts," and traditional practices can be invaluable tools for mangrove management if properly handled.

Underpinning the idea of community-based resource management is the recognition that humans are part of the ecological system and not separate from it, and wetland management by local people can extend as far back as thousands of years. Nowadays, participatory management is generally defined as a partnership in which government agencies, local communities and resource users, and perhaps other stakeholders, such as NGOs, share the authority and responsibility for management of a specific area or set of resources.

People are currently expected to be aware of the need to protect natural environmental resources, which are the natural capital on which mankind depends. Local people as "critical social capital" and the mangroves as "critical natural capital" have lived side-by-side for hundreds of years. The mis-management of the mangroves, such as their conversion for other land uses, has caused the careful co-existence of these two capitals to fail. Through resourceful use, the situation can be reversed so that the present downward trend can be turned upwards again. Fortunately, unlike other ecosystems, the mangroves have, to a great extent, shown their resilience (Alongi 2002); however, their destruction would take a long time even under cryptic ecological degradation. By taking this opportunity, the restoration of the mangroves is not far beyond our capacity; however, the surrounding social systems that co-exist with them provide a challenge in meeting sustainability goals. Rapid population growth and increasing dependence on the mangroves now threatens the mangrove ecosystem, despite a long coexistence with local communities.

Based on the above backdrop, the present study aims to explore the awareness and attitudes of the local Myanmar people and their indigenous knowledge of mangrove utilization in order to fill the gaps in thinking about restoration measures. It is hypothesized that the Myanmar mangroves have been in a state of continuous decline because of local stakeholders' lack of awareness, attitudes, and participation.

The concepts of awareness and attitudes have been defined by the previous scholars as follows:

1. The awareness of environmental problems is the attention, concern, and sensitivity of the respondents to environmental problems (McHenry 1992; Soukhanov 1992). For instance, local stakeholders know about the nature of the mangroves and their life-supporting systems.
2. The attitude toward environmental problems is a set of values and feelings of concern for the environment, and the motivation for active participation in environmental improvement and protection (Dooms 1995). For instance, local stakeholders think that

the mangroves urgently need restoration.

Local people, without doubt, are of crucial importance in shaping their surroundings, and they can either destroy or create a better environment. In other words, throughout the world, people are said to be the major drivers of forest degradation and other irreversible environmental damage, whereas they can also be considered as the major drivers of restoration, reforestation, and rehabilitation of renewable resources in wise-use scenarios. In this regard, most of the local people dwelling in mangrove forests are economically marginalized and have limited education. Hence the mangroves in the mega-delta of Myanmar are subject to degradation for the time being.

The hypotheses in the present study are:

1. Is mangrove degradation due to stakeholders being unaware of mangrove conservation?
2. Do local stakeholders have an attitude that will allow them to actively participate in the remedial measures required for mangrove restoration?

These questions are critical in understanding the potential of the current mangrove restoration processes. Furthermore, an attempt is also made to recognize and assimilate the indigenous knowledge of local users with respect to mangrove utilization in order to provide useful information regarding the restoration processes of the mega delta of Myanmar.

5.2 Materials and methods

5.2.1 Study site

Communities in the two separated mangrove regions of Pyindaye Reserved Forest (R.F) and Kadonkani Reserved Forest (R.F) provided the focus of this study. They are located close to Meinmahla Kyun Wildlife Sanctuary, a totally protected area. Kadonkani R.F was in the eye of the path of Cyclone Nargis in 2008 and was severely affected, while Pyindaye R.F was outside the eye of the cyclone path and was less affected by it (Figure 5.1). Five villages in each R.F were selected for the present study. The study villages in Kadonkani R.F are Atwinmayan, Kyeinchaungkyee, Gwechaungkyee, Ngapokethin and Padegaw, while those in the Pyindaye R.F are Anaukmee, Ashaepya, Gawdu, Htaungyitan, and Thameinpale. The population of the former five villages was subject to severe devastation caused by the cyclone. Figure 5.2 shows that almost half of the population in Kadonkani mangroves was decimated by the deadly cyclone, whereas the latter five villages in Pyindaye mangroves did not undergo any change to their social structure and there was no loss of human life.

Data was generated by conducting semi-structured interviews with local respondents as well as through our field-based observations. The questions were structured in order to ascertain demographic information, awareness, attitude, and participation, as well as species preferences and utilization, as shown in Appendix V. Local stakeholders were divided into six main categories according to their livelihood patterns, i.e., fishermen, farmers, casual laborers, workers, shrimp-pond owners, and salt-pan owners. With respect to the casual laborers and workers, the former means the people who are temporarily hired by fishermen, farmers, and other business factories, and the latter is defined as the people who spend most of their time working at shrimp-pond and saltpan factories. Casual laborers are mostly mobile albeit exclusively in the mangrove environment, while workers are predominantly outsiders coming from non-mangrove areas and who can otherwise be regarded as recent migrants to the mangroves. In fact, there is no clear boundary to divide the patterns of their livelihoods, in particular for the marginalized communities. For example, a casual laborer might work at a farmer’s house during the paddy harvesting season and is likely to fish in other seasons, especially during the rainy season. Nevertheless, attempts have been made to classify these two groups based on their most commonly-applied livelihoods. In general, the workers and the shrimp pond owners represent the stakeholders coming from non-mangrove area and others have settled in mangrove area for a long time. The former group is thus referred to be "mobile communities" and the latter is "immobile communities". The surveys were conducted twice, in September 2009 and December 2010. The number of respondents representing each household was 161 in the more cyclone-affected region—Kadonkani R.F, and 156 in the less cyclone-affected area of Pyindaye R.F.

Based on our preliminary survey of the area, the local stakeholders were categorized into the six aforementioned categories. All of the groups are suggested as stakeholders since they depend mainly on the mangroves either directly or indirectly. During the first survey in 2009, draft questionnaires were prepared and tested in order to ensure consistency with local conditions. Thereafter, in the 2010 survey, the questionnaires were finalized, and the interviews were conducted again.

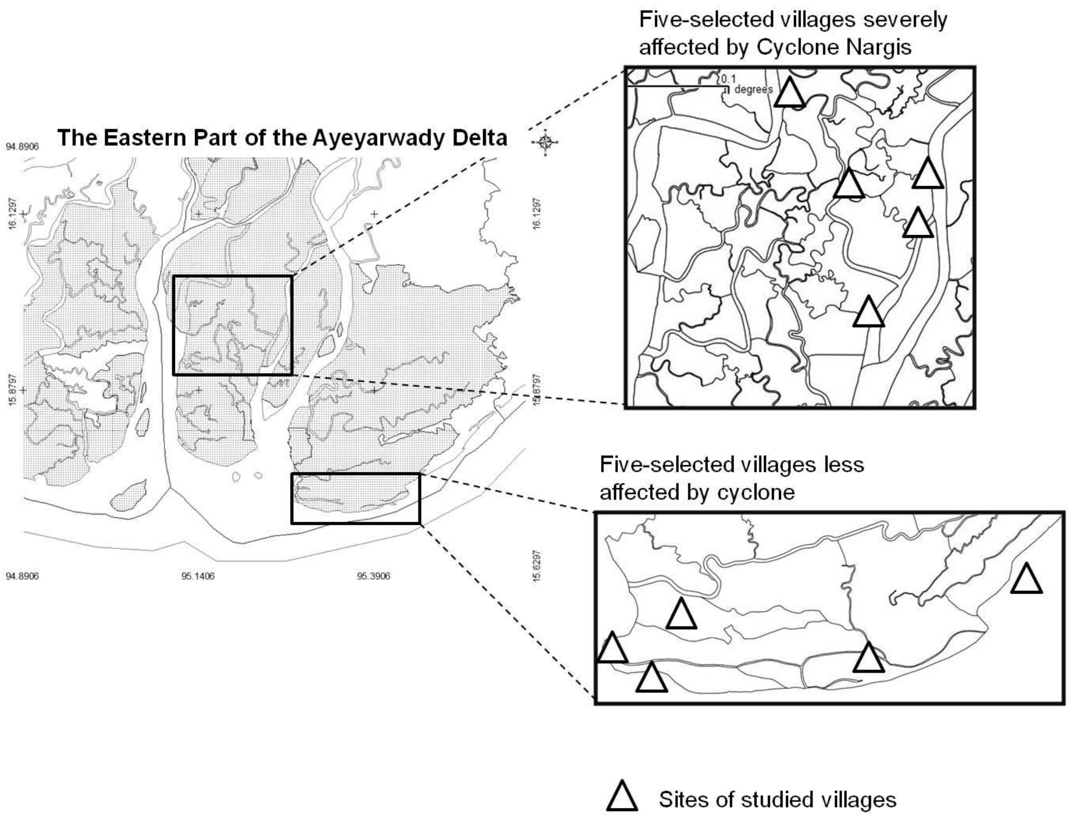


Figure 5.1 Map showing the location of the study villages in the two separate regions

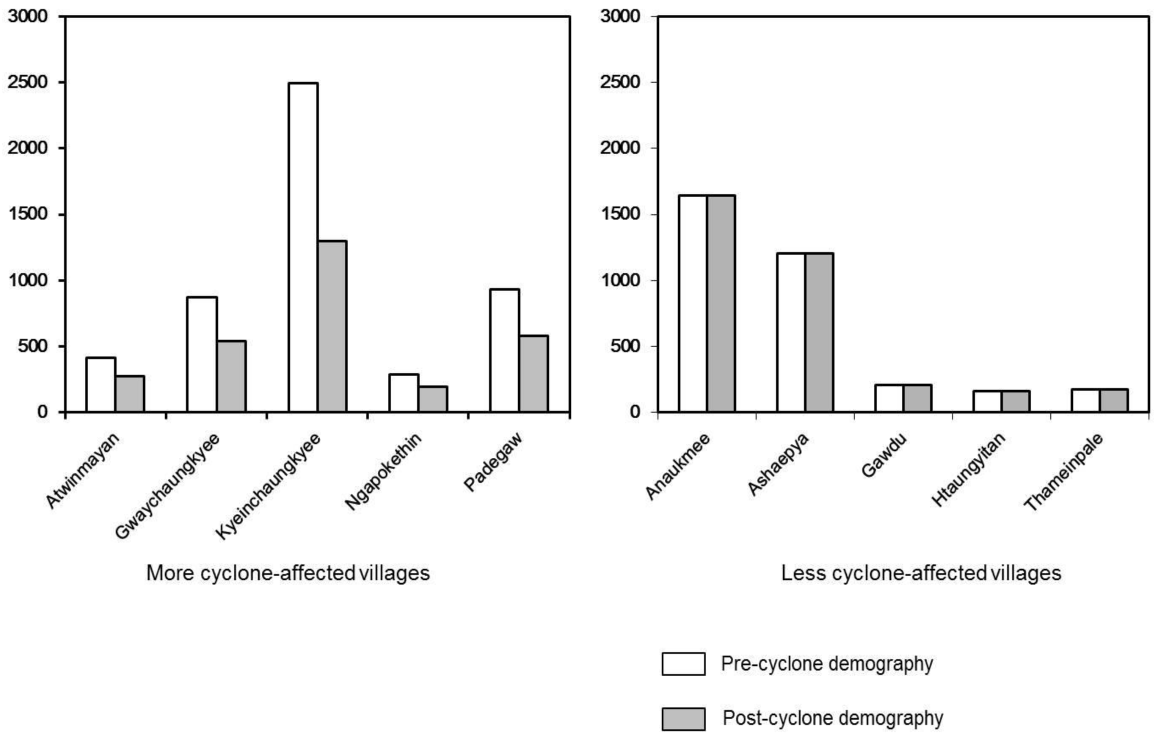


Figure 5.2 Pre-cyclone and post-cyclone population sizes of five severely cyclone-affected villages in the Kadonkani mangroves and five less cyclone-affected villages in the Pyindaye mangroves.

Most interviews were done with the help of local educated persons who were trained in advance so that more reliable information could be obtained. For instance, if local people were interviewed directly by outsiders, they were more likely to have shown hesitation in response to our questions. With the help of the trained local persons or key informants, they were more likely to answer freely. For some of the respondents, household visits were carried out in the evening following their return to the villages from fishing and farming. The method used therefore is not from absolute questionnaires, but can be participatory statistics that is an emergent field to empower local people and groups. It can also be persuasive and more credible than those from questionnaire investigations (Chambers 2007). To avoid repeated information, only the responses of one adult person per household were logged. We also recorded information regarding species-specific utilization of the mangroves and species preferences.

5.2.2 Data analysis

The analysis was carried out by dividing awareness, attitudes, current participation, and future participation prospects based on location, gender, education, and livelihood or occupation. More than one question, as shown in the questionnaire, was used to cross-check the awareness and attitudes of the respondents. Although some questions required just a “yes” or “no” answer, the recorded answer was made based on the adjustment of talk between the interviewer and interviewee in order to obtain a real sense of the respondent’s reaction. It should be noted that the questions under each category were correspondingly described as “observations” in analysis, that is, observation means question.

The analysis was determined with the chi-squared test (X^2) using SPSS software version 16.0 to ascertain significant differences ($p < 0.05$) in the awareness and attitude of local respondents. A principle component analysis (PCA) was performed to assess the patterns of species utilization based on indigenous knowledge, which has been retained throughout the people’s long-term settlement in the mangrove environment. In this regard, it should be noted that the data on mangrove utilization was not available from all respondents since most respondents only knew about the genus level, and their responses on species level was limited. In such cases, the recording of species-specific names did rely on the interpretation of local informants.

5.3 Results

5.3.1 Overall responses

Figure 5.3 shows that most of the local respondents were highly aware of the mangroves and its relationship with environment, such as its life-protecting function against storms and its life-supporting one as a nursery ground. Observation III (AW3) was a question regarding the mangroves as a nursery ground, and Observation IV (AW4) concerned the erosion-protective function of the mangroves. Awareness in (AW3) and (AW4) was slightly lower compared to other cases (see detailed questionnaires in Appendix V). These two questions may need much more in-depth knowledge compared to the others. Collectively considered through all five observations, the majority of local respondents had considerable awareness of the mangrove environment. In terms of their attitudes, more than 90% of respondents agreed that the mangroves need to be conserved. However, in the second counter-check question about their original sense of thinking on whether or not the mangroves are important in terms of conservation and management, their responses were considerably different from the first observation on attitudes. Further tests were conducted for all observations to determine their differences according to the extent of cyclone impact, level of education, gender, and livelihoods in the following section (5.3.2).

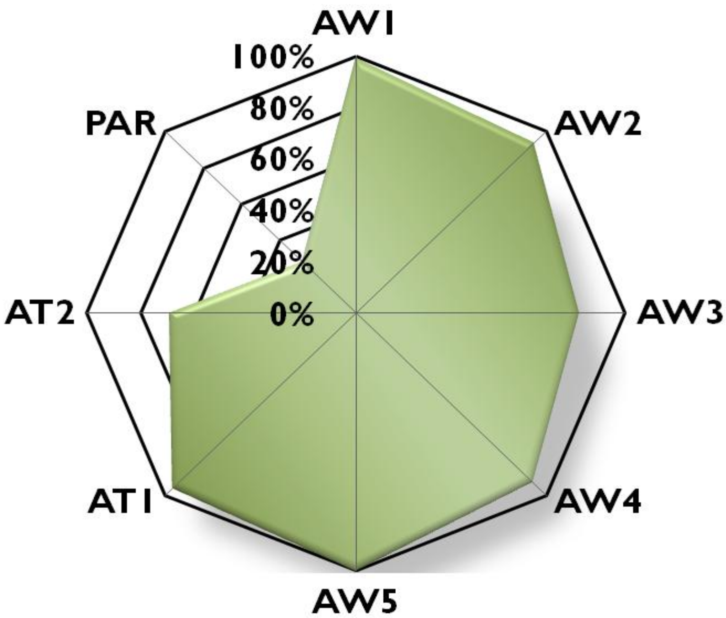


Figure 5.3 Amoeba diagram of awareness, attitudes, and participation: AW represents awareness, AT represents attitudes, and PAR represents participation in mangrove conservation and restoration activities. The numbers represent the observations (See in the Table 5.1 to 5.3).

5.3.2 Specific responses by cyclone impact, education, gender, and livelihood

Table 5.1 details the slightly significant differences between the two regions with their different cyclone impact extents for the second observation of awareness and the first observation of attitudes, but no significant differences for gender. Table 5.2 shows awareness and attitudes according to the levels of education of the local stakeholders divided into three categories, i.e., low, medium, and high. Low represents the individuals who completed their education at primary level or at a monastery; medium represents those who completed middle school; and high represents those who completed high school and/or some level of university education. No significant differences according to their different levels of education were shown in any of the tests.

Interesting results were derived from the observations of awareness and attitudes with the patterns of livelihood of local respondents, shown in Table 5.3. Two observations on awareness are highly significant among the different livelihoods, and after excluding workers, a null hypothesis was accepted. Therefore, the workers, i.e., the outsiders or recently migrant people to the mangrove area, had the most limited awareness of the mangrove environment. In terms of attitudes as well, highly significant values were found among different livelihood patterns of people. These significant differences in p-values can be reduced by first excluding shrimp-pond owners. The extent of the differences can be seen clearly, particularly for shrimp-pond owners. Although the first observation shows high significance in terms of attitudes, the second observation was found to be considerably different, with considerably low significance in attitudes. The number of "limited" attitudes of shrimp-pond owners was far more than that of "yes" attitudes in response to questions about the importance of the mangroves. It was evident that shrimp-pond owners had a limited willingness to show the importance of mangrove conservation. Overall, despite the fact that there showed considerable awareness and attitudes of mangroves by all local stakeholders, there was a slightly difference occurred between the mobile communities and the immobile or settled ones.

Table 5.1 Comparison of awareness and attitudes by site and gender differences

	Extent of Cyclone Impact					Gender Difference				
	Low		High			Male		Female		
Awareness	Yes	Limited	Yes	Limited	p-value	Yes	Limited	Yes	Limited	p-value
Observation I	150	6	160	1	**0.0508***	247	5	61	0	0.2674
Observation II	135	13	150	3	**0.0083***	234	10	58	5	0.2078
Observation III	125	28	135	26	0.6136	208	41	51	12	0.6257
Observation IV	143	11	148	12	0.9025	234	15	56	7	0.1589
Observation V	152	2	160	1	0.536	252	2	62	1	0.557
Attitude	Yes	Limited	Yes	Limited		Yes	Limited	Yes	Limited	
Observation I	141	8	159	1	**0.013***	240	8	58	1	0.5307
Observation II	98	55	118	41	0.536	170	78	44	18	0.7123

Table 5.2 Comparison of awareness and attitudes by education level

	Level of Education						
	Low		Medium		High		
Awareness	Yes	Limited	Yes	Limited	Yes	Limited	p-value
Observation I	188	4	58	0	64	1	0.53
Observation II	178	9	56	2	59	5	0.5197
Observation III	157	35	51	6	52	13	0.3193
Observation IV	179	12	54	4	58	7	0.4826
Observation V	192	2	57	1	65	0	0.6035
Attitude	Present	Limited	Present	Limited	Present	Limited	p-value
Observation I	182	8	55	1	62	0	0.1986
Observation II	129	62	39	18	48	16	0.5289

Table 5.3 Comparison of awareness and attitudes in terms of different patterns of livelihood.

	Patterns of Livelihood												
	Farmers		Fishermen		Casual laborers		Workers		Shimp-pond owners		Salt-pan owners		
Awareness	Yes	Limited	Yes	Limited	Yes	Limited	Yes	Limited	Yes	Limited	Yes	Limited	p-value
Observation I	83	1	61	4	79	5	20	7	24	2	26	0	**0.0002***
Observation II	84	0	65	0	85	1	24	4	26	0	26	0	**0.0000***
Observation III	67	16	54	11	75	12	20	8	18	7	26	0	0.0523
Observation IV	78	6	60	5	81	5	22	6	24	1	26	0	0.0519
Observation V	84	0	65	0	86	1	28	1	25	1	26	0	0.3083
Attitude	Yes	Limited	Yes	Limited	Yes	Limited	Yes	Limited	Yes	Limited	Yes	Limited	
Observation I	83	0	64	0	83	3	23	3	25	1	22	2	**0.016***
Observation II	56	27	38	27	73	13	21	6	7	18	21	5	**0.0000***

Note: The significant differences (* $p < 0.05$) in awareness and attitudes are represented in bold. Variations in response rates are the result of missing answers or missing information in the answer sheets.

5.3.3 Levels of participation in restoration

As shown in Figure 5.4, unlike awareness and attitudes, no group of local respondents showed more than a 50% level of participation in restoration. Among different patterns of livelihood, the highest participation in community-based mangrove restoration was found farmers and shrimp-ponds owners, followed by casual laborers and fishermen. This was followed by a very limited number of workers and salt-pan owners who take part in restoration activities, possibly since their livelihoods are less directly dependent on the mangroves compared to the other groups.

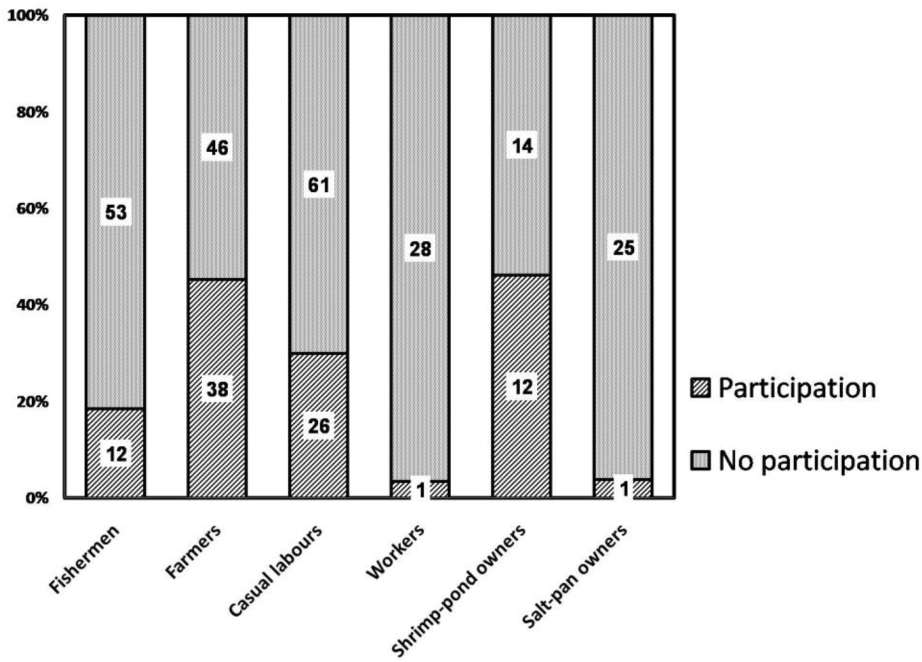


Figure 5.4 Proportion of participation by different stakeholders

5.3.4 Indigenous knowledge of utilization of mangrove species

Most of the local people have been settled in the mangrove environment for a long time so they play a major role in mangrove restoration, though data to the detailed period of their settlement is necessary to be presented here. More importantly, their indigenous knowledge, derived from living in the mangroves and experiencing the mangrove environment over a set of decades, should be considered invaluable tools for mangrove conservation and restoration if the mangrove environment is regarded as a single unit of the socio-ecological system. Based on the principal component analysis (PCA) results, there is a clear partition of three purposes, which are divisible according to local people's preferences for different species. These three categories are environmental protection, household utilization, and ornamental purposes.

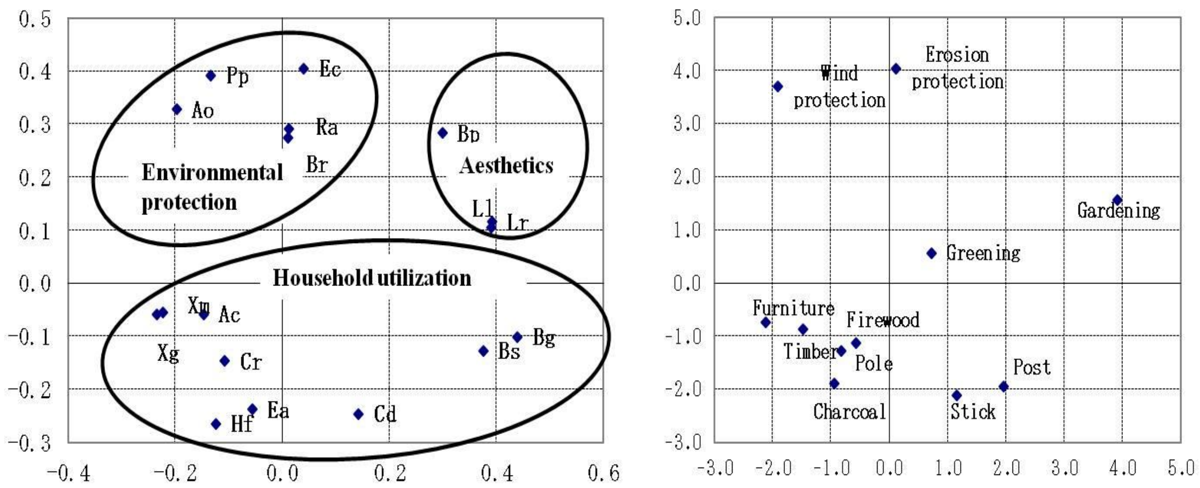


Figure 5.5 Indigenous knowledge of local people with respect to mangrove utilization

The results analyzed by PCA in Figure 5.5 show that the species collectively considered appropriate for environmental conservation in terms of wind protection and erosion control were *Avicennia officinalis* L. (also *Avicennia marina*), *Pongamia pinnata* (L.) Pierre, *Eucalytus camadulensis* Dehnh., *Rhizophora apiculata* BL., *Barringtonia racemosa* L., while those appropriate for household utilization were *Heritiera fomes* Buch.-Ham., *Excoecaria agallocha* L., *Ceriops decandra* (Griff.) Ding Hou, *Bruguiera gymnorrhiza* (L.) Lamk., *Bruguiera sexangula* (Lour.) Poir., *Cymnometra ramiflora* L., *Xylocarpus granatum* König, *Xylocarpus moluccensis* (Lamk.) Roem., and *Amoora cuculata* Roxb. Those considered appropriate for aesthetic purposes or gardening were *Lumnitzera racemosa* Willd., *Lumnitzera littoralis* (Jack) Voigt., and *Bruguiera parviflora* Wight & Arnold ex Griffith. It should be noted that it was considered to have recorded possible mistakes between *Avicennia officinalis* with *Avicennia marina*, *Rhizophora apiculata* with *Rhizophora mucronata*, and *Bruguiera gymnorrhiza* with *Bruguiera sexangula*. The reason is that most of the local respondents merely knew the genus level of these species, and species-level knowledge was limited. Nevertheless, it was adjusted based on the knowledge of the local informants as much as possible.

5.4 Discussion

5.4.1 Awareness, attitudes, and participation

Cornwall (2008) investigated that, in environmental awareness, there are significant differences in occupation, location, land tenure status, sex, caste, religion, or tribe, although they are related in different ways. However, the present study of location, education, gender, and occupation was not considerably significant. Only slight differences were found. It was hypothesized that the mangroves in the mega-delta region have been continuously decreasing because one of the factors is local people’s lack of awareness about the mangroves. This assumption is rejected in the present study- the majority of people living in the mangrove environment illustrated an appreciable level of knowledge and awareness about the mangroves. In this regard, McNeely (1993) also states that, for most of human history, the natural world has been protected from the most disruptive human influences through relatively humble technology, local laws, and cultural or religious taboos that have prevented overexploitation. In addition, local people often have an understanding of wetland ecology. Over two decades ago, a number of mangrove restoration and rehabilitation projects were implemented with the financial support of government agencies, UN-related organizations, NGOs, and INGOs. During these restoration measures, there have also been awareness raising campaigns through talks, calendars, posters, pamphlets, and other kinds of tools. These could collectively account for one of the possible reasons that the majority of local stakeholders were considerably aware of the mangroves and their importance. Beyond this, their own experience of the dramatic decline in the number of fish available to catch and the limited availability of fuel wood to meet their subsistence needs could have made them realize the value of the mangrove ecosystem. Most importantly, in 2008, their personal experience of Cyclone Nargis, and the concomitant loss of human life and property was unforgettable. It is, therefore, not surprising that the majority of local respondents were aware of the crucial importance of the mangroves in terms of their life-supporting and life-protecting functions. However, in the present study, the key finding pertained to the recent migrants and remote resource users, that is, the mobile people, in particular workers and shrimp pond owners were less awareness and attitudes compared to the immobile ones who have settled in the mangroves since at least a decade.

In terms of the workers, they seemed to be slightly less aware of the importance of the mangroves when compared to other local respondents. This community group, which comprised mostly recent migrants, relies partially on the mangroves because, although most of them are not direct mangrove cutters, they do use the mangroves for fuel and construction materials. The second community group that showed limited attitudes compared to the other groups was the businessmen who operate shrimp farming. Some of them were reluctant to accept the importance of the mangroves as it was their perception that mangrove restoration and conservation would affect negatively their business. Mangrove habitats need to be cleared for the establishment of shrimp ponds, and the businessmen claimed that the shade of the mangrove canopy causes a decline in the shrimp production rate as well as a reduction in the size of tiger prawn (*Penaeus monodon*). This is a direct conclusion derived from their experience. This fact should not be supposed as a hindrance in mangrove restoration measures. The critical point here is how to draw up a strategic management plan that integrates both social and ecological needs of all relevant stakeholders.

Overall, people relying on mangrove resources have fairly sufficient awareness and attitudes to implement mangrove restoration. A big challenge is their limited participation. As shown in the Figure 5.4, the highest percentage of participation in community-based forest management was observed among farmers and shrimp-pond owners. Barbier *et al.* (2004) tested the hypothesis that the degree of mangrove dependency was a major causative factor in the active participation of households. This correlates with the present study since most of the farmers traditionally own land inside the mangrove R.Fs, and the farmers' livelihoods are much more stable compared to other stakeholders as a result of having been settled in the study area for a few decades. Their livelihoods also depend primarily on the mangroves. Therefore this stable community is more likely to participate in the community-based restoration processes. Another supporting factor is that they may have a sense of ownership and they receive tangible benefits from their restoration activities.

In the case of the shrimp-pond owners, they have converted a large extent of the mangrove areas in order to conduct extensive shrimp farming. Their participation is relatively high even though their attitudes toward mangrove restoration were shown to be relatively low compared to others. It can be surmised that theirs is passive participation because they have been forced by local organizations to compensate for their illegal or irresponsible activities. Some local respondents, including these shrimp-pond owners, are more or less mobile communities, and they believe that the benefits from the resources produced from the restored mangroves are not beneficial to them as they often move from one place to another. With respect to the responses of local stakeholders, some are shown in Box 1 below, indicating that if restored mangroves were privately owned, the local stakeholders would have a greater desire to participate in restoration measures. It is critically important to understand that these mobile stakeholders are increasingly exploiting mangrove resources, but their participation in mangrove restoration is limited. In Figure 5.6, an attempt is made to ascertain the conceptual trends of mangrove utilization and restoration that are theoretically necessary for their sustainability.

Box .1. Concluded answers of respondents with respect to questions about their restoration participation motivations and limitations

Motivations	Limitations
• "If we plant mangroves, we can get shelter from storms in future." • "Planting mangroves can regulate the climate again." • "If the extent of mangroves increases again, fish, shrimp, and crabs will flourish once more." • "I would like to secure fuel wood and plants for household use in the future, so I want to plant mangroves." • "Under tree shelter, we have better lives." • "I do not want there to be scarcity of fuel wood, I want to plant mangroves." • "We want large adult trees to protect our lives from storms." • "It is our experience that, if we plant mangroves, they save our lives." • "(I want it) to be green again the same as before." • "We have to participate because we are asked to do it by organizations."	• "I have to struggle for my family's livelihood daily—if there is no income today, there is no food for tomorrow." • "Time is too limited to participate in planting because I have to go fishing." • "Not enough people at home to participate in restoration." • "That is not private(ly owned)." • "Only if I can get that land privately, then I will protect it." • "Too busy doing my own business of fishing and farming." • "I am too busy with my shrimp pond business." • "I am not a man, just a lady, so it's difficult to take part." • "(There is) no household leader at home." • "I am not quite healthy (enough) to participate in planting activities." • "I am getting old."

In the first conceptual graph of Figure 5.6, if the population—especially migrants and mobile communities—increases, then the number of potential users of the mangroves will increase. Unfortunately however, there is little chance that they will take part in community-based mangrove management measures because they move from one place to another on a regular basis. If the fate of the current mangrove downturn is to be reversed, their exploitation must be reduced and the participation of the migrants and mobile communities is much more necessary. However, in reality, the second conceptual graph shows that there is little possibility of this happening, and the third one is even more pragmatic. If migrant and mobile communities are allowed to use the mangroves to an acceptable extent under wise-use scenarios that include their participation in restoration activities, the fate of the mangroves can be reversed.

In the developing world, that people have access to natural resources is unavoidable, but how to tackle overexploitation requires a strategic plan. As mentioned above, local respondents have suffered a shortage of resources, and experienced a deadly cyclone in which even family members disappeared. These experiences have encouraged them to actively participate in mangrove restoration. The present study also demonstrated that there is a slight difference in awareness and attitudes between highly-affected and less-affected mangrove groups. Relatively speaking, the people who suffered the most from the cyclone showed a much greater willingness to conserve and restore the mangroves to order to ensure their security from future storms. They have realized that the mangroves provide a life-protecting function during a cyclone. Most of the interviewed respondents stated that they would go to the nearby *Avicennia officinalis* plantations to climb up the mangroves, thereby avoiding floods during future storms.

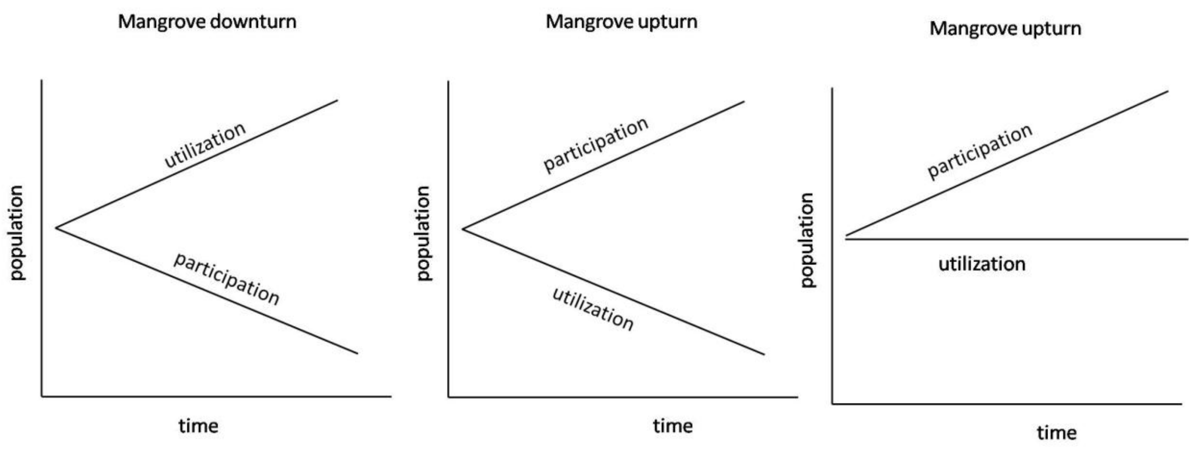


Figure 5.6 Conceptual trends of the relationship between the three primary factors that is important for the fate of the mangroves

Based on the limitations shared in Box 1, the majority of local stakeholders face daily hardship in that, if they don't work today, e.g., are unable to go fishing, their livelihood tomorrow will be a challenge. They also want to privately restore the mangroves instead of working on public or commonly-owned land. Although the community forestry program initiated in 1995 included a 30-year land-use lease, the respondents appear not to have sufficient trust in the policy. One clear lesson learned to date is that, unless a relationship of trust is established and maintained between communities and government agencies, it is unlikely that even the simplest co-management regime can survive. Unfortunately, in the majority of situations where communities have a subsistence relationship with resources, their level of trust in government agencies is extremely low or even non-existent, and long periods of dialogue and shared learning are needed to build the trust required for co-management to work (Claridge & O'Callaghan 1997). According to Addun & Muzones (1997), there are five basic principles that are required for community-based resource management:

1. Empowerment: The actual transfer of economic and political power from the few to the

impoverished many, and the implementation of sustained community management and control.

2. Equity: Benefit for the community as a whole, rather than a few individuals.
3. Sustainability: Inter-generational equity, based on the capacity of the ecosystem to carry and assimilate.
4. Systems orientation: The community functions in the context of other communities and stakeholders, just as resources are ecologically linked to wider ecosystems.
5. Gender fairness: Women are involved in the control and management of community resources, and their practical and strategic needs are addressed.

The degree of community participation in the wise use of wetlands varies depending on the local context: from high levels of empowerment, to effective partnerships between government authorities and local communities, to situations where government remains firmly in control and stakeholders are consulted on decisions. Similarly, the study of Thomason (2006) also reports that local people fully recognize the important role played by the mangroves in their local economies. Furthermore, in that study, the voice of the local people was stated in parentheses as “mangrove is the most important thing for us,” “if we don`t have mangrove we will not eat, we will not live,” and “if mangroves disappear, we will all be finished, mangrove is our life, our source of work.”

5.4.2 Potential of economic incentives

As mentioned above, local people are highly aware of the mangroves and their life-supporting system, and they believe that the disappearance of the mangroves will inevitably lead to the disappearance of their communities. However, the present study highlights the fact that, although they are aware of the mangroves, their participation is limited. The limitations to their participation in restoration activities are shown above through the voices of the respondents. Based on their views and the judgment of regional experts, community participation plays a crucial role in mangrove restoration, and existing policy should be revised based on the lessons learnt in the past. In Myanmar, community forestry (CF) has existed since 1995 and private forestry initiatives commenced in 2008, both in order to achieve sustainable mangrove management through the participation of local stakeholders. Under the former CF program, the Forest Department has been instrumental in the introduction of CF in degraded areas with the primary objectives of afforestation and meeting local demand for forest products (Lin 2005). Although there is still limited information about private forestry, the strengths and weaknesses of CF were thoroughly reviewed by Tint *et al.* (2011), and some of the recommended reform initiatives include a legal framework to ensure land tenure, the market-orientation of CF, the idea that food availability and income must be realized as early as possible and on a continuous basis, and so on. Some of these points are in line with the comments in Box 1.

In terms of economic benefits, some successful community plantations have provided the following, based on our discussions with the CF owners of a 30-year lease:

1. Previously, their wood consumption for fuel mostly came from local markets, but it can now be replaced with products from their own CF plantations.
2. Rice cultivation can be included in the initial stage of mangrove plantation establishment.
3. Construction materials for domestic utilization can also be harvested from their established mangrove plantations.

Although these opportunities partially provide subsistence needs for local people, there are still limited economic incentives that address their welfare needs, such as access to education and medical facilities. The financial benefits of *Avicennia officinalis* (known locally as Thame) plantations under the CF program have been evaluated by Tint *et al.* (2011). It is shown in Figure 5.7 that an investment in one acre of a CF plantation have started to produce an interest only after the sixth year. Then, in the 10th year, the net cash flow equates to approximately US$ 200 a year. For a family who has rights to a six-acre lease, the net benefits can be more or less US$ 90 ~ 100 per month for a 10-year period. Otherwise, since the 9th year, average cash income are estimated US$ 40 ~ 50 per month. This return is considerably too slow and may be sufficient for the subsistence needs of a three- to five-member family, but far insufficient for their well-being such as access to education and health facilities. Moreover, even such an evaluation on monetary values might have been based on successful plantations. In reality, at the beginning of plantation establishment, there is obviously uncertainty about whether or not the plantation will be successful, meaning that the actual investment may be more costly than what is initially anticipated at the outset.

In addition to these challenges, ownership of the 30-year CF lease is not guaranteed due to the complicated politico-economic situation. Therefore, the property rights in this CF program should be revised with respect to the bundles of property rights, that is, access and withdrawal, management, and exclusion and alienation (Schlager & Ostrom 1992). It was also indicated that alienation right together with exclusion right, produce incentives for owners to undertake long-term investments, but unfortunately ownership may not guarantee the long-term survival of mangroves. Based on past experience, the failure and/or success of the CF program requires a policy reform in favor of local social capital in order to meet the mangrove sustainability objectives. Recent years, there has been a growing interest on these local stakeholders as the term social capital. As this social capital lowers the costs of working together, it facilitates cooperation (Pretty & Smith 2004). In parallel with mitigating a set of global problems such as deforestation, climate change, and sea level rise, the livelihoods of socio-economic status of the marginalized communities can be improved. A number of evidence has increasingly proved that these well-organized and well-connected social capitals have higher incomes (Krishna 2002), and much healthier lives, more achievements in education, and increase in longevity (Fukuyama 2000). Even trust between government and communities has been improved (Putnam 2000), and this social capital is not just the sum of the institutions which underpin a society—it is the glue that holds them together.” (Farley & Costanza 2002).

Years	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	TOTAL TO DATE
Benefits (K)	0	0	0	0	0	0	17,430	19,920	86,990	86,500	210,840
Costs (K)	29,650	3,970	2,570	1,000	1,000	1,000	1,000	1,000	1,000	1,000	43,190
Net cash flow (K)	-29,650	-3,970	-2,570	-1,000	-1,000	-1,000	16,430	18,920	85,990	85,500	167,650

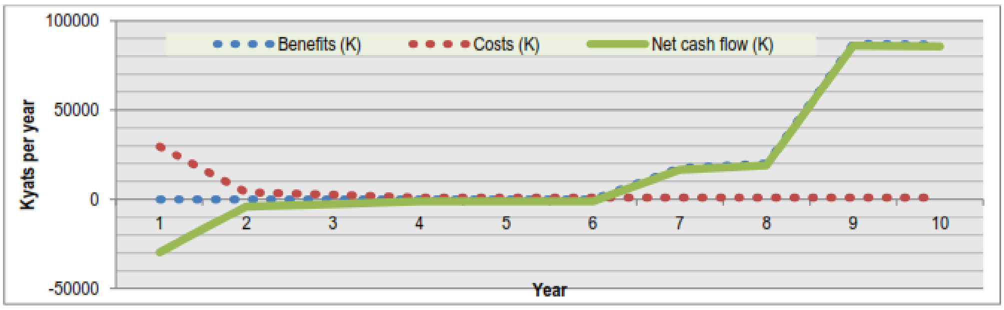


Figure 5.7 Costs, benefits, net cash flow of a one-acre plantation (kyat/year); US$ 1 is approximately equal to 850 ~ 900 Myanmar Kyat MMK (Adapted from Tint *et al.* 2011)

It should be also noted at this juncture that, if the polluters are permitted to purchase these biomasses from the community and private forestry programs, both sides will be able to share the economic benefits, and with the resultant reduction in CO_2 emissions, ecological benefits for society at large can similarly be met. In this regard, such as Reducing Emissions from Deforestation and forest Degradation (REDD-plus) and Clean Development Mechanisms (CDM), to what extent can these global mechanisms become a reality for the pro-poor measures? If this can be put into practice, the CF users can have great opportunities to benefit from their carbon sequestration measures. And would they then not be highly motivated to participate actively in mangrove sustainability given the satisfactory economic incentives for their efforts? It is an opinion that this would result in a win-win scenario for all concerned parties.

5.4.3 Species preferences

The loss of traditional knowledge regarding effective resource use is one of the central problems of our times. Thus, in order to retain important information pertaining to mangrove species, the practical uses of the different mangroves species preferred by local people in both study sites were investigated. These traditional uses and practices can be invaluable tools for mangrove restoration and management if the mangroves are considered to be part of a socio-ecological unit. Attention should also be paid to the needs of the local respondents who represent critical social capital in the mangrove environment. For instance, most of the local respondents prefer *Avicennia officinalis* over other species for construction materials, fishing tools, and fuel for daily use. They can also get a quick return-on-investment from this species if it is planted in their community-based management forests. Similarly, other species also their own specific uses. However, traditional utilization of the mangroves does not necessarily translate into environmentally sustainable practices, and assessments need to be done in light of the increasingly densely populated circumstances and the simultaneous pressures on the resource. Likewise, local knowledge of the mangroves may need to be reviewed within the context of scientific understanding rather than simply extracting local knowledge for the benefit of wetlands science. Therefore, the traditional use of the mangroves by local people should be part of the management plan so that their subsistence needs can be satisfied with locally available materials. Dahdouh-Guebas & Koedam (2008) have highlighted that the livelihood of local communities is threatened by rapid population growth and the subsequent increased utilization of mangrove habitats. Although a number of ecological problems have been reported about *E. camadulensis*, the preferences of local people here included this species. Olowolafe & Alexander (2007) indicate that the lower pH induced by the allelopathic effects of *Eucalyptus* has led to higher aluminium saturation of the soil. The long-term effects of aluminium toxicity can be dangerous for the environment. This may show the fact that local preferences and knowledge alone are not necessarily reliable, and scientific-based information is also important by considering the local knowledge. As a result, sustainable management policies that incorporate the subsistence requirements of the local people must be developed as a high priority.

5.5 Conclusion

The present study first attempted to hypothesize that local people have limited awareness and attitudes with respect to the mangrove environment, and hence they did not actively participate in restoration processes. Indeed, we sought to establish that this factor was one of many reasons that caused the degradation of the mangroves.

These hypotheses are rejected in the present study as it was demonstrated that most of the local stakeholders have fairly sufficient awareness and attitudes to enable active participation in mangrove restoration although there are slightly differences between the different stakeholders. In particular, poorer attitudes were observed in some mobile communities compared to the stable or immobile communities. This slight difference may not be an issue, and the key point is that restoration strategy through the participation of all local stakeholders is needed in order to restore, reforest, and rehabilitate the mangroves. However, local participation in restoration measures is still limited. In developing a management strategy, participatory management should be incorporated by prioritizing the subsistence needs of the local people. In addition to assessing the status of local participation in the restoration process, the indigenous knowledge of the local people with respect to species utilization was also recognized in this study, and species preferences were also considered with regard to mangrove restoration measures. More research is recommended in order to highlight the specific requirements that will result in the active participation of the local communities—migrant, mobile, and stable—in the mangrove restoration process. All in all, it is necessary to consider and prioritize local and regional backgrounds while also balancing social and ecological needs.

Chapter VI

Assessing the Status of Three Mangrove Species Restored by the Local Community in the Cyclone-affected Area of the Ayeyarwady Mega Delta, Myanmar

Abstract

This paper assesses the extent of success and failure of mangrove plantations in Myanmar, restored by local people with the help of foresters under a community forestry program initiated in 1995. The species of these restored plantations are *Avicennia officinalis*, *Avicennia marina* and *Heritiera fomes,* each of which was restored on two plots, one on low and one on high ground, yielding a total of six plots. These plots have been continuously monitored in order to investigate survival and growth rates. The plots were established on abandoned land that had been previously used for paddy cultivation. Cyclone Nargis hit these plantations during the monitoring period, at the beginning of May, 2008. As a consequence, the survival rates of *A. officinalis* on low ground and *A. marina* on high ground declined slightly, but the overall affect was not severe. Excluding individuals affected by the cyclone, height and diameter growth of *A. officinalis* and *A. marina* were significantly higher on low ground than on high ground, i.e. on sites thought to be consistently similar to the natural habitats of these species. Contrary to these two *Avicennia* species, the height growth of *H. fomes* was higher on high ground than on low ground; the diameter growth was not significantly different. As the growth of *H. fomes* was very slow, however, it is still not possible to describe the differences clearly. This study may provide useful guidelines for foresters and local people to establish successful mangrove restorations and to predict

production from community-owned mangrove forests.

Key words: Restoration, *Avicennia officinalis*, *Avicennia marina*, *Heritiera fomes*, Ayeyarwady Delta, Cyclone

6.1 Introduction

Mangroves are a valuable economic resource, serving as important breeding grounds and nursery sites for birds, fish, crustaceans, amphibians, shellfish, reptiles, and mammals; a potentially renewable resource of wood; and accumulation sites for sediment, carbon, contaminants, and nutrients (Alongi 2009). Mangroves also offer some protection against coastal erosion and catastrophic events, such as tsunami. The average monetary value of mangroves has been estimated at $ 10,000 US ha−1 year−1 (Costanza *et al.* 1997). In recent decades, scientific concern has begun to focus on the unprecedented loss of naturally occurring mangrove ecosystems around the world, leading to the realistic prospect of a world without mangroves (Duke *et al.* 2007). Rehabilitation and sustainable utilization of mangrove resources have thus become an international conservation priority (Kairo *et al.* 2008).

Mangrove ecosystems, especially in developing countries, play a key role in human sustainability and livelihoods (Alongi 2002), being heavily used traditionally for food, timber, fuel, and medicine (Saenger 2002). Nowadays, however, these invaluable mangroves are disappearing at an increasing rate. Mangrove areas decreased from 18.8 million hectares in 1980 to 15.2 million hectares in 2005, due to various biotic and abiotic disturbances (FAO 2007), which represents one of the highest rates of degradation of any major habitat type, exceeding 1% of mangrove area per year (Valiela *et al.* 2001). To mitigate or reverse this extremely vulnerable situation, there is a need for immediate, massive mangrove replanting (Primavera *et al.* 2008). Kairo *et al.* (2008) have stated that conservation alone is not enough to reverse this degradation and that concerted efforts must be made to reforest degraded mangrove areas in order to achieve the objectives of sustainable forest management. The Sundarbans (Bangladesh and India), Mekong River Delta (Vietnam), and Ayeyarwady Delta (Myanmar) are examples of major wetland complexes where the effects of climate change are evolving in different ways. Successful long-term restoration and management of these ecosystems will hinge on how we choose to respond to the effects of climate change (Erwin 2009).

In Myanmar, mangroves in the Ayeyarwady Delta are also threatened, and government and non-governmental organizations have been taking counter-measures to mitigate mangrove degradation, caused by natural stressors (e.g cyclones) with the superimposed effects of other recurrent anthropogenic disturbances. The main historical causes of mangrove degradation in the study region were allocation to human settlement in the 1960s, allocation to paddy cultivation in the 1970s, over-exploitation for charcoal and fuel wood, and continuous migration of people from other parts of the country into the mangrove forests (Maung 2005). As a consequence, only the non-wood forest products such as *Nipa fruticans* Wurmb. and *Phoenix paludosa* Roxb are provided for local people nowadays. In this regard, the community forestry (CF) program initiated by the Forest Department in 1995, under the Ministry of Forestry, appears to be an innovative measure. The purposes of this program are regaining environmental stability and addressing the basic needs of local communities by planting trees in barren lands and to reforest degraded areas (Maung 2004). Elsewhere in the world, many initiatives have been undertaken to reforest degraded sites in response to widespread global degradation of mangrove forests (Bosire *et al.* 2008).

The research plots in the present study may be useful as lessons for community-based forest management, as these plots are owned and managed by local communities themselves, called user groups. Thus, the assumption that people are always destroyers of mangroves has been challenged by the discovery of cases in which local people are actively planting and managing mangrove and nipa-palm forests entirely on their own initiative (Yao & Nanagas 1984; Cabahug *et al.* 1986; Fong 1992; Weinstock 1994; Walters 2000). However, these community plantations for mangrove restoration met with mixed results; some were successful, based on well-understood ecological principles and well-defined aims, but others were not. Some previous literature reported that most available information on reforestation projects deals with species of the genus *Rhizophora* and other *Rhizophoraceae* (FAO 1985; Jin-Eong 1995; Field 1996; Komiyama *et al.* 1996). Thus, effective rehabilitation with other mangrove species is especially difficult, because planting guidelines are incomplete (Elster 2000).

The case of the Ayeyarwady Delta mangroves is similar as there has still been very limited research not only on restoration measures, but also on various aspects of existing mangrove forests in the region. Hence, we have been monitoring these community plantations continuously, as research plots, since their establishment. For this paper in particular, data from 2007 to the present were analyzed to assess the effects of natural disturbance, especially by Cyclone Nargis, which struck the study area on the 2nd and 3rd of May, 2008. This study examines the survival and growth rate of three dominant mangrove species after the abiotic impact.

6.2 Materials and methods

The study plots were established between 1999 and 2002 in the Pyindaye Reserved Forest in the eastern part of the Ayeyarwady Delta, which is located between latitudes 15º 42′ and 16º 3′ north and longitudes 95º 16′ and 96º 41′ east, surrounded by the Myanmar Sea and the Bay of Bengal to the south and south-west (Figure 6.1). The research plots in the present study were established on abandoned land that had been cleared of mangroves and used for paddy cultivation since 1970 (Maung 2005) in Pyindaye mangroves. This study focuses on three species, *Avicennia officinalis* L., *Heritiera fomes* (Lour.) Poir. and *A. marina* (Forssk.) Vierh. The first two species have wide ecological amplitudes in this area (Aung *et al.* 2004, Than *et al.* 2006) and seem to have a high potential for successful plantation as well as quick return to people in the form of poles, post and fuel wood, and high quality timber from *H. fomes*. *A. marina*, on the other hand, has narrower an ecological amplitude, but local people prefer it for use as poles for their construction materials.

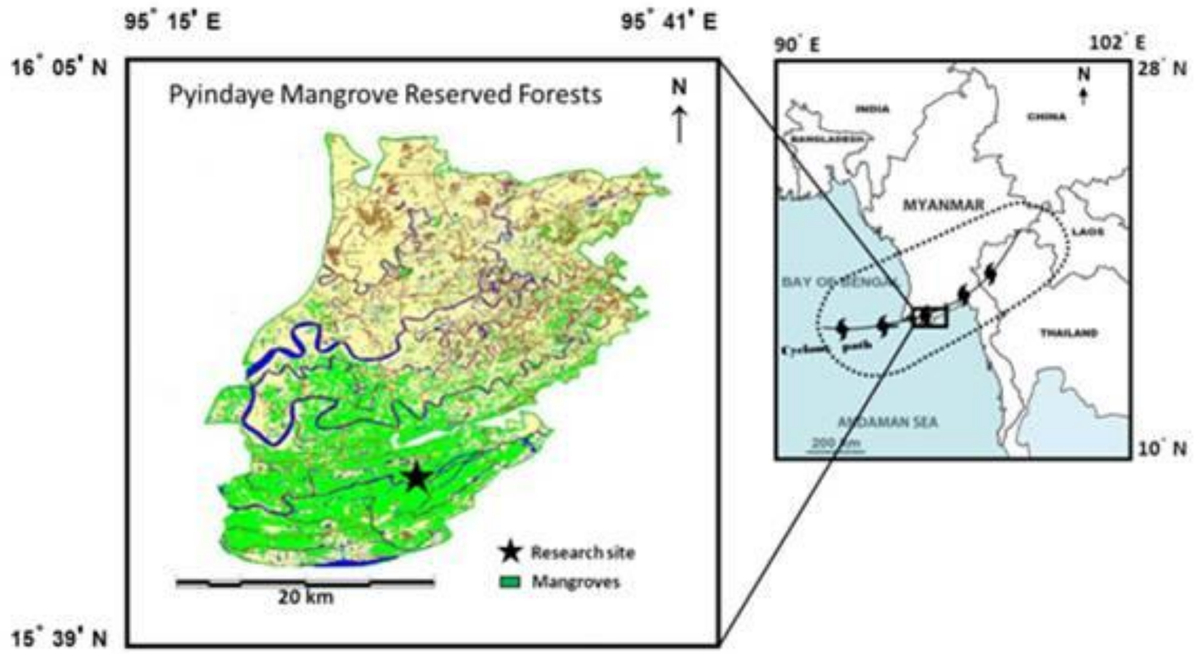


Figure 6. 1 Map showing the study area and research site

Each of these three species was available for monitoring on two plots (each 18m x 18m), representing low and high ground levels relative to sea level, for a total of six permanent plots. These were established over the period between 1999 and 2002, using potted seedlings planted at 1.8m x 1.8m spacing. Since plantation establishment, each plot including a hundred individual seedlings of each species, on both low and high ground, was chosen randomly for monitoring, although the areas of community mangrove plantations are wider than our selected extent. In order to evaluate the immediate impact of Cyclone Nargis, together with the survival, growth and productivity rates of these restored plantations, data were analyzed for a period of two and a half years (2007~2009), including more than one year before and after the cyclone. We measured tree height up to live branches, using a 12-meter glass fiber pole (SK, Japan), and the diameter at breast height (dbh) of each tree stem, following the guidelines of Cintrón & Schaeffer-Novelli (1984). Cyclone damage to the individual trees in the plantations was assessed as relatively slight to very severe by dividing them into four damage categories: no significant damage, foliage damage or defoliation, stem damage, and root damage.

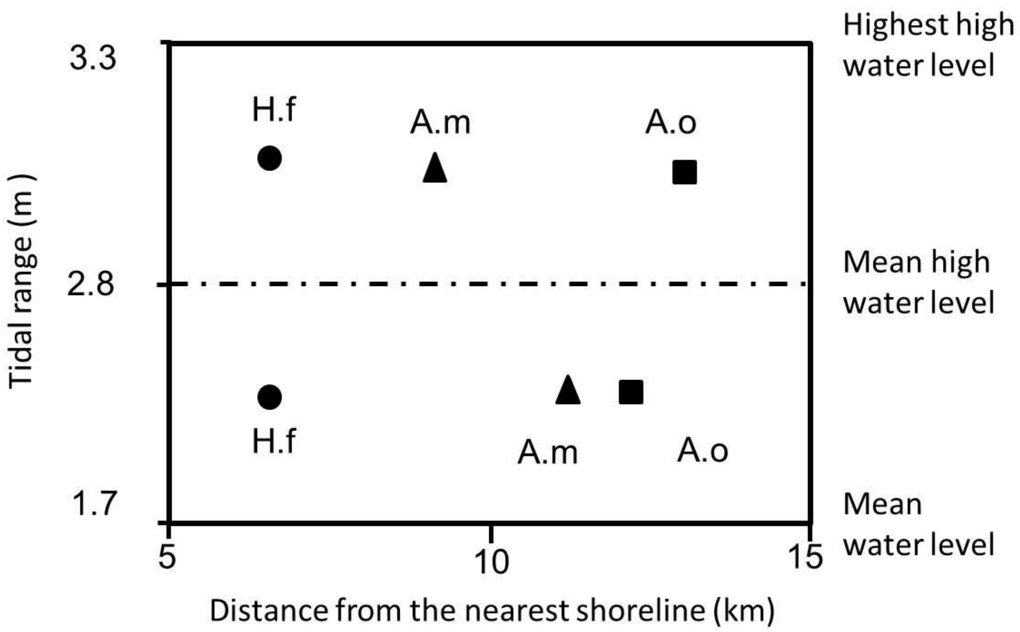


Figure 6. 2 Classification of ground levels for the six research plots

The high and low ground levels recognized in this study were identified from tidal amplitude, the tides being semi-diurnal. Firstly, tidal levels were classified as highest high water level, mean high water level, mean water level, mean low water level and lowest low water level. ‘Highest high water level’ is that maximum that occurs at the spring tide of every month. ‘Mean high water level’ is the average high water level of spring and neap tides of every month. ‘Mean low water level’ is the average low water level of spring and neap tides of every month. ‘Lowest low water level’ is the lowest level at the spring tide of every month. ‘Mean water level’ is the mean between highest high water level and lowest low water level. Then, ground levels corresponding to water levels were defined to identify the levels of the sample plots. Ground level was examined by using equipment for measuring micro-topography (MODEL TRACON L5−25; USHIKATA, Japan). The ground located between mean high water and highest high water was defined as high ground, and ground located between mean water level and mean high water level as low ground in the present study. Accordingly, the corresponding frequency of flooding per month can be observed as 10-15 days on high ground and 15-21 days on low ground. The locations of sample plots, their ground levels and distance from the shoreline are illustrated in Figure (6.2). Productivity of each plantation was calculated as follows:

Biomass productivity = $(D^2_{130cm}\ H)$ x individuals per hectare x survival percentage at the corresponding time

where, D = mean diameter at breast height and H = mean height of trees.

The salinity of surface water was measured using a hand-held salinity meter (S/Mill-E, ATAGO, Japan) when the tides came up to each plot and at a nearby stream. To measure soil physicochemical properties, soil samples were collected manually, using a soil core sampler, during the rainy season in 2008. In each plantation, soil samples were taken at three different depths of 0 cm, 20 cm and 50 cm from five different plot locations (the four corners and the middle of the plot), for a total of 15 samples from each plot. Soil moisture was determined gravimetrically by oven-drying for 48 hours at 105ºC. Soil pH was determined using a pH meter and glass electrode on a 1:2.5 soil: water suspension by weight. Electrical conductivity was tested using an EC meter and electrode on a 1:5 soil: water suspension by weight. Particle size distribution was determined by the pipette method and categorized as sand, silt and clay according to the USDA classification (United States Department of Agriculture). Results of data collected during the dry season, at the same study plots and with the same sampling and testing methods have been discussed by Than *et al.* (2006).

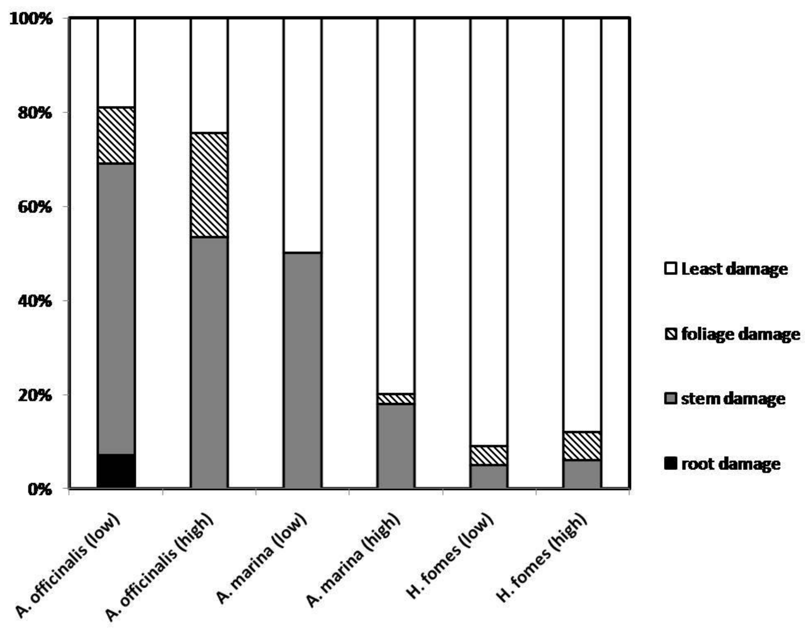
Differences between the pre-cyclone and post-cyclone situations were assessed by means of calculating differences in height growth over a three-month interval. Pre-cyclone tree heights in March 2008 and post-cyclone tree heights in June 2008 were analyzed. We considered two scenarios of increase and decrease in height. Without disturbance, tree height in each plantation would increase; with disturbance, however, tree height in each plantation would decrease. For this, the variables did not meet the required assumptions of normal distribution and homogeneity of variance, and so tests were conducted with the non-parametric Wilcoxon signed-rank test for paired samples. For testing differences between the growth rates of the same-age plantations for each species, with disturbed individuals excluded, most variables on the two different ground levels also violate the assumptions of normal distribution and homogeneity of variance. So we assessed this using the non-parametric Mann-Whitney test instead of using a t-test for independent samples. In these analyses we also considered effect sizes, following Cohen’s (1988, 1992) suggestions, namely no effect, small effect, medium effect and large effect. All statistical tests were conducted with SPSS version 17 (Field 2009).

6.3 Results and discussion

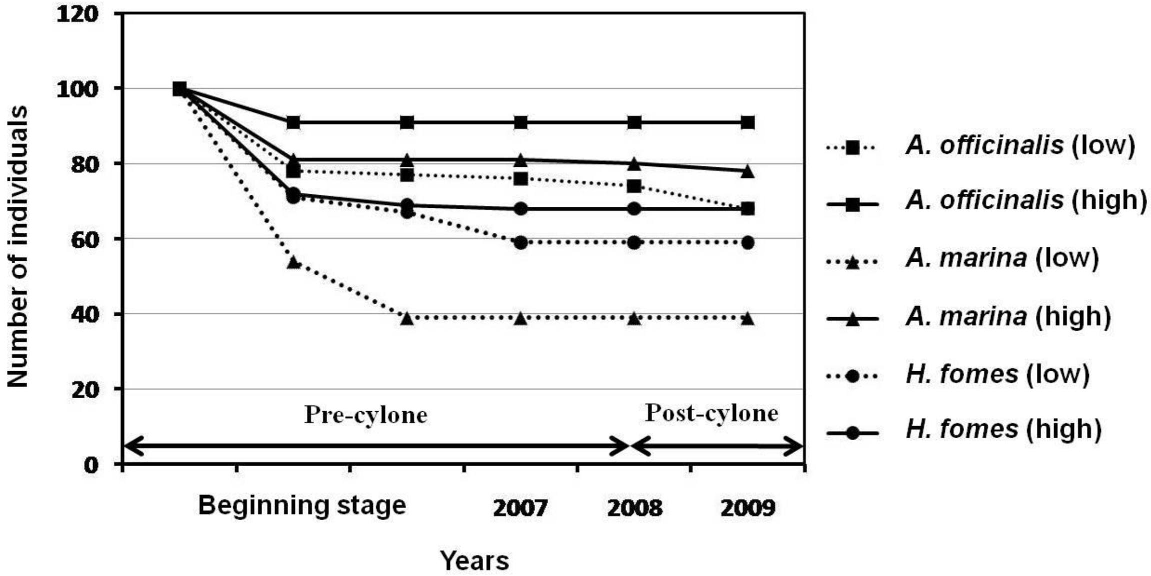
6.3.1 Disturbance and survival

Figure (6.3a) shows that about 80% of *A. officinalis* individuals on both low and high ground were mostly defoliated and broken, while the rates of such damage with the other two species, on both low and high ground, were less than 50%. The *A. officinalis* plantations were also affected by caterpillars, which infested fresh sprouts produced after the cyclone. Aung *et al.* (2009) reported that the sprouting ability of this species was the highest among 13 dominant mangrove species observed throughout this study region after the disturbance by Cyclone Nargis. This distinct strong sprouting characteristic after the cyclone was assumed to have caused the outbreak of caterpillars infesting these *A. officinalis* plantations. Defoliation by caterpillars was rarely found on other species. Caterpillar infestation on *A. officinalis* was observed on both low and high ground, but no mortality of *A. officinalis* trees on high ground was found. This suggests that mortality in *A. officinalis* might have been due to the cyclone, especially as a result of root damage. It is also worth noting that both the *A. officinalis* and *H. fomes* plantations were affected more by defoliation, as compared to *A. marina* plantations, which showed little defoliation. This is consistent with the belief held by local people, based on their common knowledge of the region and without any special scientific investigation, that *A. marina* was very resistant to defoliation by Cyclone Nargis.

(a)



(b)



(c)

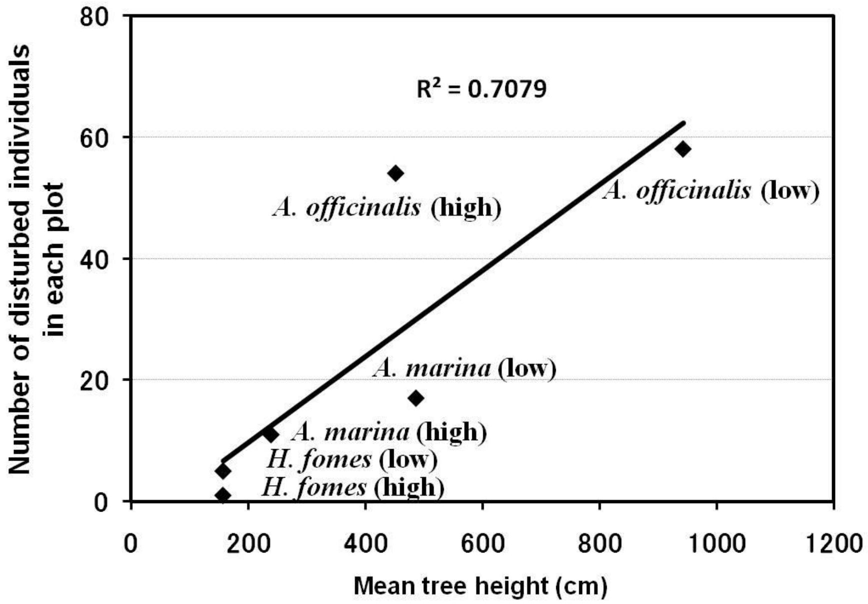


Figure 6. 3 (a) Percentage of four damage categories in each plantation .(b) Survival rate in the six research plots from plantation establishment to the present (c) Relationship of the mean height in the six research plots and the number of disturbed individuals, observed in each plantation after disturbance by the cyclone. The ages of plantations at the endpoint of the study are: 10-yr-old *Avicennia officinalis* on low ground, 8-year-old *A. officinalis* on high ground, 10-yr-old *A. marina* on low ground, 9-yr-old *A. marina* on high ground, 7-yr-old *Heritiera fomes* on low ground, and 7-yr-old *H. fomes* on high ground.

Figure (6.3b) shows that, up to the end of 2009, the survival of *A. officinalis* on high and low ground was 91% and 76%, respectively, that of *A. marina* on high and low ground was 81% and 39%, and that of *H. fomes* on high and low ground was 68% and 59%. For all three species, survival was better on high ground than on low ground. The slight mortality of 8% for *A. officinalis* on low ground and 2% for *A. marina* on high ground was down only after cyclone disturbance. The mean height of the *A. officinalis* plots was the highest among the plots in this study, and it was possible that the cyclone impact to this plot was more serious than to the others. All of the plots in this study were established inland far from the shoreline. Thus, the effect of strong, high waves might be negligible, and disturbance was seemingly due to strong wind from the cyclone. Again, it can be seen clearly in Figure (6.3c) that more disturbed trees were found in the *A. officinalis* plot on low ground. So it is highly probable that the taller the trees in a plantation, the greater the impact by cyclones. The very low mortality of 2% for *A. marina* seemed to be due not only to the cyclone, but also due to effects of unfavorable site factors for this species such as drought in summer.

6.3.2 Growth

Trends of pre and post-cyclone growth

The mean height of corresponding ages of *A. officinalis* on low ground was 876.65 cm at the outset of the study and 916.18 cm at the end of the study. On high ground, the mean height was 352.54 cm at the outset and 495.81 cm at the end of the study. The mean heights of *A. marina* at the beginning and at the end of the study were 431.14 cm and 512.14 cm respectively on low ground and 201.26 cm to 241.58 cm respectively on high ground. The relevant means for *H. fomes* were 135.75 cm and 187.33 cm respectively on low ground and

159.41 cm and 245.83 cm respectively on high ground. The mean diameters of *A. officinalis* were 7.97 cm at the outset and 9.75 cm at the end of the study on low ground, and 2.89 cm and 5.31 cm respectively on high ground. Then, the relevant mean diameters of *A. marina* were 4.22 cm and 5.75 cm respectively on low ground and 1.6 cm and 2.39 cm respectively on high ground. For *H. fomes*, which was recorded only in the later period of study, the mean diameters in 2009 were 1.81 cm on low ground and 1.82 cm on high ground. For this section, the *H. fomes* plantations were excluded from analysis due to lack of pre-cyclone data and since they were still too small.

The effect of cyclone disturbance on tree heights of *A. officinalis* on low ground was obvious, as witnessed by the significant decline from pre-cyclone tree heights to post-cyclone heights ($z = -5.89$, $p < 0.05$, $r = -.69$), and also *A. officinalis* on high ground ($z = -3.81$, $p < 0.05$, $r = -.40$). The cyclone effect on tree heights of *A. marina* on low ground was also apparent, ($z = -2.78$, $p < 0.05$, $r = -.44$), but no significant disturbance effect was found for *A. marina* on high ground ($z = -.343$, $p > 0.05$, $r = -.04$). Using r as a measure of effect size, one can characterize the effect as large for *A. officinalis* on low ground, medium for *A. officinalis* on high ground and *A. marina* on low ground, and small or nearly absent (no effect) for *A. marina* on high ground. Figure (6.4) shows that, for *A. officinalis* on low ground, the mean height declined sharply after the cyclone but had previously been the highest among these six research plots. Also, mean diameter stopped increasing for half a year after the cyclone. For *A. officinalis* on high ground, height growth decreased slightly, not sharply, and the diameter growth did not show significant changes. The results were similar for *A. marina* on low ground.

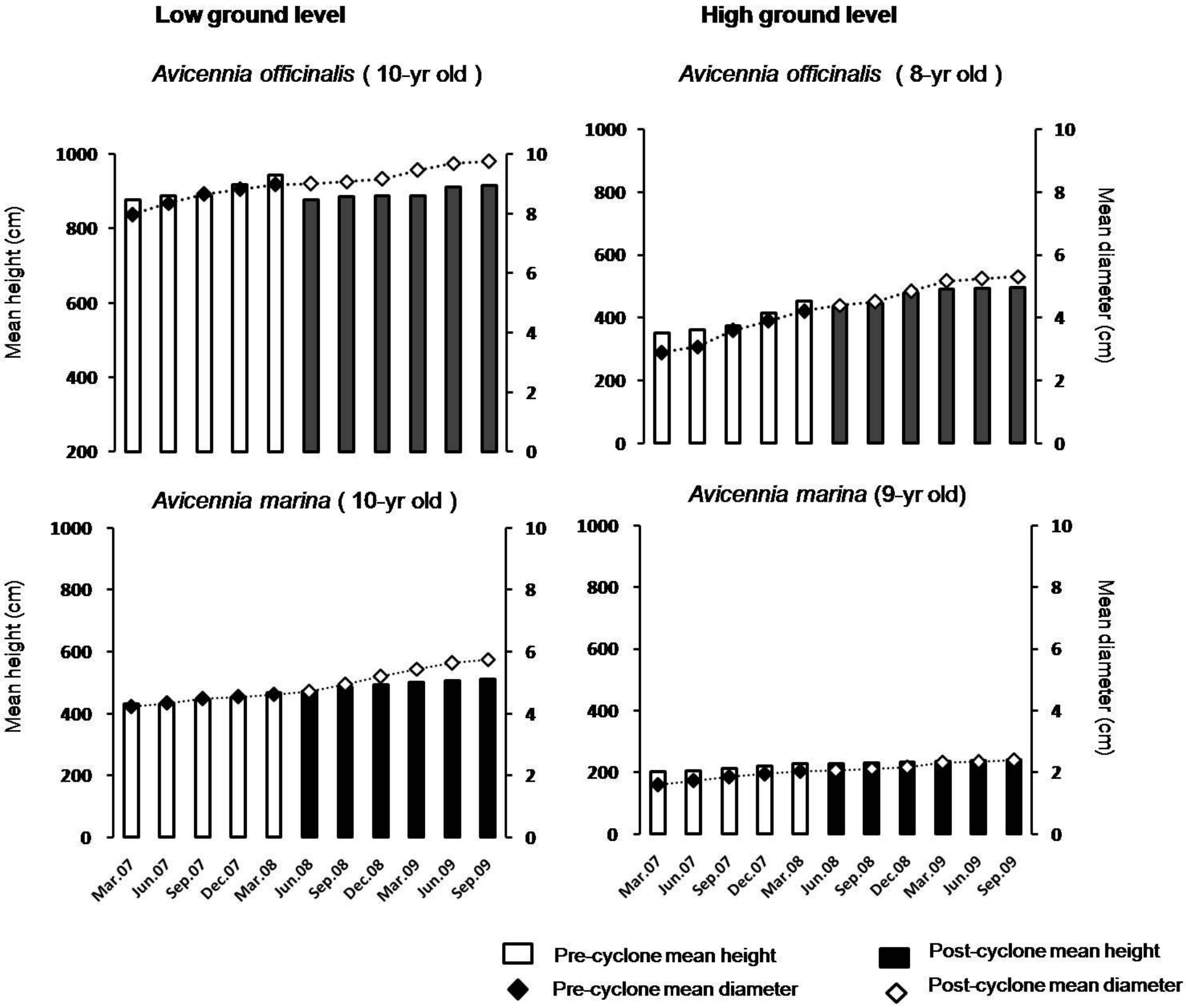


Figure 6. 4 Trends in height and diameter growth of cyclone-affected plantations at low and high ground levels.

For *A. marina* on high ground, height growth was almost flat throughout the study period of two and half years. Diameter growth, on the other hand, increased steadily, both before and after the cyclone. As mentioned above, some decrease in survival rate was observed with this plantation, but it was also suggested that these effects were due not only to the cyclone but also to hydrological stress in the dry season (Than *et al.* 2006).

A diameter limit for exploiting the three species in this study was stated as > 19.41 cm (dbh) by the forest management plan (Maung 2005). So, 10-year-old *A. officinalis* trees now have reached nearly half the exploitable size. The exploitable diameter limit for *H. fomes*, on sites of medium site quality, was 12.8 cm in the Sunderbans mangroves (Hussain *et al.* 1994). According to our field observation, local people prefer restoring *A. officinalis*, rather than other species, because of its quick return benefit. If the the main objective behind restoration of the plantations is utilization of the trees by local people, for example, as wood for fuel or poles other than timber, exploitable limits should be reconsidered carefully. Harvesting too many trees from the forest, however, diminishes soil stability, which causes propagules and saplings to be washed away with the tides and makes natural regeneration impossible (Kairo *et al.* 2001), as natural recruitment of seedlings is also a key factor in restoration mangroves.

6.3.3 Growth of sound individuals

In this section, in order to clarify the growth performance of the three mangrove species on low and high ground, excluding the severe cyclone effect with some limitations, only sound individuals of each species are analyzed. For this analysis, data were used for individuals of the same age, from the two plots of each species. For instance, data for 8-year-old *A. officinalis,* on low and high ground, were used for analysis. Table (6.1) shows that both height and diameter growth of *A. officinalis* was significantly better on low ground than on high ground ($z = -4.612$, $P < 0.001$ level, $r = 0.69$) ($z = -4.238$, $P < 0.001$ level, $r = -0.63$); that of *A. marina* was also significantly better on low ground than on high ground ($z = -6.356$,$P < 0.001$ level, $r = -.68$) ($z = -.5004$, $P < 0.001$ level, $r = -.66$). Effect sizes (r) here appeared to be large for height and diameter of both species. It has been suggested that the sites of these plots on low ground are consistently restored to their natural habitat conditions, as can be observed near the seaward side or on lower ground (Mochida *et al.* 1999). On

Iriomote Island in Japan, the habitats of this species can be found at shoreline. The frequency of tidal inundation appears to affect the growth of the *Avicennia* species significantly.

On the contrary, the height growth of *H. fomes* on high ground was found to be significantly better than on low ground ($z = 4.082$, $P < 0.001$, $r = .40$); diameter growth, however, was not significantly different ($z = 0.52$, $P > 0.05$, $r = .08$). As mentioned above, the growth of *H. fomes* was very slow, and it is still difficult to describe the differences on low and high ground clearly, although effect sizes for height appeared to be medium and for diameter showed no effect. The natural habitat of this species on higher ground has been reported by Than *et al.* (2006).

One can compare restored sites with their natural habitats, described by Watson (1928). The natural habitats of *A. officinalis* and *A. marina* were class 2, flooded by medium high tide 45~59 times per month, and that of *H. fomes* is class 5, flooded by equinoctial or abnormal tides. Recommended sites in this study region for rehabilitation of *A. officinalis* and *A. marina* are on lower ground, confined to the mid-intertidal zone, whereas recommended sites for *H. fomes* are on high ground (Kyi 1992). All these three species occur widely over the study region (Chapman 1976; FAO 2007; Aung *et al.* 2004). Thus low ground can be assumed as the recommended site for *Avicennia* species and high ground for *Heritiera*, corresponding to their natural habitats.

Despite different environmental settings in New World and Old World mangroves, height growth of *A. marina* in Kuwait was 250 cm seven years after plantation (Huisman *et al.* 2009), which is similar to the 7-year-old *A. marina* plantation on high ground in this study (241.589 cm). The water salinity of the Kuwait study region ranges between 35 and 40 ppt., with the annual rainfall from 73 to 160 mm, which is similar to the present study region in summer, with low rainfall and higher salinity up to 28 ppt.

Table 6. 1 Growth rates of the three dominant mangrove species in this study on low and high ground

		Low ground	High ground	Low ground	High ground
		Height (cm)		Diameter (cm)	
Avicennia officinalis	8-year old	936.67±96.82	514.46±90.02	9.91±2.67	5.35±1.68
	Annual increment	117.08	64.31	1.24	0.67
	d.f.	44		44	
	P-value	***		***	
Avicennia marina	9-year old	494.18±136.31	241.58±85.21	5.2±2.14	2.39±1.13
	Annual increment	54.91	26.84	0.58	0.27
	d.f.	86		55	
	P-value	***		***	
Heritiera fomes	7-year old	187.33±75.83	245.83±69.28	1.81±0.63	1.82±0.62
	Annual increment	26.76	35.12	0.26	0.26
	d.f.	102		42	
	P-value	***		ns	

6.3.4 Biomass productivity

Table (6.2) shows biomass productivity before and after the cyclone. Total biomass productivity of 10-year-old *A. officinalis* on low ground and 8-year-old *A. officinalis* on high ground were 96.56 m^3/ha and 20.99 m^3/ha, respectively. That of 10-year-old *A. marina* on low ground and 9-year-old *A. marina* on high ground were 23.84 m^3/ha and 1.32 m^3/ha, respectively. Productivity of same-aged 7-year-old *H. fomes* on low and high ground was 0.51 m^3/ha and 0.83 m^3/ha. Comparing the measurements just before the cyclone and at the end of this study, one sees that the increase in productivity seemed to be lower for *A. officinalis* on low ground and for *A. marina* on high ground than at the other sites, because of greater impact by natural disturbance. Biomass productivity of each species, on low and high ground, showed a trend similar to that for the growth rate on low and high ground described above, although the ages are not the same. Despite the paucity of information and varied plantation techniques and calculation methods, the mean yield of wood from 10-year-old plantations of *A. officinalis* was estimated at 200 m^3/ha, providing a mean annual increment (MAI) of 20 m^3/ha (Saenger *et al.* 1993). These more acceptable volume increments appeared with an initial spacing of 1.2 m x 1.2 m, which is less than the spacing in this study (1.8 m x 1.8 m). At 1.2 m x 1.2 m spacing, the trees became congested within 4 or 5 years and thinning was carried out after 9-10 years, with up to 50% of the stems possibly being removed. This 1.2 m x 1.2 m spacing is perhaps a good guideline to follow in the Ayeyarwady Delta, in order to meet basic needs of local people, due to benefits from early thinning.

Table 6. 2 Biomass productivity of the three dominant mangrove species on low and high ground

Species (plantation age)	Ground Level	Pre and post-cyclone (One and half year difference)	Actual productivity with cyclone impacts (cubic meter/hectare)	Annual productivity (cubic meter/hectare)
Avicennia officinalis	Low	Before	95.37	11.22
10-year-old		After	96.56	9.66
Avicennia officinalis	High	Before	12.05	1.85
8-year-old		After	20.99	2.62
Avicennia marina	Low	Before	15.91	1.87
10-year-old		After	23.84	2.38
Avicennia marina	High	Before	1.14	0.15
9-year-old		After	1.32	0.15
Heritiera fomes	Low	Before	NA	NA
7-year-old		After	0.51	0.07
Heritiera fomes	High	Before	NA	NA
7-year-old		After	0.83	0.12

Table 6. 3 Chemical properties of soil on low and high ground in the dry and wet seasons

Wet Season	Moisture(%)			EC(mS/cm)			pH		
	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max	Mean±SD
Avicennia officinalis **(Low)**	2.33	5.76	3.79± 1.77	0.65	2.43	1.66±0.92	6	6.3	6.2±0.15
Avicennia officinalis **(High)**	6.38	7.68	6.88±0.7	1.14	3.37	2.26±1.12	5.8	5.9	5.8± 0.06
Avicennia marina **(Low)**	3.61	7.21	5.33±1.81	0.94	2.55	1.89±0.84	5.7	5.8	5.77±0.06
Avicennia marina **(High)**	5.18	7.05	6.15±0.94	0.83	3.37	2.49±1.44	5.8	6.2	6±0.2
Heritiera fomes **(Low)**	6.09	7.42	6.76± 0.67	1.07	2.76	2.04±0.86	5.9	6.3	6.1±0.2
Heritiera fomes **(High)**	2.14	2.72	2.4±0.3	0.59	1.81	1.3±0.64	6	6.3	6.13±.0.15
Dry Season									
Avicennia officinalis **(Low)**	2.74	2.95	2.83±0.12	3.63	4.86	4.18±0.63	5.4	6.2	5.87±0.42
Avicennia officinalis **(High)**	3.6	4.39	3.9±0.43	2.11	5.81	3.36±2.12	5.2	6	5.7±0.44
Avicennia marina **(Low)**	2.74	3.12	2.92±0.19	3.23	4.56	4.01±0.7	5.7	6.4	6.03±0.35
Avicennia marina **(High)**	2.31	2.66	2.49±0.18	2.24	4.83	3.16±1.45	4.9	6.8	6±0.98
Heritiera fomes **(Low)**	NA	NA	4.5	NA	NA	3.63	NA	NA	6
Heritiera fomes **(High)**	NA	NA	1.04	NA	NA	3.11	NA	NA	5.56

6.3.5 Micro-environmental factors

As shown in Table 6.3, soil chemical properties such as moisture, EC and pH did not show significant differences between low and high ground. These factors seemed to differ consistently only between the dry and wet seasons, owing to more freshwater input in the rainy season. Special attention should be paid to the moisture as these data were gained from laboratory testing after air and oven drying. It had been stated previously that species replanted on high ground were affected by shortage of soil moisture (Kogo 1993); Than *et al.* (2006) also stated that the mean annual increment of tree height is lower on high ground than on low ground, due to hydrological stress. Soil moisture shortage in the dry season, i.e. hydrological stress, is unavoidable on high ground, owing to the different frequency of tidal inundation on low and high ground. So, although soil moisture does not show significant differences in the above table during the same season, we need more research to compare the moisture in the field, in addition to the laboratory test described in the Table (6.3). Water salinity throughout this area ranges from 1 to 2 ppt (0.1 to 0.2 %) in the rainy season and is about 25 ppt (2.5 %) in the dry season. Even higher water salinity in this research area, 28 ppt (2.8 %), has also been reported (Kogo 1993). Thus, water salinity also shows distinct differences between the wet and dry seasons. It can be suggested, though, that there was no significant difference in water salinity between the two plots of each species, even in the summer, because the plots on low and high ground are not far away from each other. Than et al. (2006) also stated that the effect of salinity on the survival and growth of mangroves was not significant, since seawater was much diluted in this area throughout the rainy season. The substrate for *A. officinalis* was clay loam on low ground and clay on high ground; for *A. marina* it was silt loam (low) and silty clay (high), and for *H. fomes* it was silt loam (low) and sandy loam (high). It was observed that the soil texture on low and high ground was not so different and seemingly did not affect the growth rate of these species. The requirements of *Avicennia* species in their natural habitats are deep mud within the influence of rivers; *Heritiera* requires sandy loam (Watson 1928). Therefore, soil texture requirements of the two *Avicennia* species on low ground and of *H. fomes* on high ground were assumed not to differ too much from their requirements under natural conditions.

6.4 Conclusion

In summary, the cyclone did not affect the survival rates of the mangrove species on these study plots to a great extent; only a slight decline was observed in *A. officinalis* on low ground and in *A. marina* on high ground. The plantations in this study are far from the seaside, and the wave effect might be negligible. Thus, damage was seemingly due to the strong wind. Also, no obvious silt deposition was observed after the cyclone. Mortality, where it occurred, was most likely a consequence of root damage by the cyclone. Also, in this case, it seems that the taller the plantation, the more damage that plantation received. Hence, abrupt change in survival rate is more likely in young plantations, and survival is likely to become steady with maturity. During the intense cyclone of April 1991 in Bangladesh, many of the mangrove plantations were damaged, but by July 1991 most plantations showed clear signs of recovery (Siddiqi, unpublished data), except in areas of significant silt deposition. Damage to non-mangrove species raised on coastal embankments (such as *Acacia nilotica)* was significantly higher than that to mangrove species; the less developed root systems in non-mangrove species may have contributed to their susceptibility to 'wind-throw' (Saenger *et al.* 1993). Terrestrial dry forests are prone to natural, catastrophic disturbances such as hurricanes, which appear to affect forest structure on a longer time-scale (Imbert *et al.* 2008). A study conducted after Cyclone Vance in the eastern Exmouth Gulf of northern Australia (Paling *et al.* 2008) has also suggested that much of the mangrove loss was due to the longer-term consequences of sediment deposition or smothering, rather than the immediate effects of wind or waves. It was also stated in that study that the mangroves exhibited accelerated recovery. Our preliminary study on the recovery potential of thirteen mangrove species in natural forests throughout the cyclone-disturbed area (Aung *et al.* 2009) indicated that, three months after Cyclone Nargis, 97.2% *of H. fomes*, 83.02% *A. officinalis* and 56.0% of *A. marina* individuals were observed with reproductive sprouts, whereas no tree of the genus *Rhizophora* produced vegetative sprouts and these damaged, non-sprouting *Rhizophora* stands then died from the cyclone impact. From this perspective it thus seems that the three species studied here have higher potential for recovery after cyclone disturbance, perhaps more to wind than to wave effects, whereas the *Rhizphora* species and other non-mangrove species seem to be more vulnerable to wind-throw.

In terms of growth in height and diameter, excluding damaged individuals, it was found that the *A. officinalis* and *A. marina* plantations grew better on low ground than on high ground. This suggests that less frequent tidal inundation, especially in summer with low rainfall, caused the plantations on high ground to suffer moisture shortage that affected their growth in height and diameter. In particular, *A. marina* seemed to be more sensitive to this unfavorable condition, as seen from much slower growth in height and diameter on high ground. Contrary to the other two species, the height growth of *H. fomes* was slightly better on high ground than on low ground, although the diameter growth was not significantly different. The reason was that it is slow-growing, and difference in growth rate, especially in diameter, might not reasonably clarify the real condition when a plantation of this species is still young, containing small sized trees. The biomass productivity of each species on low and high ground showed trends similar to those for growth rate in height and diameter.

Analysis of soil physical and chemical properties and of surface water salinity did not reveal significant differences on low and high ground. Conditions differed consistently only between wet and dry seasons, although more research is needed. The exception is soil moisture, which is most likely related to the tidal patterns. MAP-Indonesia (2006) stated that the single most important factor in designing a successful mangrove restoration project is determining the normal hydrology (depth, duration and frequency of tidal inundation and of tidal flooding) of existing natural mangrove communities. It was stated in that study that most *Avicennia* species thrive on low-lying substrates (deeper water) and *Heritiera* species thrive inland, on higher substrates (shallow water), which is in agreement with the current study. The hydrology pertaining to tidal inundation is a very important factor for successful ecological restoration of mangroves. Although it is difficult to generalize planting sites for successful mangrove restoration, as this would based on local environmental conditions and the species planted, it was generally agreed that the hydrologic regime was the single most important overall site condition governing the survival and subsequent growth of restored mangroves (Field 1996, 1998). In this study, the two *Avicennia* species grew well on lower ground and *H. fomes* on higher ground. It should be noted that *A. officinalis* is a very fast-growing species, as compared with the other two species, and thus it may be more beneficial for quick biomass return from restored plantations, albeit with many limitations such as the local people's preference of specific species.

Since growth and productivity differ significantly on low versus high ground, more successful benefits for local communities can be achieved by establishing *A. officinalis* and *A. marina* on low ground and *H. fomes* on high ground. The contrary pattern would meet with less successful results. If the local population needs quick economic returns from their plantations, they should focus their attention on the best site selection for the species they prefer most. Compared to other terrestrial forest types, mangroves are generally very sensitive to site selection, as they grow only in the narrow range of intertidal zones. So careless selection, such as *Avicennia* species on high ground, would cause them to waste time, budgets and labor, and yield only slow economic returns; ecological services would also be less effective. If cyclones become more frequent in this region, attention should be paid to species that are more resistant to natural disturbance, not only for economic purposes but also for safety. Complete planting guidelines at a regional level would become essential in order for successful restoration. This study provides necessary information for community-based management planning, successful rehabilitation and predicting production from community-owned mangrove plantations.

Chapter VII

General Conclusions

To sum up the present study, attempt was made to explain by dividing two parts. The first part including Chapter II, III and IV was related to the mangrove dynamics after natural and anthropogenic impacts. The second part including Chapter V and VI was regarding the prospects of local critical social capital in restoration measures and the assessment of current restoration activities through the participation of this local social capital. The second part "restoration" was considered as a way to assist the "recovery" process of the first part.

7.1 Resilience after natural and anthropogenic impacts

Post-Nargis Recovery Potential

The present study focused on the status of mangrove vegetation after catastrophic disturbance, Cyclone Nargis in 2008. It can be assumed that cyclone impact was low-severity disturbance according to Frelich (2002) because only a few species belonging to the *Rhizophoraceae* showed high mortality, and the overall recovery of mangroves have shown considerable rapid rate. For the resilience of the post-cyclone mangroves, this study has confirmed that although the post-cyclone mangroves are resilient in general, the species like *B. sexangula* and *R. apiculata* belonging to the *Rhizophoraceae* group have shown very sensitive to natural disturbance, in particular, this sensitivity are supposed due to wind-induced impacts. Apart from these two particular species, other species, generally the non-*Rhizophoraceae* group, have shown rapid recovery after cyclone impact. In the former case of being sensitivity to cyclone impact, the indirect post-cyclone consequences, rather than direct impacts, cause to slow the recovery process of mangroves. The observed reasons of slow recovery processes are; 1) high mortality caused by limited sprouting ability after wind-induced disturbance, 2) erosion that occurred in the stressful habitat on riverbank mud flats with frequent tidal inundation, and 3) delayed reproduction or phenology after the catastrophic cyclone. From this part of study, it can be also generalized that the two main categories of the *Rhizophoraceae* and the non-*Rhizophoraceae* are relatively different in their sensitivity to cyclonic storms. The *Rhizophoraceae* here mainly refers to *Rhizophora* and *Bruguiera* species. In trying to compare within these two genera, the habitat of the latter occurs on higher ground and inland sites. Therefore, although the genus *Bruguiera* is sensitive to cyclone storms, the legacy of its seedlings and saplings do not receive the impacts of erosion consequences unlike the *Rhizophora species* mentioned above, and so they have shown highly resilient through release. It should be noted that although there are only six species selected in this study, these species are suggested to cover other species of the same genus. For instance, the findings in the *Rhizophora apiculata* species can represent the same patterns for the *Rhizophora mucronata* species, and similar cases are considered for other species. In case forest managers need rapid recovery and budgets are affordable, management intervention should be considered in order to mitigate the adverse consequences of the catastrophic impact such as erosion and invasion of herbaceous species. Otherwise, management intervention may not be an urgent need in the cyclone-disturbed mangroves. In general, the overall recovery rate of the Ayeyarwady mangroves based on the six dominant mangrove communities in the current study can be expressed 61.06 % for a period of three years and eight months later after Cyclone Nargis in 2008.

Furthermore, in thinking about sustainable management and restoration of mangroves in developing world, conservation alone might not be enough to manage mangrove forests because densely-populated coastal or delta communities rely primarily on mangrove products. Theoretical utilization of mangroves, thus, has been developed in the present study, in which

Avicennia officinalis has illustrated high cutting or harvesting tolerance. After the proper opening of canopy by harvesting for local subsistence use, a carpet of recruited seedlings waiting for gap opening can be facilitated to graduate next stages. These strong points of some mangrove species can be taken as an opportunity to consider for the co-existence of mangroves and people, that is, sustainable living with risk reduction. However, pragmatic and long-term research is needed whether or not it is indeed feasible and then how much threshold should be kept for local harvesting in real situation. As a result, through species-specific functional ecology, local needs, and mitigation of tsunami and storm impacts, and climate change effect as well, it should be investigated more in order to achieve the ultimate goal of sustainable utilization on mangrove ecosystem services. Moreover, if cyclonic storms become more frequent in this region, attention should be paid to species that are more resistant to natural disturbance, not only for economic purposes but also for life-protecting function of mangroves to local stakeholders.

Recovered vegetation after anthropogenic impacts

In addition to understanding on the recovery potential of mangroves after natural disturbance, it also requires examining the status of actual living communities or recovered vegetation after human impacts and environmental risk potential on human disturbed sites for the consideration of restoration processes. Unlike the natural disturbance mentioned above, they can be varied from low-severity to high-severity because the impacts range from local subsistence needs to extreme economic profits by cutting mangroves habitats clearly. In this part, first, recovered vegetation in the ex-agriculture sites or abandoned rice fields were explored in order to understand the extent of vegetation recovery, back to mangrove forests again. Mangrove habitats were clearly cut in these agriculture-driven sites. The consequence is that even in the mature fallow lands, that is, at least a 10-year period later after abandoning rice fields, have still composed of mostly shrubs, herbs, ferns and palms. It is rare to discover mangrove trees. For both young and mature fallow lands, the only true tree mangroves species, *Sonneratia caseolaris* community have appeared. In these agriculture-driven sites, the patterns of vegetation succession can be generalized as four main phases; the first phase with grasses, the second phase with a mix of grasses, shrubs, herbs, ferns and palms, and then the third phase with pioneer mangrove vegetation, and finally the fourth phase with climax mangrove vegetation. Based on the availability of propagules and the intensity of fragmentation of mangrove landscapes, the onset of third phase would be either rapid or slow. Nevertheless, according to the present observation, the vegetation recovery patterns in the agriculture-driven sites are likely to take a long time process, and it is recommended that restoration should be facilitated by artificial means for rapid recovery process on the sites where mangrove forests have been extensively cleared and fragmented.

After exploring the recovered vegetation in the rice field affected sites, the study proceeded to investigate the actual living vegetation occurred in the shrimp ponds affected sites. The results have shown that most of the re-growing species in the brackish water aquaculture-driven sites are herbaceous species, and only few are true mangroves as tree life forms as well. The true mangrove species dominated in these sites are expected to have the possibility to restore in the degraded sites abandoned after shrimp ponds. In other words, they may be fairly appropriate for being introduced in restoring the barren abandoned shrimp ponds. It is well-accepted that the mangrove deforested site abandoned after intensive shrimp farming practices are extremely difficult to replant and restore mangroves. In the findings that *A. marina* are becoming dominant both on the active and abandoned shrimp ponds, it has proven that they are more persistent to this aquaculture-driven mangrove environments. In the current study site, the *Avicennia* species has illustrated being not only well adaptable to the aquaculture-driven mangrove regimes, but also more desirable to fulfill other local needs as tangible benefits. In doing so, should the mangroves-friendly aquaculture be initiated with this kind of persistent species? It is still skeptical and needs to develop a sustainable aquaculture model by monitoring and evaluating over time. In the present study, there has shown an important finding that a risk of activating potential acid sulfate soil was detected. It could be a major impediment to recommend mangrove restoration by the so-called mangrove friendly aquaculture instead of other conventional restoration strategies. Furthermore, most of the shrimp farms worldwide are developed near the seaward mangroves which play critical natural capital for life-protecting function of mangroves to the livelihoods of local people. For such a case that the sites are exposed to the sea or close to the sea, mangroves must be prioritized as a bio-shield function instead of the silvo-fishery practices. The key point is that in Asia and Africa, despite simultaneous efforts taken for mangrove conservation and restoration, mangroves have still shown decline with a couple of socio-economic limitations that are challenging in trying to arrest further expansion of land use to mangroves. In some cases, for instance, given some parts of mangroves abandoned after brackish water shrimp farming practices and other land uses remain idle for a long time, budgets are not affordable by government agencies alone, and those from other international organizations and NGOs are also not available, alternative restoration and rehabilitation strategies, that is, the small scale fishery or the mangroves-friendly aquaculture through local social capital should be taken into account in order to restore urgently instead of the areas that are left as barren lands. Thinking mangrove restoration alone, therefore, may be clearly simple, but its sustainability is subtle and not yet achieved.

Under these combined pressure of natural and anthropogenic impacts, mangrove deforestation in the Ayeyarwady Mega Delta has been facing an alarming rate and highly likely to disappear in the short run. This is particularly due to anthropogenic disturbances which have cleared a large extent of the Ayeyarwady mangroves. In the present study, not only the in-depth site investigations was done but also the trends of mangrove deforestation for the whole landscape of the study area, and the pre-cyclone and post-cyclone vegetation health indices were detected by using time-series Landsat satellite images over a two-decade period. The study has shown evidence that the recent natural impact does not affect the Ayeyarwady mangroves seriously. Instead, there was a slightly increasing trend of vegetation health indices. Based on the facts and figures obtained from the analysis, the conceptual models of vegetation health by commonly-occurred land-use regimes were developed. These resulted figures have proven that the catastrophic cyclone did not influence mangroves seriously whereas the human disturbances, in particular rice cultivation in mangroves, need a long time to leap back to their original patterns of vegetation health. There was almost lack of vegetation health in the sites where mangroves have been converted to rice fields. During a two-decade period from 1990 to 2010, the overall mangrove deforestation rate was high by 0.7 % per year exclusively for this study region, and the dense mangroves were also extremely decreasing by 1.5 % per year. This situation made this region more liable to catastrophic disturbance in 2008, in which more than a hundred thousand of people lives were dead and massive loss of property happened in the open landscape without the natural barriers of mangroves unlike a huge coverage of dense mangroves in this region two decades ago.

It is hoped, therefore, that the findings in the present study can highlight the needs to revise current management strategies, and to urgently restore and rehabilitate the mangroves in this Ayeyarwady Mega Delta.

7.2 Restoration Perspectives

Restoration is a process that assist the recovery and management of mangroves. With slow recovery process in resilience, restoration by artificial means should be provided for facilitating recovery process to become more rapid. In this respect, the study proceeded to do with restoration views. In order to meet the goal of restoration measures, it requires understanding how local social capital takes account of mangrove environments, and their participation status. Without the awareness of mangroves and the attitude of local stakeholders to actively participate in conservation and restoration activities, the ultimate goal of mangrove sustainability would not be achieved. It was, therefore, tested in the study whether or not different local stakeholders were aware of mangroves, and whether or not they have strong attitude to take part in mangrove restoration activities. Instead of viewing them as mangrove destroyers, they should be perceived as critical social capital and real mangrove conservator through proper management. In this study, the test results have shown that most of the local stakeholders have sufficient awareness and attitudes to actively participate in mangrove restoration although there are only slight differences observed mainly between the mobile and immobile groups. Specifically, the mobile communities have shown slightly lower in number in testing awareness and attitudes compared to the immobile communities who have settled down in the study area for a couple of decades. A need in restoration measures would be with their more active participation. Participatory management, therefore, should be focused on prioritizing their subsistence needs through creating economic incentives and paying attention on the indigenous utilization of local people in developing management strategy. Further work is recommended to seek the in-depth requirements or motivation factors to actively participate in mangrove restoration processes by revising current conventional ways, and it should be based on local and regional background through considering the social and ecological needs. In case awareness raising campaign is implemented, the mobile communities dwelling in mangrove environment should not be neglected in mangrove restoration measures.

In some parts of this mega delta region, there have already had a number of mangrove plantations restored through the local social capital under the Community Forestry initiative (CF), although there are still a couple of limitations in restoration progress under this CF initiatives. By selecting some of these plantations for three commonly-planted species restored by local community themselves with the support of the Forest Department, NGOs (mainly ANDAMAN) and UNDP, attempt was made to demonstrate the extent of success in these current restoration activities. In the monitoring on restored plantations, cyclone impact was also considered. It is shown that the cyclone did not affect the survival rates of the mangrove species on these study plots.

In these restored plantations, in terms of productivity as potential immediate economic incentives to local people, it was found that the *A. officinalis* and *A. marina* plantations grew better on low ground than on high ground. This suggests that less frequent tidal inundation, especially in summer with low rainfall, caused the plantations on high ground to suffer moisture shortage that affected their growth in height and diameter. In particular, *A. marina* seemed to be more sensitive to this unfavorable condition, as seen from much slower growth in height and diameter on high ground. Contrary to the other two species, the height growth of *H. fomes* was slightly better on high ground than on low ground, although the diameter growth was not significantly different. The reason was that it is slow-growing, and the difference in growth rate, especially in diameter, might not reasonably clarify the real condition when a plantation of this species is still young, containing small sized trees. The biomass productivity of each species on low and high ground showed trends similar to those for growth rate in height and diameter.

The hydrology pertaining to tidal inundation, therefore, is a very important factor for successful ecological restoration of mangroves. Although it is difficult to generalize planting sites for successful mangrove restoration, as this would be based on local environmental settings and the species planted, it was generally agreed that the hydrologic regime was the single most important overall site condition governing the survival and subsequent growth of restored mangroves. In this study, the two *Avicennia* species grew well on lower ground and *H. fomes* on higher ground. Since growth and productivity differ significantly on low versus high ground, more successful benefits for local communities can be achieved by establishing *A. officinalis* and *A. marina* on low ground and *H. fomes* on high ground. The contrary pattern would meet with less successful results. If the local people need quick economic returns from their plantations, they should concentrate carefully on site-species matching. Compared to other terrestrial forest types, mangroves are generally very sensitive to site selection, as they grow only in the narrow range of intertidal zones. So careless selection, such as *Avicennia* species on high ground, would cause them to waste time, budgets and labor, and yield only slow economic returns; ecological services would also be less effective. Complete planting guidelines at a regional level thus would become essential in order for successful restoration through considering all integrated socio-economic and ecological needs.

All in all, fortunately, mangroves have shown considerable resilience after the cyclonic storm, Cyclone Nargis 2008. In spite of the fact that management intervention is not a must after natural disturbance, on the sites of mangrove deforestation after human impacts, particularly by rice field, have appeared to take a long time for self-help recovery process. In this regards, restoration should be facilitated by artificial means for rapid recovery process. In terms of the aquaculture-driven sites, the mangrove-friendly aquaculture is potential to initiate under robust systematic management, but only after testing a wise-use silvo-aquaculture model to comply with the tidal nature of local hydrology. Lastly, it is highly recommended to implement mangrove restoration without displacing the local stakeholders who are critical social capital in all stages of conservation and restoration measures.

7.3 Overall implication and future direction

1) Cyclone-sensitive mangrove species should be focused for conservation purposes, especially the genus *Rhizophora* and *Bruguiera* belonging to the family *Rhizophoraceae*
2) Cyclone-persistent mangrove species should be paid attention in establishing plantations as life-protecting function of mangroves to the livelihoods of local people in order to adapt to future cyclone events.
3) Great sprouting mangrove species discovered after Cyclone Nargis are highly likely to initiate coppice management practices in community-based forest management.
4) Empirical research on coppice management of higher sprouting ability species and more preferable species by local people such as *A. officinalis* and *H. fomes* are strongly suggested to develop as soon as possible. It can be applicable to a wise-use scenario under community-based mangrove management.
5) In site preparation for restoration measures, the remaining mother adults should be strictly kept for reproduction under plantation instructions and guidelines.
6) In order to implement the mangroves-friendly aquaculture as an alternative measure of restoration activities, long-term experiment should be done through monitoring and evaluating the physical and chemical properties of soil, its impacts on faunal communities, and the relationship between the relative distribution of mangrove vegetation and shrimp production.
7) On the rice field affected mangrove sites, management intervention should be considered in order to facilitate the slow recovery process observed on these sites. Further expansion of rice fields to mangrove areas should be strictly prohibited.
8) Clear land-use management and policy is urgently needed so as to arrest further expansion of agriculture and aquaculture to mangroves

9) In restoration process, more attention should be paid on local critical social capital.

10) In current restoration measures, more than the three species investigated in the present study and other species preferred by local people and highly potential for quick economic returns to the livelihoods of local people should be monitored, evaluated and recorded.

11) The products from restored mangroves through the participation of local people need market creation and sustainable market in order to motivate them for their long-term participation.

12) Lastly, the economic valuation of mangroves, rice fields, and extensive shrimp farming practices are strongly recommended so as to be able to compare their relative importance in ecological, social and economic approaches for decision making processes.

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Appendices are numbered according to their corresponding chapters. For example, Appendix I represents Chapter I.

Appendix I

Cyclone Nargis and mangrove damage

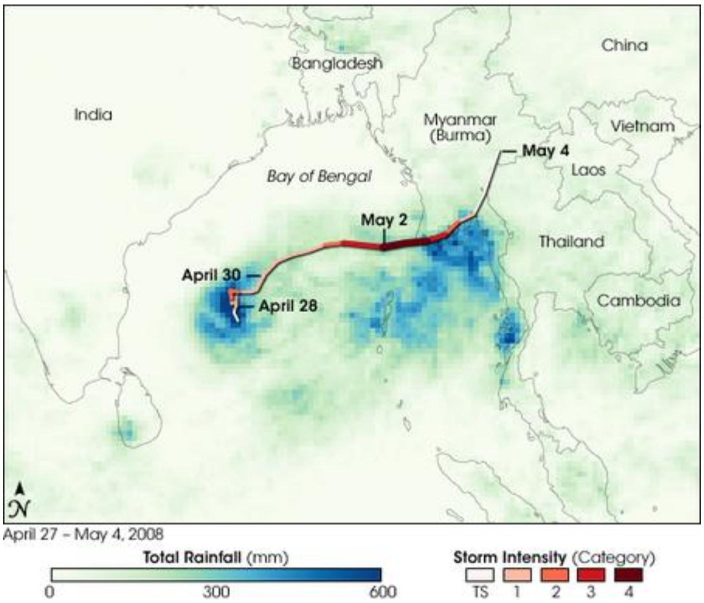

Plate.1. Available at http://clairelight.typepad.com/atlast/power/page/3/

Photo.1.1 Devastated mangroves by catatrophic cyclone, Cyclone Nargis 2008 (Courtesy: Zaw Min Htun, Forest Department in Myanmar)

Appendix II

Mangrove dynamics by natural disturbance

Photo.2.1. *Heritiera fomes* dominated sites (a) Pre-cyclone, (b) Cyclone impact in 2008 (c) Post-cyclone recovery in 2011

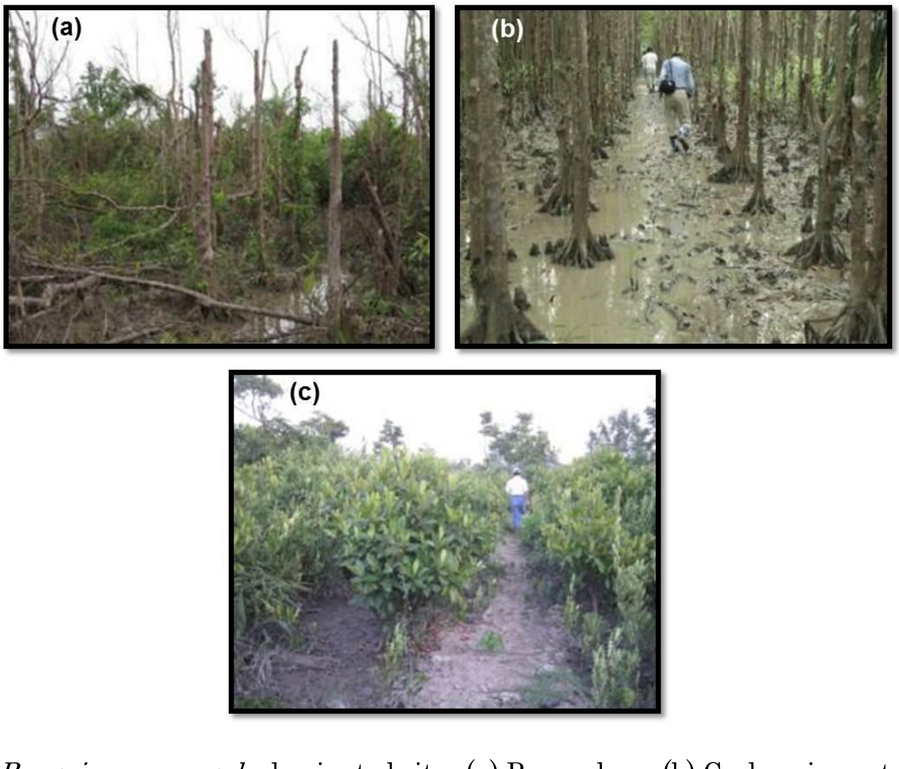

Photo.2.2. *Bruguiera sexangula* dominated sites (a) Pre-cyclone, (b) Cyclone impact in 2008 (c) Post-cyclone recovery in 2011

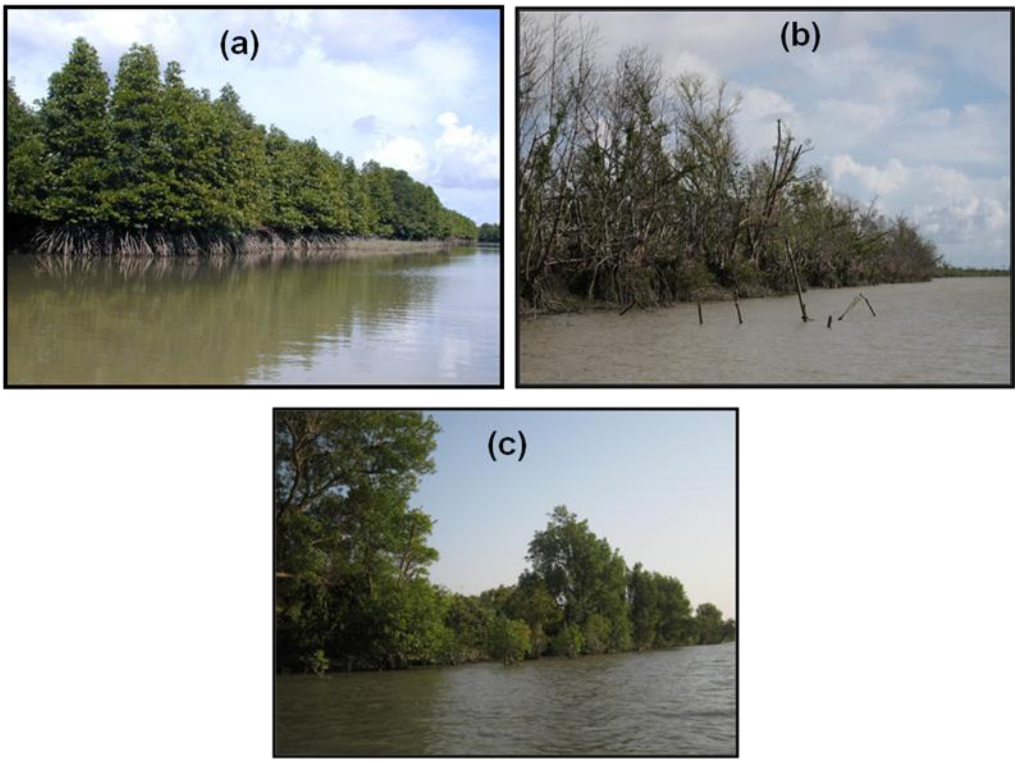

Photo.2.3 *Rhizophora apiculata* dominated sites (a) Pre-cyclone, (b) Cyclone impact in 2008 (c) Post-cyclone recovery in 2011, canopy is dominated with other species

Photo.2.4 Recovered mangroves in 2011, 3 years later after Cyclone Nargis

Appendix III

Mangrove dynamics by anthropogenic activities

Photo.3.1 Harvested rice field inside Kadonkani mangroves

Photo.3.2 Recovered vegetation on fallow lands, dominantly *Graminaceae*

Photo.3.3 Recovered vegetation on fallow land, dominantly *Graminaceae*

Photo.3.4 Abandoned brackish water shrimp ponds with the growth of *Graminaceae*

Photo.3.5 Active extensive shrimp ponds by partially clearing mangroves

Photo.3.6 *Derris trifoliata* communities on abandoned shrimp farming site

Appendix IV

Recovered mangroves, degradation and deforestation

Photo.4.1 Dense mangrove sites with canopy trees

Photo.4.2 Dense mangroves with Nipa communities

Photo.4.3 Recovered *Sonneratia caseolaris* community after natural impacts

Photo.4.4 Degraded mangroves by human activities

Photo.4.5 Mangrove deforestation by salt pan

Photo.4.6 Mangrove deforestation by rice fields

Appendix V

Interviews in the two regions with and without severe cyclone impact

Photo.5.1. Interview by local trained person at less cyclone-affected village

Photo.5.2. Interview at severely cyclone-affected village

Questionnaire Form

Interviewer:………………………………………………..

Date:……………………………………………………….

I. General information

District:…………………………………………….

Township:………………………………………….

Village tract:……………………………………….

Village name:………………………………………

- Name of respondent………………………
- Age:………………………………………..
- Gender: 1. Male 2 . Female
- Educational background:………………………..
- Occupation/Livelihood:…………………………

II. Awareness, attitudes and participation

1. Do you know mangroves? If you know mangrove forests, can you briefly describe its nature and characteristics?
2. Do you think there is a relationship between mangrove forests and environment? If say yes, please briefly explain how to relate?
3. Do you know fish, shrimp and crabs are breeding inside mangroves?
4. Can mangroves protect soil erosion?
5. Do you think mangroves serve storm protection function to your environment?
6. Do you think mangroves need conservation and protection? Why?
7. What extent do you think mangroves are important?
   (a) not important (b) slightly important (c) important (d) extremely important
   (e) no idea
8. Have you ever participated in any kinds of mangrove restoration activities?
9. Are you a member of user group under community-based mangrove management or community forestry program?

III. Mangrove utilization

Please describe your favourite species on each purpose

1. Wind protection
2. Soil erosion protection
3. Pole
4. Post
5. Timber
6. Fire wood
7. Charcoal
8. Furniture
9. Greening purpose
10. Aesthetics

Appendix VI

Restored mangroves by local social capital

Photo.6.1 *Avicennia marina* 9-year old plantation restored under community-based forest management

Photo.6.2 *Avicennia officinalis* 9-year old plantaion restored under community community-based forest management

Photo.6.3 *Avicennia marina* 9-year old plantation restored by local people

Photo.6.4 *Heritiera fomes* 9-year old plantation restored by local people

Photo.6.5 Monitoring 9-year old *Heritiera fomes* plantation

Photo.6.6 Monitoring 9-year old *Avicennia marina* plantation

Appendix VII

Recovery strategy, coppice management potential, and restoration need as the life-protecting function of high vulnerable villages in the mega delta

Photo.7.1 Epicormic sprouts of *Avicennia officinalis*, three months later after Cyclone Nargis (Courtesy: Yamin Thant)

Photo.7.2 Epicormic sprouts of *Heritiera fomes*, two and half years later after Cyclone Nargis

Photo.7.3 Release from the seedlings of *Bruguiera sexangula*, three years and eight months later after Cyclone Nargis

Photo.7.4 Vulnerability of a village along eroded river bank in the Ayeyarwady Mega Delta

Photo.7.5 Vulnerability of a village without any bio-shelter after conversion of mangroves to other land uses in the Ayeyarwady Mega Delta

Save the Ayeyarwady Mega Delta
through the restoration of native mangrove species with great resilience!