Geo-ecological Rehabilitation Process of the Intensive Damaged Mangrove Forest in Can Gio District, Vietnam

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1. Introduction

Mangrove forest Development is promoted by land formation on the upper half of the tidal range, dispersion of the seeds, and promotion of sedimentation caused by formation of mangrove forest at the place at a pioneer stage. At the same time, mangroves change the forest structure largely depending on the environmental gradation caused by slight differences in the height of the ground (ex. frequency of inundation of tidal water, variation in the advantages of the seed spraying caused by the distribution of vegetation types) in the upper half of the tidal range that has a vertical range. Thus, we could say that development of a mangrove forest is not only physiological and ecological development of a forest itself but is geo-ecological development including changes in the geomorphic and hydrological conditions.

Can Gio district in Vietnam used to have rich mangrove forests before spraying of defoliants during the Vietnam War. Although the forests were destroyed massively because of the defoliants, the district has managed to regain mangrove forests steadily by the reforestation program. In this report, we are going to clarify what kinds of changes were made through the process of the destruction and restoration in this district.

2. Research Area and Method

2-1. Outline of Research Area

Can Gio district where located about 30 km southeast from Ho Chi Minh City. The total area is 73,000ha, and the land area excluding the rivers and ponds is 51,100ha. Today, about 37,300ha out of the land area is covered with mangrove forests (Fig. 1).

The whole district is on the deltas of the river Dong Nai, Saigon, and the stream network is divided into main streams (Nha Be River, Dong Tranh River and Nga Bay River), inter distributaries which develops complicatedly between the main streams and tidal channels which work as drains at low tide. Some tidal channels seem to join at a inter distributaries and creates drainage areas. Therefore, a inter distributary basin enclosed by these river systems can be considered to be one land unit (Miyagi, 1995). At the river mouth of the Dong Tranh River, one of the main streams, has a large tidal flat where tidal channels directly flow into the main streams neighboring. The surrounding area is administrated as "Can Gio Forest Park" (Fig. 1).

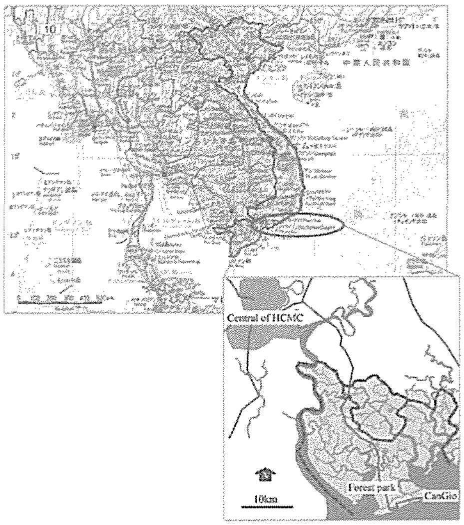


Fig. 1 Location map of the study area

The landform of Can Gio District is divided into the following five types; unflood type upland (2-10m above the sea), multi-year cycle flooded lawland (1.5-2m above the sea), monthly cycle flooded lowland (0.5-1.0m above the sea) daily cycle flooded lawland (0.3-0.5m above the sea) and lawer tide accretion area (0.3 or lower above the sea) in connection with tidal situation. Mangrove forests always develop on the upper half of the tidal range and the vertical range they grow is at 0-2m. Because of the spraying of defoliants called "orange gas" by the U.S. army during the Vietnam War from 1964 to 1970, most of the mangrove forests in this region were extinguished. This also caused the main species of mangrove called "Rhizophoraceae" to face extermination. Some small communities of Avicenniaceae on the tidal flat, *Ceriops* spp. and *Excoecaria aggarocha* which grow on higher ground survived, but where *Phoenix paludosa*, *Acrostichum aureum* and *Derris trifoliata* had grown wild turned into degraded land, and rich mangrove forests were nearly extinguished. The inhabitants utilized the dead mangroves as firewood.

In 1978, the inhabitants and the Ho Chi Minh City Forestry Department launched a big forestation program. They chose *Rhizophora apiculata* as a plantation species for its rapid speed of growth and affordability, and planted on the degraded land and tidal flat. *R. apiculata* were planted on the area of 18,795ha till 1994. Since 1984, *Ceriops tagal, C. decandra, Lumnitzera racemosa, Xylocarpus* have been planted on higher ground and the area of the planted forest in the whole Can Gio District has reached 22,000ha. As of the year 2000, 72 mangrove species, mangrove associations and 440 fauna have been confirmed in this region. This restoration of the ecosystem was highly evaluated and the area was authorized as a UNESCO/MAB Biosphere Reserve on January 21, 2000. In Can Gio Mangrove Biosphere Reserve, 24 forest units are divided into three zones; Core zone, Buffer zone and Transition zone. In Core zone, only limited activities such as research, monitoring and traditional use by the native people are allowed in order to preserve the flora and fauna of the ecosystem and landscape. Buffer zone surrounds Core zone, and outer Transition zone is used as farmland and as well as a resident area (Tuan et al. 2002, Tri et al. 2000).

Table 1 Forestation area of Rhizophora apiculata in Can Gio District (Miyagi et al. 2003)

Year	1966	1973	2001
Area Held by Mangroves in Analysis Area (ha)	36,386	20,779	37,311
Total Area in Analysis Area (ha)	66,157		
Percentage Mangroves Hold in Analysis Area	55%	31%	56%

Table 2 Plantation processes of mangroves at Can Gio district.

Year	Forestation Area (ha)	Year	Forestation Area (ha)
1973	8,4	1986-88	2,132.7
1978	1,557.7	1989	24.0
1979	1,321.0	1990	11.9
1980	3,135.0	1991	1,465.0
1981	1,787.0	1992	1,168.3
1982	1,842.9	1993	1,100
1983	553.1	1994	900
1984	983.5	Total	18,795
1985	803.9		

The data for the year 1973 was quoted from the Experimental Forestation in Than Ton Hiep Village. (after V.N.Nam, 1998m, Hong, 1996)

2.2 Research Method

Observing the mangrove forest habitat in the Can Gio district, we find that the habitat is categorized as a typical delta type mangrove forest (Miyagi et al, 1990), with rich sedimentation and is under the influence of tides in connection with the inter distributaries and tidal channels. In the region with such landform and characteristic vegetation, we conducted this research to understand the change in the distribution of mangrove forests from before the Vietnam War to today and to analyze the change process in the geo-ecosystem based on the field survey in the area where we can grasp the history of the change in the landform and vegetation.

Using aerial photo map, satellite images interpretation, we grasped the dynamics of the mangrove distribution that change in the following several periods; just before the destruction of the mangrove forests caused by defoliants, right after the destruction and since then to today. For the area estimations, we used the GIS software Arc View GIS 8.2 by ESRI.

To obtain the data about vegetation before the destruction of the forests, we interpreted and abstracted the area of the mangrove forests from the aerial photo map taken by the U.S. army in 1966 (PICTMAP SUPPLEMENT TO STANDARD 1:50,000 SCALE MAP) and transformed the data into polygon data. To obtain the data right after the destruction, we used the images taken by Landsad MSS on December 15, 1972 and January 1, 1974. For the changes after that, we used a Landsat TM image taken on January 16, 1989 which was the 11th anniversary of the start of the forestation, March 6 of the same year, January 7 1994 (the 16th year after the start of the forestation), December 11, 2001, Landsat +ETM image taken on January 5, 2002 (the 23rd-24th year after the start of the forestation) and an ASTER image taken on February 5, 2005 (the 27th year after the start of the forestation).

To abstract the area of the mangrove forests from the satellite images, we took both of the following two ways; one is to use pseudo colour images which catch the wavelength from the area around 0.7-1.3μm which is said to give off a strong reflection based on the structure of the cells of the plants, and the other one is use the value which seems to reflect the real distribution of the forests. We transformed the data into polygon data and added some handwork for some revision. On revision, we referred to false colour images and the observation/survey in the research area we are going to mention later in this report.

To verify the process of destruction-forestation-restoration of mangrove forests, we performed research on the mangrove forests, micro landform, and sedimentation at two points; the tidal flat (Forest unit No.17, Forest Park Survey Area) on the left shore of the river Dong Tranh which is one of the main stream in the delta and the inter distributary basin on the upper reaches (Forest unit No.10, MEET Center Survey Area). This survey led us to analyze the change in the land and vegetation after the spraying of the defoliants.

3. Results

3.1 Changes in the Distribution of Mangrove Forests in the Whole Can Gio District

Today, the total area of the mangrove forests in Can Gio district is about to reach 40,000ha which is almost the same as that before the destruction. The forestation has been carried out as a national project after the massive destruction caused by the spraying of the defoliants. However, at the same time, we should not forget the fact that forests with almost the same size have been restored naturally there. In this chapter, we are going to see how the forests have been changing.

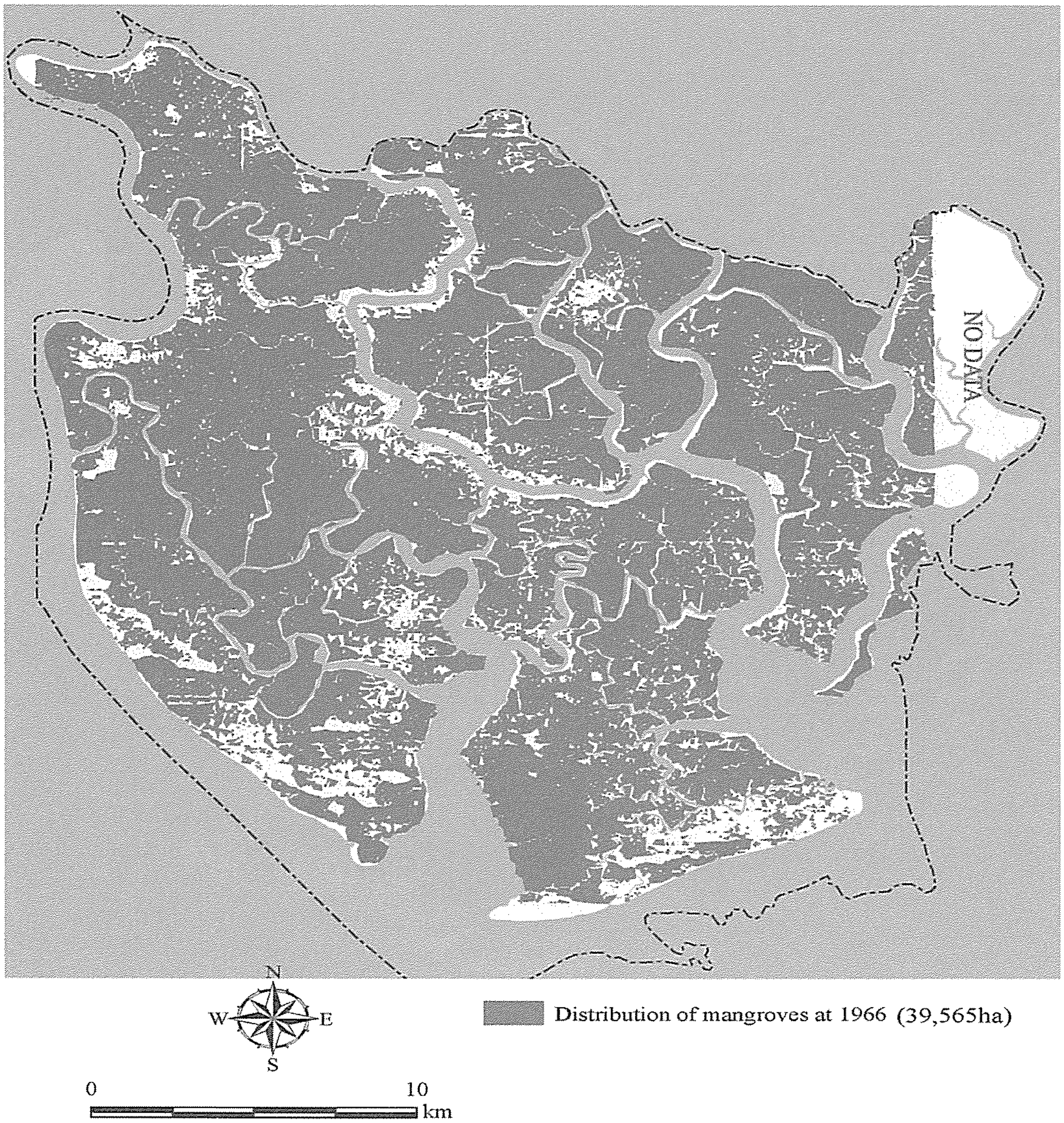


Fig. 2 Mangrove forest at the age of 1966 in Can Gio (after the Pict Map by US)

The Fig. 2 shows the distribution of the mangrove forests in 1966, just before the destruction of the forests by the spraying of the defoliants. We confirm the poor vegetation in the area where small villages lie scattered along with the rivers in the mangrove forests, on the slightly higher ground on the upper part of the inter distributaries, and in the bigger villages on the beach ridge in the southernmost tip in of the figure. Also, we confirm some small bare ground but we do not have any idea how the ground can be used. Also we confirm a lot of mangrove forests in the inter distributary basins and tidal flat on the left shore of the river Dong Tranh river. The total area is estimated to be 39,565ha.

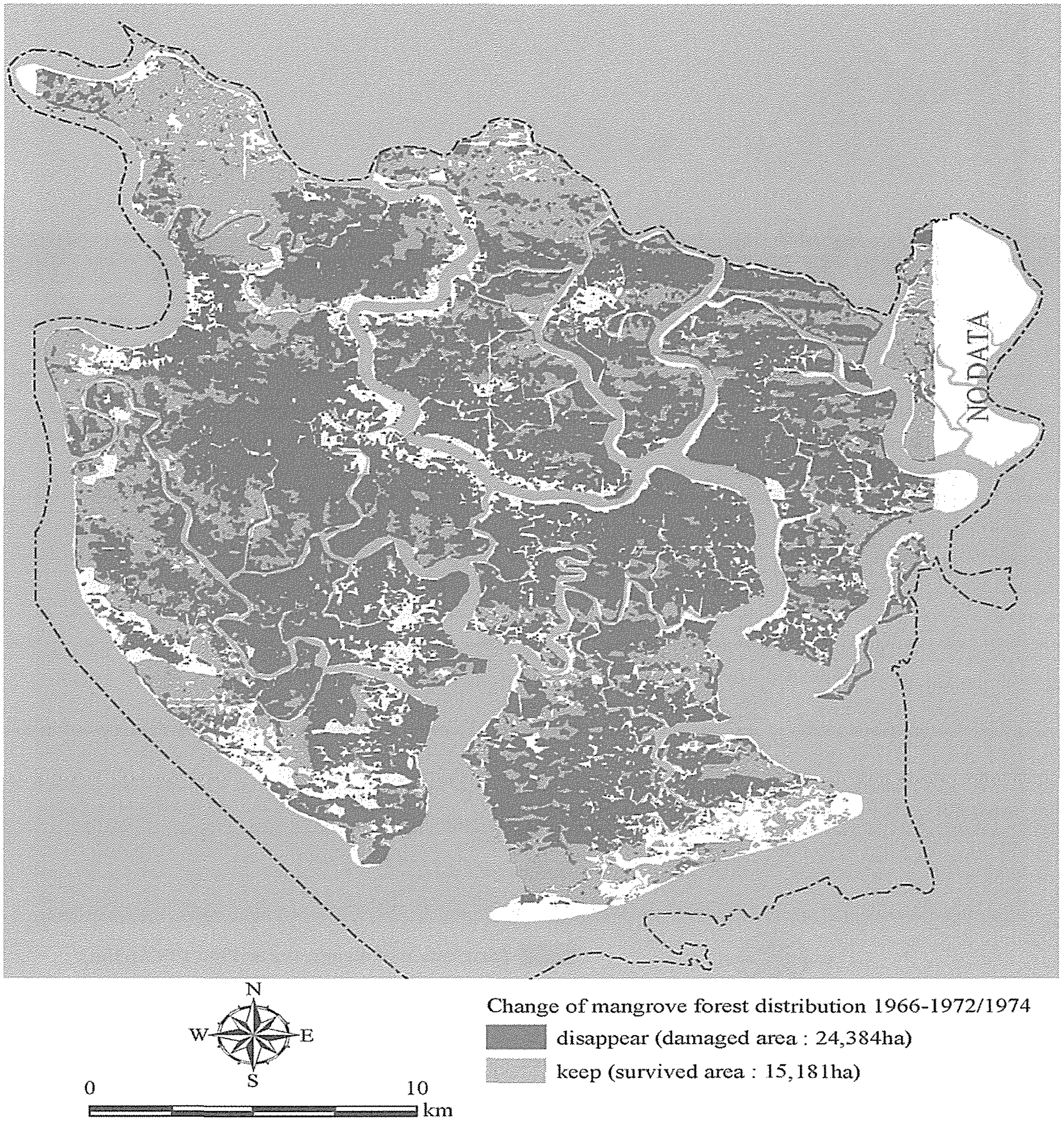


Fig. 3 Mangrove cover changes between 1966～1972 and 1974 in Can Gio

We overlaid a distribution map of the mangrove forest interpreted from the Landsat MSS images taken in 1972 and 1974 (right after the spraying of the defoliants) on a distribution map of 1966 in order to distinguish the parts where the vegetation survived and as well as that was extinct. This is shown in the Fig. 3. The area where the vegetation was extinct is estimated to be 24,384ha (62%) and that where the vegetation survived is to be 15,181ha (38%). In 1978, the reforestation work started to move ahead in earnest. The Fig. 4 shows the time when the mangrove forests developed. The data was interpreted from the satellite images taken at four different times; 1989, 1994 (Landsat TM), 2001/2002 (Landsat+ETM) and 2005 (ASTER).

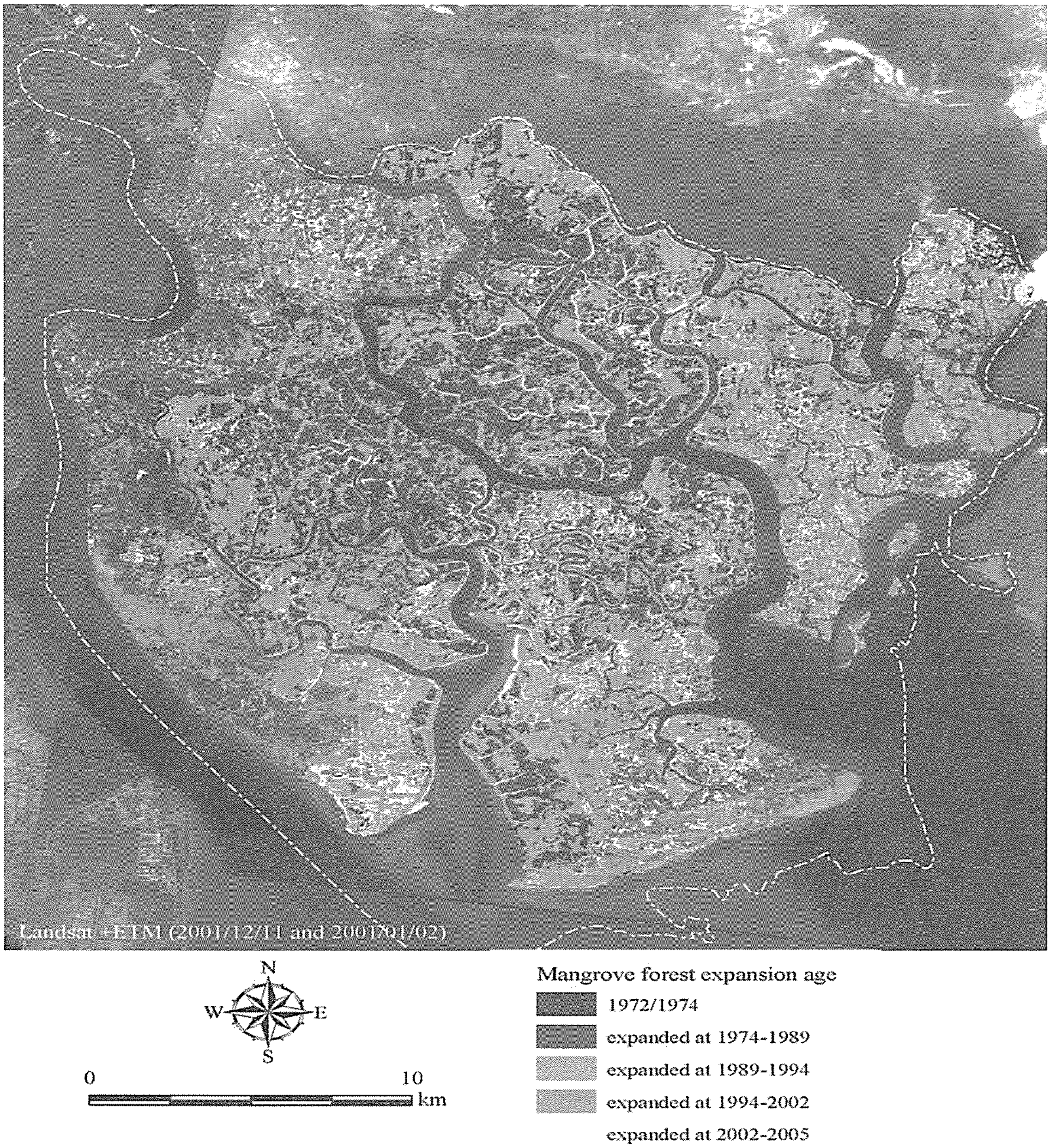


Fig. 4 Expansion processes of the mangrove cover in Can Gio from 1974 to 2005

According to the figure, we can see that the forests had been almost restored in the center of Can Gio district by 1994 after the start of the forestation. We can also see that after 1994 the mangrove forests started to spread partially towards the streams where mangrove forests did not used to develop. We can often see this development at a meander of a small inter distributary. We generally assume that formation of land on the upper half of the tidal range causes development of a mangrove forest. If we take this assumption, it means that the land on the upper half of the tidal zone at such meanders has spread to the rivers. Usually, the speed of a current at such a point is slow. Therefore, we can hardly assume an active erosion or sedimentation caused by rivers and streams, and we have never heard any of such examples. Because of the spraying of the defoliants, the land became bare. The surface of the bare land became dried, oxidized and was eroded. In addition, the eroded earth and sand piled up on the neighbouring lowland. We cannot deny the possibility that all these factors have helped mangrove forests grow up.

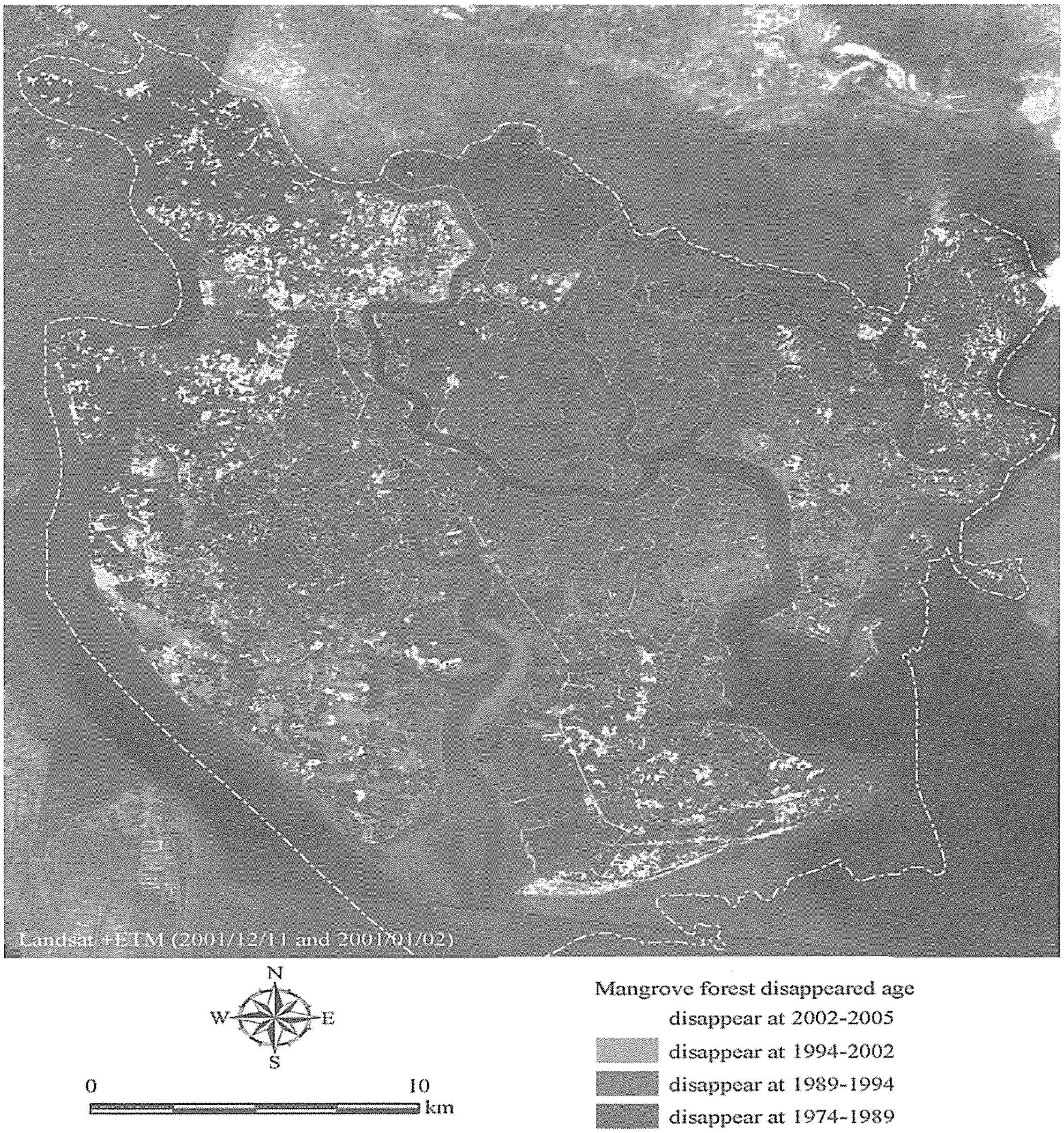


Fig. 5 Disappearing processes of the mangrove forest in Can Gio from 1974 to at present

The Fig. 5 shows the area and periods of the extinction of the mangrove forests after the spraying of the defoliants. After the spraying of the defoliants, the mangrove forests that had developed in the large area of the Can Gio district gradually started to disappear, and they vanished by 1989. We assume that the reason for this extinction is the inhabitants cut the trees and used for the fire wood and the materials for constructions during the poverty period after the war. After 1989, the northern and western areas in particular of the Can Gio district were developed, and those developed areas seem to have turned into residence, salt fields, shrimp ponds and so on. In recent years 2002-2005, we have also confirmed that highways have been developed in these areas.

The followings are the summary of the changes in the distribution of the mangrove forests and land conditions in the Can Gio district we gained through the interpretation of the images.

① The spraying of the defoliants which continued till 1970 bared, oxidized and dried the huge area of the land, and it also caused the surface of the land to have erosion.

② The vegetation managed to be restored because of the forestation conducted mainly at the inter distributary basins in the center of Can Gio district after 1978, while the forests around the forested area were cut down.

③ After 1994, three types of land were confirmed; land on which mangrove forests rapidly moves and spreads to the rivers, land on which mangrove forests moved back because of the erosion on the river banks, and land on a shore without any changes.

④ Mangrove forests were turned into residence, salt fields, shrimp ponds and so on under the influence of the development in the neighbouring area in recent years.

3.2 Field Survey of Changes in the Topography and Vegetation

At the Forest Park and MEET Center, we measured micro-landform, sedimentation and vegetation to see how the landform and vegetation have changed since before the destruction of the forests caused by the spraying of the defoliants.

The mangrove forests in the southern area of the Can Gio district and the Can Gio Forest Park develop on the tidal flat on the left shore of the River Dong Tranh. Its width is 3km and the length is 10km. According to the vegetation map made by our collaborator V.N.Nam et al. in 1957, forests consist of *Avicennia alba* and *Sonneratia alba* used to hold the most of the mangrove forests on the water courses, while *Rhizophora apiculata, Ceriops* spp and *Phenix pardosa* used to be distributed on the land. Most of these forests died after the defoliants rained onto them twice, in 1967-1968 and 1968-1970. In 1978, forestation of *R. apiculata* started, and *R. mucronata*, *C. tagal* were also planted after 1983. As a result, we confirmed that afforested areas of *R. apiculata* spread from the central part of the tidal flat to the inland in 1987. Also, natural forests of *Avicennia alba* have been rapidly growing on loose clay on the river banks (Miyagi et al. 2003).

We set a belt transect of which width is 2m and length is 500m from the waterside of the rivers towards land (Fig. 6). The belt transect covers used to have watery areas and forests consist of *A. alba* and *Sonneratia alba* before the spraying of the defoiants. Fig. 8Geomorphic, geological and vegetation cross profiles at the Can Gio study area shows the landform, geological features and vegetation along the transect. As for the landform, the most of the land has flat topography which does not reach the range between above the mean sea level (from 0.3m a.m.w.l. to 0.6m a.m.w.l.) and the mean highest sea level (0.91m. a.m.w.l.) except the tidal channels near the point of 150m and 450m. The land near the point of –30m-50m on the river is lowland and it has a small irregular slope between the land on the level of 0.5m-0.6m a.m.w.l which spreads towards the land after the point of 50m. Most of the sedimentation we observed on the transect is of clay. We are able to identify the abundant Ferric mottols which is comparatively tighter on 20cm of the surface of the earth on the higher land. However, the earth on the relatively lower land on the river consists of very loose clay. This loose clay dramatically gets thicker from the point of 60m towards the river and its thickness reaches 70cm at the point of 0m (datum point).

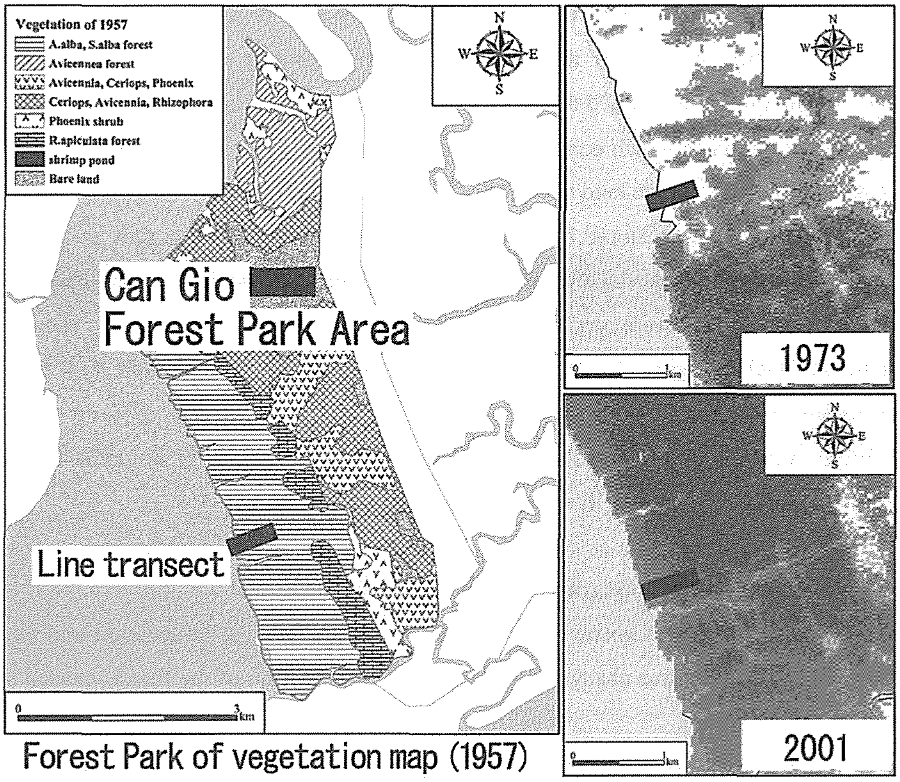


Fig. 6 Changes of mangrove forest and the location of line transect in Can Gio Forest Park

The seven mangrove species which appeared on the surveying line are *Avicennia alba, A. marina, A. officinalis, Ceriops tagal, C. decandra, R. apiculata, R. mucronata, S. alba*. We found in the area, from the river to the land, an *Avicennia alba* forest (at the point of -30m-50m), a mixed forest of *A. officinalis, R. apiculata* (at the point of 50m-130m), a *R. apiculata* forest (130m-200m), and again a mixed forest of *A. officinalis* and *R. apiculata* (at the point of 200m-450m). On the small tidal channels, we a found bush of *C. decandra* and *R. apiculat*a (at the point of 450m-491m). This makes us realize that the vegetation changes clearly in zonal arrangement which reflects the ground level, water exchanges and material characteristics (Fig. 7)

The followings are the analysis of the forest structure in the main three communities. We used a Kodorat for the analysis.

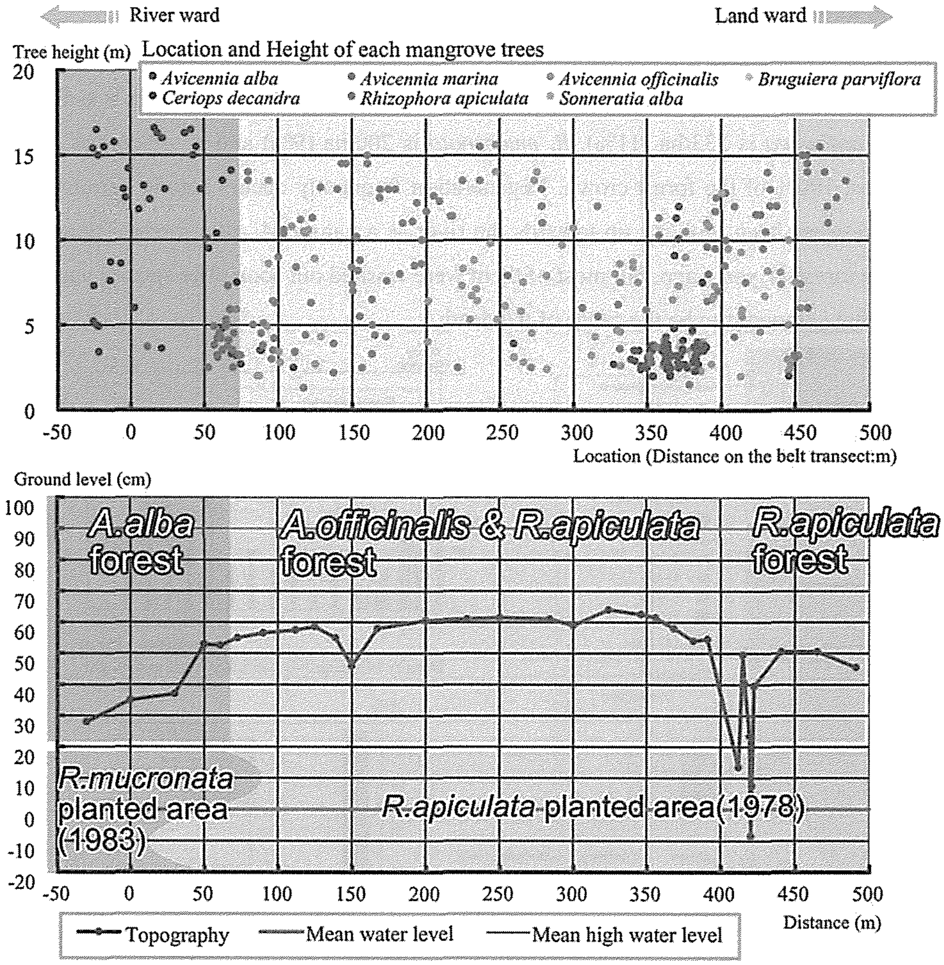


Fig. 7 The relationships of the micro topography and forest structure along the transect, Can Gio Forest Park

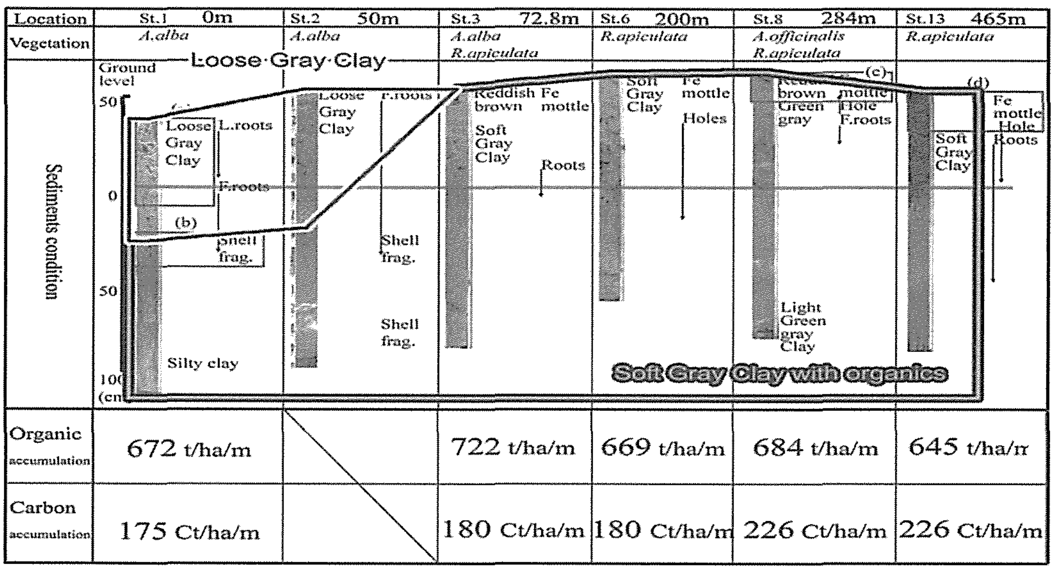


Fig. 8 Geomorphic, geological and vegetation cross profiles at the Can Gio study area

1) *Avicennia alba* **natural forest**

We set 10 m by 30 m kodrats from the point of –30 m to 0 m of the transect (Fig. 9). The ground level distributes between 0.39m to 0.21m a.m.w.l. The density of the trees which form the forest is as follows: *A. alba* is 1700/ha (78%), *R. apiculata* is 233/ha (11%), *R. mucronata* is 200/ha (9%) and *A. officinaris* is 33/ha (2%). *A. alba* occupies almost 100% of the forest crown. Regeneration frequently occurs among germinations and young trees there. The forest has been growing up towards the river as a natural *A. alba* forest. Trees of *R. mucronata* were planted in this forest 11 years ago, but most of them were washed out soon. The species and the ground level did not match and that is thought to be the cause of the death.

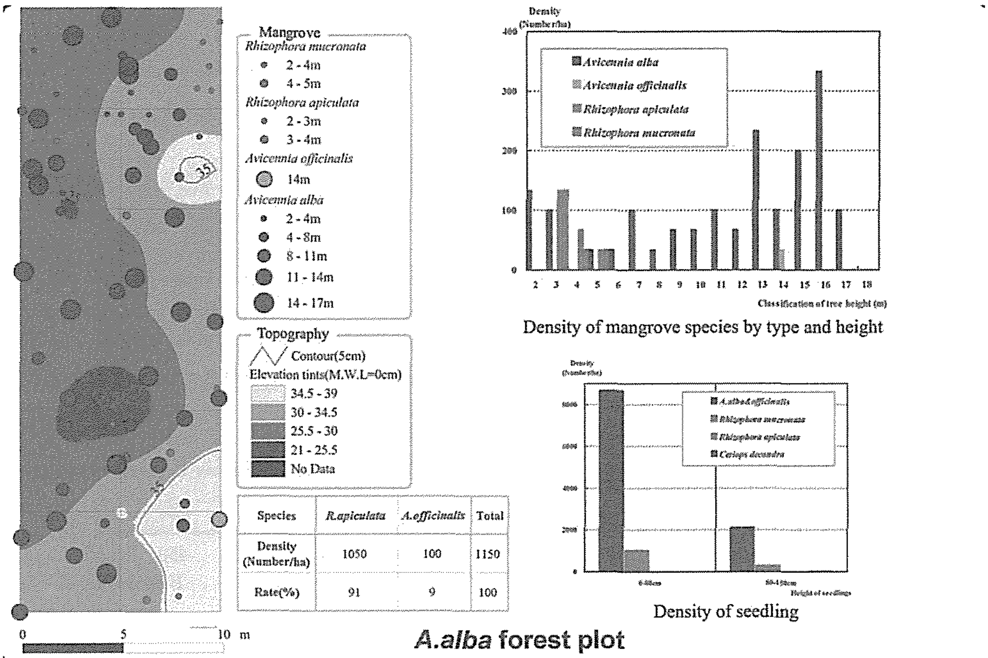
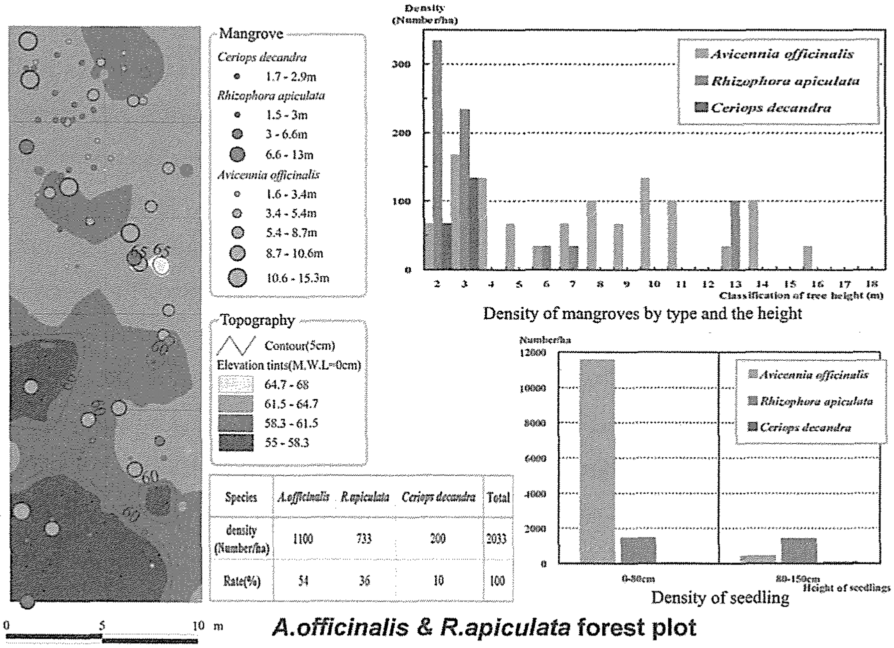


Fig. 9 Micro topography and the forest structure of the *Avicennia alba* habitat in the Forest Park

2) *Avicennia officinaris* **and** *Rhizophora apiculata* **mixed forest**

In a forest of which tree crown consists of *A. officinaris* and *R. apiculata*, we attached 10 m by 30 m kodrats to the transect from the point of 274m to 304m (Fig. 10). The ground level distributes between 0.68m to 0.55m a.m.w.l. That place used to be a bare land. *R. apiculata* was planted in the beginning of 1980s and later *C. tragal* was planted. However, the natural invaded species of *A. officinaris* that became predominant among them today. The density of the trees which form the forest is as follows: *A. alba* is 1,100/ha (54%), *R. apiculata* is 733/ha (36%), *C. decandra* is 200/ha (10%). Most of the tree crowns are *A. officinalis*. The species keeps high density not only canopy but even on the shrub layer and regeneration occurs frequently.

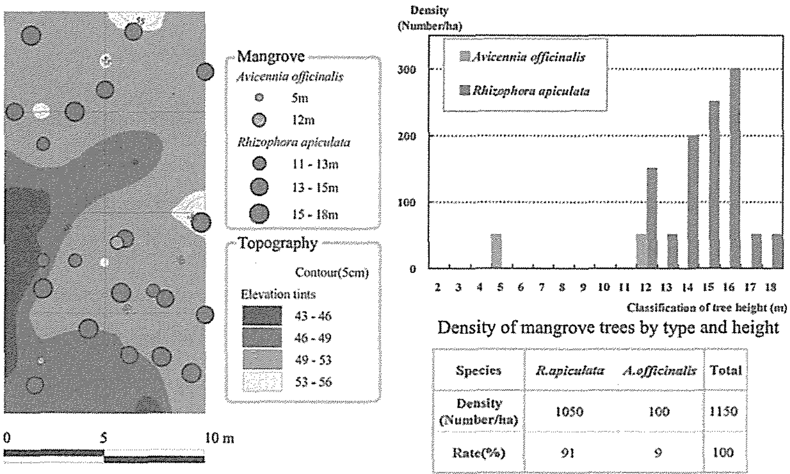


Species	A.officinalis	R.apiculata	Ceriops decandra	Total
density (Number/ha)	1100	733	200	2033
Rate(%)	54	36	10	100

Fig. 10 Micro topography and the forest structure of the *Avicennia officinalis and Rhizophora apiculata* habitat in the Forest Park

3) Rhizophora apiculata plantation forest

We attached 10cm by 20cm kodrats to the transect from the point of 465m to 485m. (Fig. 11) The ground level distributes 0.56m to 0.43m a.m.w.l. The density of the trees which form the forest is as follows: *R. apiculata* is 1,050/ha (91%), *A. officinaris* is 100/ha (9%). This means that this is nearly a pure forest of *R. apiculata*, and this species planted in 1978 has satisfactorily grown up. On the shrub layer under the *R. apiculata* which consists of the tree crowns, there is a layer of *R. apiculata* which of height is about 10m. This means that natural regenerations from the *R. apiculata* which were afforested have occurred. The density of the trees here is lower than that of the other forests, and this is because there are few trees of which height is less than 10m. In this forest, we did not confirm the predominance of *A. officinaris* in this forest.



Species	R.apiculata	A.officinalis	Total
Density (Number/ha)	1050	100	1150
Rate(%)	91	9	100

R.apiculata forest plot

Fig. 11 Micro topography and the forest structure of the *Rhizophora apicultta* habitat in the Forest Park

4) Changing process of mangrove geo-ecosystem in the Forest Park

We are able to estimate that the land conditions and the changing process of the forests shifted as follows; Before the Vietnam War, the mangrove forests by means of the forest structure in this area seemed to have been typical deltaic mangrove forest one. This area was affected by the spraying of the defoliants very severely and more forests were cut and dead than in the surrounding regions. In addition, the region was also affected by the severe erosion and oxidation because of the lack of the forest cover. The huge amount of the eroded suspensions such as clay materials transported and accumulated to beside of the bared forest area. The suspensions established the very loose clayey area at the tidal zone. After 1978, forestation started in the inner land and the activities continued and spread gradually, and the clay accumulations continued along the river banks. We assume that the clay has been accumulated because of the land erosion that occurred when mangrove trees died. As the clay accumulated, the forest of *Avicennia alba* grew up rapidly. During then, seeds of *Avicennia officinalis* and *Ceriops decandra* have flown into the forests by tide through the tidal channels and in places where the ground level is a little lower, and this has changed the forest structure in the forested area largely.

5) Mangrove forests in the MEET Center

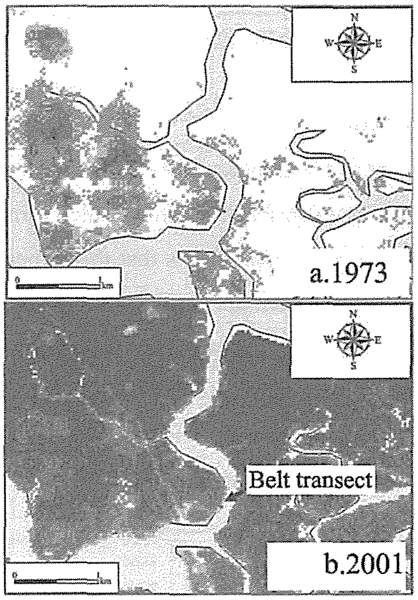


Fig. 12 Location of the belt transect at the MEET center and the forest expansion processes

The mangrove forests in this area are situated in the core zone of the Biosphere Reserve which is on the inter distributary basin along the inter distributary river of the delta. We carried out a detailed research in area of which width is 30-40m and the length is 182m, from the land to the river. By carrying out research in this area, we can study not only the small forests which has been survived the Vietnam War but new forests which has been growing today. The Fig. 12 shows the process of the development of the mangrove forests in the survey area. The spraying of the defoliants killed almost all of the vigorous mangrove forests and only a few *Phenix pardosa* remained on the slightly higher ground. Afterwards, the reforestation activities helped *Rhizophora apiculata* recover and hold up to the half area of the land in the survey area by 1989. Then by 1994, the forest stretched 60m towards the river. For the three years from 2002 to 2005, the forest stretched to the rest of the area (Y=105-132m). In recent years, *A. alba* has been rapidly grown up at the front of the reforestation area of *R. apiculata*. We carried out the field survey in August in 2003 and 2004 and March in 2005. The Fig. 13 shows the geographical features of the area we carried out the survey in and this area is in the site of the MEET Center. After we started the survey there, a promenade for observing the forests was installed in the center of the kodrat. The promenade was constructed on a bank built on the bottom of the mangrove forest. Today, the water is adjusted through a 20m wide watercourse in the north of the survey area. The tide water has flown without any remarkable intersections, but there seems a 15-30 minutes delay in the inflow of the seawater on the land side of the promenade.

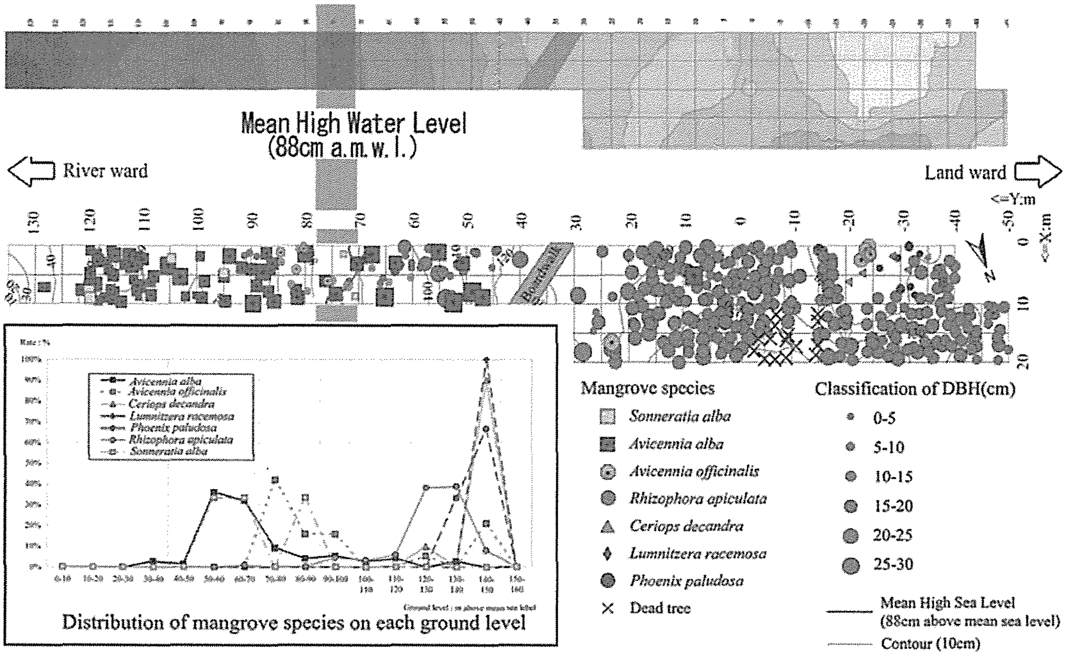


Fig. 13 Micro topography of the belt transect at MEET center(A), distribution of the species and the height of mangroves (B), density of the species in each location (C) in the MEET center, Can Gio.

We clarified the micro landform of the survey area using the field measurement by Auto Level (Fig. 13). The ground level of the survey area as a whole is higher than the Mean Water Level, and a part of the area is higher than the Highest High Water Level. This highest part is consisted by mounds which made by mud lobster. Towards the river, the ground level becomes lower in the survey area. Small tidal channels developed in a part in the survey area bend to the river at the riverbank. There are other tidal channels developed on the river side of the riverbank. The riverbank is almost flat except where there are the tidal channels. However, the ground level on the river side has ups and downs considering the Mean High Water Level as a datum point. The Fig. 13 shows the arrangement of the mangrove tress in the kodrat. The 13 mangrove species appearing there; *Avicennia alba, Avicennia marina, Avicennia officinalis, Ceriops tagal, Ceriops decandra, Rhizophora apiculata, Sonneratia alba, Sonneratia obata, Cordia cochinchinensis, Excoecarya aggalocha, Lumnitzera racemosa, Phenix pardosa, Xyrocarpus granatum,* and *Thespesia populnea*. Pure forests of *A. alba* develops on land of which ground level on the river side is up to 0.7m a.m.w.l. On land of which ground level is nearly the Mean High Water Level (0.7-1.0m a.m.w.l), mixed forests of *A. alba*, *A. officinalis, S. alba* and *X. granatum*. Usually such land is situated in the inner part then where pure forests of *A. alba* develop. On land of which ground level is more than 1.0m a.m.w.l, *R. apiculata* planted from 1980-1981 has formed pure forests, and they have developed largely on the land area. The part which has the highest ground level on the land area (1.40m a.m.w.l) has *P. pardosa,C. tagal, C. decandra, L. racemosa*.

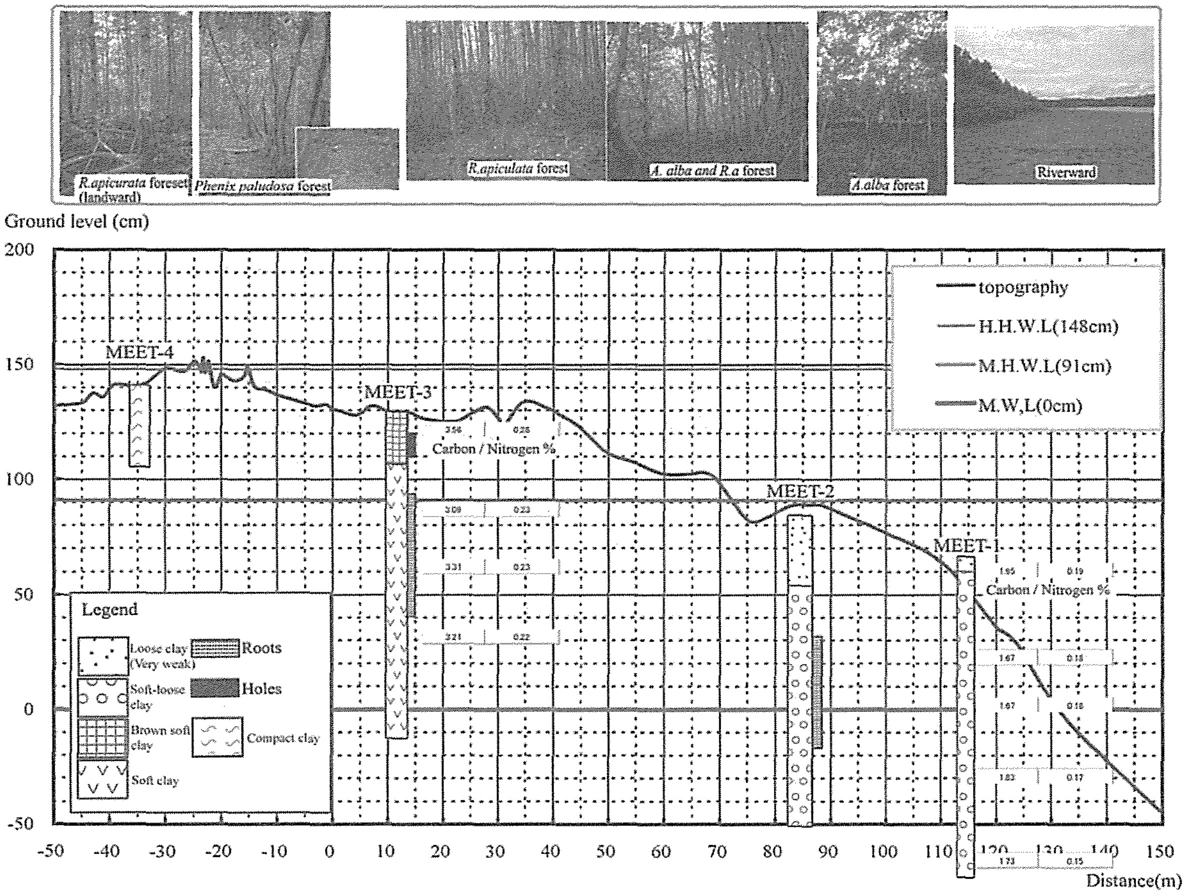


Fig. 14 Geomorphic and geological cross profile along the belt transect at MEET center

Fig. 14 shows the topographical and geological cross section of the survey area. We gather the core sample from the following points; Y=115m (MEET-1,X=0m, ground level 0.68m a.m.w.l), Y=85m (MEET-2,X=5m, ground level 0.85m a.m.w.l), Y=12m (MEET-3,X=2m, ground level 1.31m a.m.w.l),Y=-35m (MEET-4,X=2m, ground level 1.41m a.m.w.l) on the river side. We found that the soil that lies from the surface to the depth of 0.6m a.m.w.l in both the MEET-1 and MEET-2 was very loose and weak clay. As the changes in the distribution of the mangrove forests, we assume that the clay is new sedimentation which accumulated in the past ten and odd years. On the other hand, the MEET-3 sample gathered in an afforested area of *R. apiculata* contains a lot of organic substances, and it also contains carbon 1.5-2 times more than the MEET-2 sample does. We assume that this sedimentation is that stayed on the bottom of the forests which existed even before the Vietnam War. The forests *P. pardosa* dominates is on the other side (the land side), and the forests rarely sink under the surface of the water today. We gathered the MEET-4 sample from the forests. The sample is very solid clay and its upper surface layer has very strong reddish color. This characteristic is completely different from that of the sedimentation on the bottom of the other forests, and we assume that this sedimentation is older than the mangrove sedimentation today. We have not gained any samples to verify this hypothesis, but we assume that this could be the sedimentation from the time of transgrresion maximum at about 6000 years ago in Holocene period.

6) Changing process of mangrove geo-ecosystem in the MEET Center

The spraying of the defoliants killed almost all the mangrove forests except those of *P. pardosa* situated on the close level of the highest sea level. After the death of the mangrove forests, the land was left bare. While the land was left bar, soil erosion occurred. The clay produced upon the soil erosion and accumulated around the bare land up to the level of the mean highest sea level. This has created the new habitat of *A. alba*. *R. apiculata* planted at the area of slightly higher portion in land. Between the *R. apiculata* and *A. alba* forest, the mixed forest was established. The *A. alba* forest and the mixed forest was established by the transported seed from the outside by tidal current. Such forest arrangements are very much similar to the case of the Forest Park site.

4. Summary of destruction and restoration of mangrove forests in Can Gio Region

The mangrove forests in Can Gio Region have changed its forest structure and distribution being affected by the various and large-scale artificial impacts such as the Vietnam War. Today the area of the forests has nearly reached that of the forests which existed before the war by both reforestation and natural spread. How are the planted forests and natural forests going to survive without interfering with each other and going to change from now on? To understand these processes is to understand how the natural/biological ecosystem is going to be restored seizing the forestation as a chance. The changes in the mangrove forests in Can Gio district are summarized as follows.

① Spraying of the defoliants continued till 1970 bared the land. The soil of the land became oxidized, dried up, and its surface was eroded.

② The forestation conducted after 1978 restored the mangrove vegetation in the center of the district, while the mangrove forests in the suburb areas of the district were cut down.

③ After 1994, the natural forests spread towards the rivers and streams. The filling of small rivers and tidal channels caused the habitat of natural forests to be larger. At the same time, riverbank erosion caused the forests to grow less.

④ Since 2000, some suburb areas have been developed and turned into residence, salt field and shrimp ponds.

Based on the field survey, we analysed how the actual forests and land have changed at two survey points. One survey point is a forest on a tidal flat of the shore of a main stream that forms the delta. The other one is a forest on an inter distributary. The followings are the summary of the process of destruction, restoration and expansion at each forest.

1) **Forest Park Site:** Tidal flat mangrove habitat along the main stream of Can Gio deltaic area

The Fig. 15 shows the result of the analysis of the forest structure, landform and sedimentation where mangroves grow in the survey area in the forest park as well as the information about the time of destruction/expansion of the forest we gained from images. In this area, *S. alba* and *R. apiculata* used to be dominant, but they were all killed by the defoliants. In 1978, trees of *R. apiculata* were planted where there used to be a forest (the area located at 50m point to landward along the transect). They have grown up to about 15m high by today (2002), they have formed a homogeneous forest in a part. *A. officinaris* have naturally interfered with *R. apiculata* which had been planted on the land of which ground level is slightly higher, and natural regeneration has been occurring among them satisfactorily. Observing the conditions of young trees and sprouts there, we assume that *A. officinaris* will be dominant on this land in the future. Suspension materials created by the surface erosion on the bared land accumulated just besides the bared area along the rivers, and the area became larger. In 1993, trees of *R. mucronata* were planted on this land (Miyagi, 1995). In the report (1995), Miyagi explains that bushes of *A. alba* naturally grew up in and around the reforestation area of *R. mucronata*. The bushes have grown up to the forest of *A. alba* we confirm today. Some satellite images of the area we interpreted also prove that the expansion of the forest here mainly started after 1994. On the other hand, most of the planted *R. mucronata* died because the species did not suit the ground level of the land they were planted on. Today, the trees have almost extinct and we can confirm only a few of small trees in the survey area where the forest of *A. alba* is. On the land of which ground level is near the neutral tidal level, not the planted *R. mucronata* but *A. alba* which suits the ground level formed a forest.

Dominant species	*A.alba* forest	*A.officinalis* & *R. apiculata* mixed forest	*R.apiculata* forest
Tophography (Ground level)	30-40cm a.m.w.l.	60cm a.m.w.l.	50cm a.m.w.l.
Substructure	Loose Clay sediments	Soft Gray Clay sediments with organics	
Location on the line transect	-50m 50m ◄Riverward	450m 500m Landward►	
Plantation history	*R.mucronata* planted at 1983	*R.apiculata* planted at 1978	
After defoliation	Water (lower than mean water level)	Completely destroyed	
Original vegetation	Water (lower than mean water level)	*Avicennea* & *Sonneratia* forest	

Fig. 15 The geo- ecological rehabilitation process of the mangrove ecosystem in Can Gio Forest Park

2) **MEET Center Site:** Located at the margin of large interdistributary in Can Gio

The Fig. 16 shows the arrangement of the vegetation, landform/topography and the time of the formation/expansion of the forest in the survey are in the MEET Center. We assume that *Rhizophoraceae* or *Ceriops* spp. might have formed a forest here before the destruction. The land of the river side of the forest which exists today used to be a tidal flat on a lower tidal area. Spraying of the defoliants bared the land. The soil of the land became oxidized, dried up, and its surface was eroded. During 1980-1981, trees of *R. apiculata* were planted, and they have formed a homogeneous forest of which height is about 15m. By 1994, the forest spread about 60m towards the river. *A. alba, A. officinalis* and *R. apiculata* have grown on a loose area which have been newly developed. We assume that *A. officinalis* and *R. apiculata* have come in during the past 10 years or so while the ground level was gradually becoming higher. On the lower land near the river, only *A. alba* is dominant. This is a forest formed in the last 10 years of so after 1994.

(Mean High Water Level:88cm)

Dominant species	*A.alba* forest	*R. apiculata* & *A.alba*, *A.officinalis* mixed area	*R.apiculata* forest	Landward vegetation (*C.decandra*, *L.racemosa*, *P.paludosa*)
Tophography (Ground level)	30-70cm a.m.w.l.	70~100cm a.m.w.l.	Higher than100cm a.m.w.l.	Higher than 140cm a.m.w.l.
Y:location on the belt transect	132m	90m	45m	(-20~-30m) -50m
Plantation history			*R.apiculata* planted at 1980~81	
After defoliation			Part of forest survived	

Fig. 16 The geo- ecological rehabilitation process of the mangrove ecosystem in MEET Center, Can Gio

5. Interaction of Geomorphic Processes and Biological Processes

Here, we would like to see how the aforementioned change process of the mangrove forests and land in Can Gio district have worked as interaction of geomorphic processes and biological processes. The Fig. 17 shows the change processes made by now.

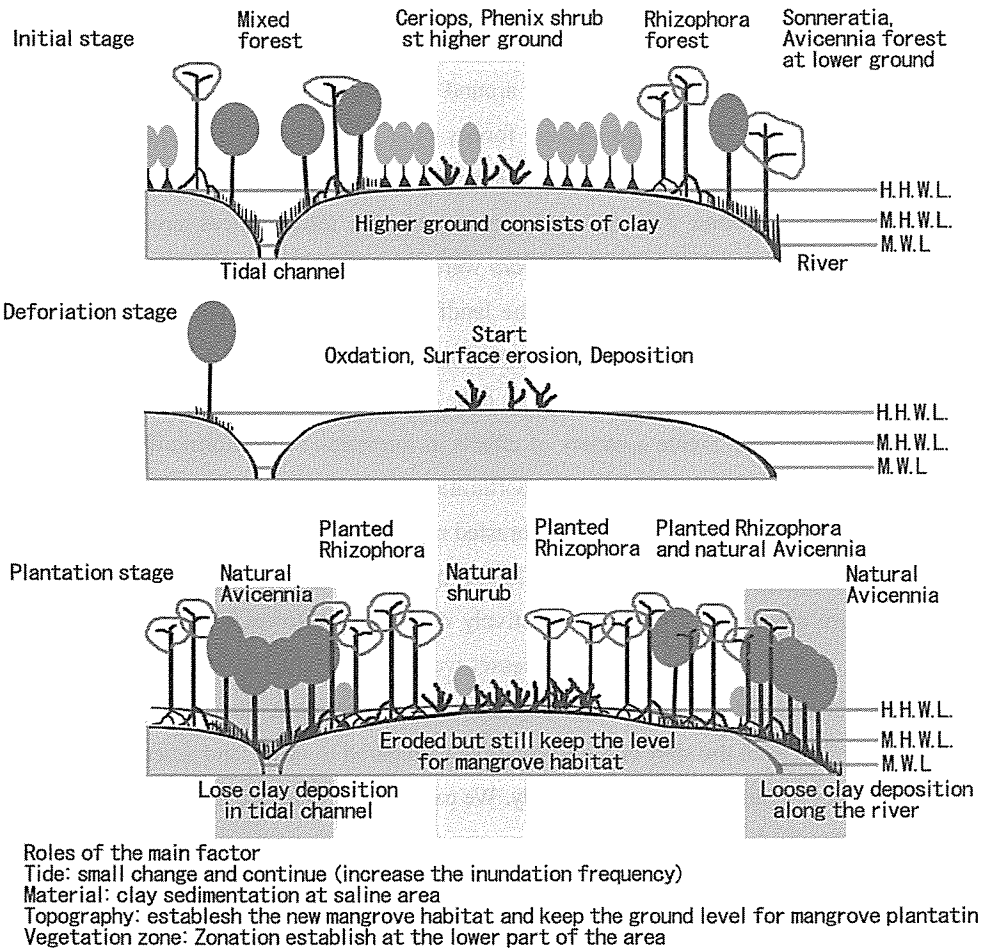


Fig. 17 Geo-ecological rehabilitation process of the Can Gio deltaic mangrove habitat

The mangrove forests in this area are typical deltaic mangrove forests. The delta which is the foundation of the forests was generally formed by the transgresion maximum of the middle Holocene. Afterwards, the tip of the delta and inter distributary basis were eroded under the influence of the small changes in the sea level, and finally the landform we see today was formed. A mangrove forest develops on the upper half of the tidal zone, and we assure that a change of the distribution was repeated during the process of the filling. Soil and sand carried from the upper reaches of the river accumulated in the delta, and the ground level reached around the highest high water level from the mean high water level. We assume that the stability of the type of the sea level after about 1000 A.D. and the existence of the forests have caused these changes.

Before the spraying of the defoliants, the most of the forests were on the upper part of the tidal zone. The soil consists of loose clay and mangrove organic materials was exposed to the sun directly, oxidized, dried up, and the biomass seemed to be broken down after the forests was destroyed all at once. At the same time, squalls during the rainy season caused the bare land severe erosion on its surface. The soil spread around the forests and finally formed the land on the upper half of the tidal area after accumulation. The mangrove species which grow up around the level of the middle tidal level became to form forests here. Forests of *Sonneratia alba* used to be here before the spraying of the defoliants. However, later *Avicennia alba* dominated here because its seeds spread and sprout effectively, and it also prefers the same ground level to grow up.

The local residents conducted forestation on this land too. They planted affordable *Rhizophora mucronata*. However, they were too much exposed to running water around the middle tidal level of the big river, and most of the trees died a few years after being planted. As the forests of *A. alba* became larger, the ground level also became higher. At MEET Center, the species of the mangroves have been mixed complicatedly because *R. apiculata* and *A. officinalis* which come from the seeds produced by the forested trees have come in. Affordable Rhizophora species such as *R. apiculata* and *R. mucronata* were planted on the land bared by the defoliants. But after forestation, there have been various changes of the landform, and seeds carried by tide have reached the forests and grown up. These factors have caused the forest structure to be complex. The forests of *R. apiculata* have contained *A. officinalis* and *C. tagal*, and such forests have become larger and lager.

The differences in ground level create a variety of effects in formation of landform affected by ebb tide and rivers. At the same time, they also create a variety of opportunities for seeds to flow into new land on ebb tide.

In this region, we have seen processes in which afforested mangroves were replaced by or mixed with natural vegetation, and re-accumulation of soil and sand. These processes, which were seen in the process of restoration/recreation, were always performed more actively on land with lower ground level. (The lower the ground level of land was, there more actively these processes were performed.) The interaction between landform and vegetation seems to be activated being interfered by movement of ebb/tide. These changes are what we saw during the first 20 years of so from the start of the forestation. Compared to other land where other kinds of trees were afforested, the changes occurred very much actively. We can say that these are the big characteristics of land where mangroves were afforested.

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Reference

Hayashi, K., Miyagi, T. and Nam, V.M. (2005) Bio-geomorphological processes and mangrove ecosystem rehabilitation –Case study of Can Gio mangrove forest Vietnam-. *Proceedings of the International Conference "Environmental hazards and geomorphology in monsoon Asia : Progress in process study and GIS mapping "* 101-111.

Hong, P.H. and Hoang,T.S. (1993) "Mangroves of Vietnam". The IUCN Wetland Programme, IUCN. 173ps.

Kiaya, Y., Suzuki, K. and Miyagi, T. (2001) Ecological rehabilitation and restoration of mangrove forests and coastal swamp ecosystem in Vietnam. Ann Rept. of FY 2000. 172-180.

Miyagi, T. (1995) Mangrove forest and natural environment at Vietnam coast. The Tohoku Gakuin Univ. Review (History and Geography), 27. 1-28.

Miyagi, T. (2002) Mangrove ecosystem development. *The third meeting of the project on ASPACO.* 30-37.

Miyagi, T., Ajiki, K. and Fujimoto, K. (2003) "Mangroves its processes, people and the future" Kokon shoin, Japan

Nam, V.N., Sinh, L.V., Miyagi, T., and Kitaya, T. (2002) 25 years of mangrove rehabilitation in Can Gio district, Ho Chi Minh City, Vietnam.

Nam, V.N., Thuy, N.S., and Thao, H.M. (Published age unknown) Vegtation and resources of Can Gio Forest Park.. *Society of forestry technique of Ho Chi Minh City*, 28ps.

Tri, N.H., Hong, P.N. and Cuc, L.T. (2000) Can Gio mangrove Biosphere Reserve Ho Chi Minh City. 41ps.