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THE EFFECTS OF HERBICIDES IN SOUTH VIETNAM

PART B. WORKING PAPERS: THE EFFECTS OF HERBICIDES ON THE MANGROVE OF SOUTH VIETNAM

NATIONAL ACADEMY OF SCIENCES-NATIONAL RESEARCH COUNCIL

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The Effects of Herbicides on the Mangrove of South Vietnam

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Mangrove forests occur in the tidal zone on most low alluvial coasts and along the saltwater estuaries of streams and rivers in the tropics. In South Vietnam (SVN) they form an extensive vegetative cover on sediments in salt and brackish water (see Classification of Vegetation Types Map, Map Section, Part A of the Report on the Effects of Herbicides in South Vietnam). They hold a place of some importance in the country's economy because of the number of products obtained from them--firewood, charcoal, timber, tannin, and dyes. They also provide a breeding place for birds, wild animals, and fish, and produce organic materials that are utilized as food by offshore marine life.

The mangroves of SVN are developed most extensively from Vung-Tau, southeast of Saigon along the coast of the Mekong Delta to the tip of the Ca-Mau Peninsula, and from there north along the west coast to the Cambodian border. Large tracts of mangrove are located in Gia-Dinh Province, south of Saigon (the area called the Rung-Sat), the estuaries of the distributaries of the Mekong River, and in the Ca-Mau Peninsula. Melaleuca woodlands--back mangroves in which Melaleuca leucadendron (Vietnamese Tram) is a major component--are sometimes considered part of the mangrove forest since they occur on the inland fringe of the mangrove. They are found south of Rach-Gia (U-Minh Forest), in small clusters inland on the Plain of Reeds, northwest of Loc-Ninh, and on the Cam-Ranh Peninsula.

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The published literature on the mangroves of SVN is scant. General descriptions of forest types, including mangroves, were published by French foresters during the period 1940-56. Two excellent studies of the mangroves of the Rung-Sat and the Ca-Mau Peninsula have been written by Vu-Van-Cuong (1964) and Moquillon (1949?), respectively. However, detailed studies of all the mangrove forests of SVN as well as accurate figures for the total area are lacking.

Maurand (1943) discusses the mangrove and Melaleuca (l'arriere mangrove) forests of Cochin China (SVN) and he states that there are 329,000 hectares of these forests. Vu-Van-Cuong (1964) states that the Department of Forests in 1944 reported that the SVN mangrove forests occupy 250,000 hectares, distributed as follows:

Ca-Mau Peninsula: 150,000 hectares, of which 120,000 hectares are classified as forest reserves;

Can-Gio and Phuoc-Hoa Region (Rung-Sat): 40,000 hectares classified as forest reserve but seriously impoverished;

Other localities of SVN: 20,000 hectares of nonclassified forests without very much value (economic timber); and

Central and Northern Vietnam: 40,000 hectares of unclassified dwarf mangrove, very impoverished.

Rollet (1962?), using aerial photography flown in 1952-53, arrived at totals of 725,000 acres (290,000 ha) for mangrove forests and 425,000 acres (190,000 ha) for Melaleuca forests. The Fact Sheet on Forestry in Vietnam (1969) prepared by the Directorate of Water and Forests and USAID Forestry Branch reported 1,546,850 acres (618,740 ha) of mangrove and

Melaleuca forests. The source of this acreage was compiled by the Joint Development Group from MACV "travel difficulty" overlays on Army Map Service maps.

The map for 1:250,000 Joint Operations Graphic (ground) prepared under the direction of the Defense Intelligence Agency and compiled in 1967, shows that mangrove and Melaleuca forests occupy 926,108 acres (370,433 ha) as determined by planimetry. These figures do not include the small tracts of Melaleuca forest that occur inland from the coast, such as are found in the Plain of Reeds, in sandy areas north of Saigon, and on the Cam-Ranh Peninsula

In the Committee's initial study of the mangrove forests of SVN, members made observations from helicopters and light planes. As far as security permitted, observations from the water and on the ground were carried out in the Rung-Sat and in the Ca-Mau Peninsula. These operations were supported by Vietnamese Army and Navy Forces as well as U.S. MACV personnel. The two areas visited will be further discussed in this report. Aerial photographs (black and white) taken before herbicides were used and others (color, black-and-white, and color infrared) taken at periodic intervals after the mangroves were sprayed have been studied in detail. Additional studies of mangrove biomass and productivity were carried out in Thailand where lack of security was not a problem. Literature on mangroves in Malaysia, Indonesia, Australia, Africa, Mexico, the United States (including Puerto Rico), and elsewhere has also been reviewed.

The mangrove forests of SVN are similar, or nearly so, in their

species composition to the well-known mangrove communities of the Malay Peninsula (except that the number of mangrove species is somewhat less), and, like them, consist of more or less zonal arrangements. These are characterized by the dominance of different genera and species of trees, the most important genera being Avicennia, Bruguiera, Ceriops, Rhizophora, and Sonneratia. In an undisturbed (completely natural) mangrove forest, the composition of the various zones depends mainly on differences in the tidal regime (relative length of immersion and emersion), which in turn depend on the height above mean sea level reached by the accumulated sediment. To a lesser extent, it also depends on other factors such as salinity and type of sediment (sandy or muddy). Like many other mangrove areas, the tidal forests of SVN are not entirely natural, because they were in the past, and to some extent still are, an important source of firewood and small timber. As a consequence, some of the forests have for many years been carefully managed and exploited on a regular rotation scheme. In some places seedlings of the more desirable species have been planted, as in the Ca-Mau, or have been haphazardly cut, as in the Rung-Sat. The system of management has modified the composition of the mangrove over large areas and natural stands have been replaced by even-aged stands.

The fact that many of these mangrove stands have been managed is important in understanding the effects of defoliation. Such stands tend to be dominated by plants of one species and of a similar age, and consequently a herbicide application tends to affect the individual trees in a uniform manner. It is also necessary to take into account the special methods by which such things as fruits are dispersed. In

Rhizophora, Braguiera, and Ceriops the seeds develop as seedlings on the plant and when they are large enough fall onto the water or into the mud, which they may pierce. In Avicennia the seedling develops to an advanced stage before separation from the much smaller fruit. Only in Sonneratia are more or less normal fruit found. Transport will be by tidal movement.

More than 40 species of trees and other plants are commonly found in the mangrove of SVN. However, only a few play a major role. In general, Avicennia alba is a pioneer species developing on newly-deposited sands or muddy clay banks along the sea face above the neap high water mark. It can also be found on river banks within mangrove areas. Rhizophora is a pioneer in some areas. Sonneratia alba is the pioneer species colonizing the deep-soft muds of estuary banks, while Ceriops tagal is usually found on consolidated earth banks. As silt accumulates and the ground level progressively builds up, Braguiera parviflora and Rhizophora apiculata seedlings begin to take root in the Avicennia stands. Rhizophora mucronata is found on muddy soils and normally seedlings establish themselves in Sonneratia stands. Overall, Rhizophora and Bruguiera species comprise over three-quarters of the species found in the well-developed mangrove forests of SVN.

Sonneratia caseolaris and Nypa fruticans are characteristic plants found on the banks of the small and large brackish rivers that intersect the mangrove forests. Lumnitzeria littorea, the palm Phoenix paludosa, and the fern Acrostichum aureum become established in the intermediate zone between the inundated mangrove and the nonflooded forests. As the ground is built up and the invasion of saltwater tides is prevented, a

freshwater swamp develops in which Melaleuca leucadendron usually becomes the dominant species.

SENSITIVITY OF MANGROVE SPECIES TO HERBICIDES

From observations in the sprayed mangrove areas of SVN, it is clear that applications of Agent Orange and Agent White applied at a rate of 3 gallons per acre are lethal to the major mangrove species. In treated areas, dead trees of the following genera have been identified:

Xylocarpus	Phoenix
Rhizophora	Scyphiphora
Sonneratia	Kandelia
Bruguiera	

The palm Phoenix paludosa appears to suffer substantial damage--including destruction of much of the upper crown--from one spray, but the survival rate is high. The pattern and rate of regrowth show that this is recovery of damaged individual trees rather than recolonization by new seedlings. However, numerous seedlings of Phoenix have been found growing under the dead fronds. Ceriops and Excoecaria seem to have the same range of sensitivity as Phoenix, as evidenced by several large trees growing in an area where Rhizophora and Bruguiera had been killed by herbicide spray. However, they are usually killed by two or three applications of the herbicide. Practically all the Ceriops and Excoecaria trees visible on current air photos are almost certainly survivors rather than new seedlings.

One genus of living large mangrove trees consistently seen in the herbicide-sprayed areas was Avicennia (see Figure IV C-3, Part A of the

Report on the Effects of Herbicides in South Vietnam). Surviving trees typically have the form of a cylindrical trunk 8-20 in. (20-50 cm) in diameter and 6.6 ft (2 m) high with coppice growth from the top of the trunk indicating top-kill and regrowth. The trees are no more than 10-13 ft (3-4 m) high. Several of these trees have been observed by before-spraying to after-spraying photography and by on-the-ground observation. A number of these surviving trees as well as Phoenix and Ceriops in herbicide-treated parts of the Rung-Sat occur in a pattern suggesting streaks of incomplete overlap between parallel spray patterns. These observations suggest that Avicennia may survive a reduced dosage or even the usual spraying of 3 gal/acre of Agent Orange or Agent White. Surviving Avicennia trees were also commonly found along the banks of streams, which are the sites usually occupied by this species.

THE RUNG-SAT

The mangrove formations 20 miles south-southeast of Saigon have developed on the deltas of the Dong-Nai River and the Saigon River (see Figure IV C-4, Part A of the Report on the Effects of Herbicides in South Vietnam). The major portion of this area is called Capital Special Zone by American Forces and Rung-Sat Special Zone by the GVN. It is a square, bordered on the north by a line from Nha-Be to Phuoc-Hiep, on the west by the Nha-Be River and Cua-Soirap, on the south by the South China Sea and Vung-Tau (Cap Saint Jacques), and on the east by Route 15 from Bien-Hoa to Vung-Tau. The Rung-Sat is located predominately in Gia-Dinh Province, with small areas in Bien-Hoa Province to the north and Phuoc-Tuy Province to the east.

The Rung-Sat is comprised of approximately 405 square miles (104,865 ha) of poorly-drained tidal swamp interspersed with many channels. Analysis of aerial photography by the Committee indicates that before the spraying of herbicides, approximately 51 percent of the area of the Rung-Sat was covered by mangrove trees, 6 percent was abandoned cultivation, 9 percent brush, 8 percent cultivated, 2 percent cultural features, 5 percent bare ground, and 23 percent of the area was covered by water, i.e., streams. The height of the land is no more than 6 ft, so that the highest tides during June-July and December-January cover the entire area. The delta is formed of recent alluvia from deposits of the Saigon, Dong-Nai, and Thi-Vai Rivers, and the sea. The soil is predominately clayey, acidic, and with large quantities of sulfides, which become oxidized to sulfates when exposed to air. Other shore strips of sand are found from Dong-Hoa to Can-Gio.

There are two high and two low tides each day, normally coming about 6 hours, 25 minutes apart. The high tide is from 10 to 11½ ft, when not influenced by heavy rains. Bore tides reaching 15 ft in height may occur with heavy rains. At low tide, many small streams are dry and major rivers and streams present high, steep banks. During normal high tides, over 85 percent of the area is under water.

The mangrove vegetation of the Rung-Sat prior to the increased American military presence of the 1960's was secondary formation, having been cut over and disturbed for many years. The only primary formations of mangroves can be found on the northern half of Phu-Loi Island; these were not cut by the villagers, as they were considered sacred and also

provided protection to the village of Phu-Loi from the monsoons. Rice farmers and fishermen living around the perimeter of the mangroves gathered construction wood and firewood. As a consequence, much of the mangrove of the Rung-Sat has been subjected to intense and often abusive exploitation.

Present State of the Rung-Sat

Approximately 57 percent of the Rung-Sat area was sprayed with herbicide between 1965 and 1970 (see Section III, Inventory of Sprayed Areas: Mangroves, Part A of the Report on the Effects of Herbicides in South Vietnam). In flying over the Rung-Sat, the impression one gets is of large areas of bare soil or mud flats with scattered trees or clumps of trees. This area supported dense mangrove forests before the herbicides were sprayed. In order to quantify the changes in the Rung-Sat, a southeast-northwest transect across the region was analyzed comparing 1958 World Wide Survey black-and-white photography (1:45,000 scale) with 1972 color photography (1:5000 scale) flown for the Committee by the Department of Defense. The transect is 18 miles (28.8 km) in length and 3750 ft (1125 m) in width (see Figure IV C-5, Part A of the Report on the Effects of Herbicides in South Vietnam). Eighty-five percent of the transect was sprayed from 1965 to 1970. The remaining unsprayed area, 15 percent of the transect, which is mainly under cultivation, is located in the northwest end of the transect.

By 1972, living mangrove trees remained on only 15 percent of the sprayed area of the transect, a decrease from 55 percent found in 1958. In this same period, bare soil with no vegetation had increased from 2.3

to 34.6 percent. There were increases of 3 percent in brush and herbaceous vegetation, 20 percent in bare soil, and 12 percent in tidal flats. Thus it is obvious that herbicides have caused a 40 percent reduction in the area of mangroves and that much of this area remains largely as bare soil. The palm Phoenix paludosa now occupies approximately 4 percent of the sprayed area of the transect and is not found in the unsprayed area. The fern Acrostichum aureum occupies approximately 6 percent of the whole transect area, of which two-thirds are found in the sprayed areas that were either formerly cultivated or covered with brush or heros (see Tables I and II).

Ground Obervations in the Rung-Sat

Site #1. The Committee's first ground observations of the defoliated area of the Rung-Sat was made on October 9, 1971, on the north bank of the Long-Tau River, about one mile (1.6 km) southeast of the junction of the Loi-Giang River and Fort Nga-Ba-Loi-Giang (see Figure IV C-5, Part A of the Report on the Effects of Herbicides in South Vietnam, for locations of study sites). The river banks had first been aerially sprayed with Agent Orange on March 1, 1965, and again on January 6, 1966. Since that time the area was directly sprayed with Agent Orange on November 11, 1967 and on August 4, 8, and 18, 1968. It was further sprayed with Agent Blue on August 7, 1968 and with Agent White on August 3 and 9, 1968. Twenty-three other spray missions from January 1966 to September 1968 passed close to the area so that spray droplets could have drifted onto it.

The soil at the site was a firm, compacted, heavy-textured, silty clay, reddish-brown and aerobic (presence of oxygen) to a depth of 10 in.

Table I.

Classification of the Rung Sat with percent sprayed and unsprayed
(From 1958 World Wide Survey photography)

Unit	Percentage of Area in 1958	Percentage Sprayed[a]	Percentage Unsprayed[a]
Trees	51.2	33.5	17.7
Formerly Cultivated	6.3	2.6	3.7
Brush and Herbaceous Vegetation	4.9	3.9	1.0
Cultivated	7.9	0.8	7.1
No Vegetation (Total)	5.4	3.3	2.1
Bare Soil		0.5	0.9
Mud Flats		1.0	0.1
Tidal Flats		1.8	1.1
Cultural Features	1.6	0.1	1.5
Water (Total)	22.7	13.1	9.6
Small Streams < 40 m		4.6	3.8
Medium Streams 40-200 m		2.4	1.3
Large Streams > 200 m		6.1	4.5
Totals	100	57.3	42.7

[a] Determined from 1972 photography.

Table II.

Comparison of sprayed and unsprayed portions of the Rung Sat transect in 1958 and 1972
(From 1958 WWS photography, 1972 Committee photography)

Unit	Percentage of Unit in Area - 1958		Percentage of Unit in Area - 1972	
	Sprayed	Unsprayed	Sprayed	Unsprayed
Trees	55.0	5.6	15.3	6.7
Formerly Cultivated	1.9	5.5	2.1	3.0
Brush and Herbaceous Vegetation	8.2	0.5	11.6	1.8
Cultivated	--	1.1	--	2.0
Debris	--	--	0.3	--
No Vegetation (Total)	2.3	0.1	34.6	0.4
Bare Soil	0.4	0.1	20.4	0.2
Mud Flats	0.8	--	0.4	--
Tidal Flats	1.1	--	13.4	0.2
Craters	--	--	0.4	--
Cultural Features	0.1	0.1	0.2	0.3
Water (Total)	18.0	1.6	20.7	1.0
Small Streams <40 m	4.0	1.4	4.2	0.5
Medium Streams 40-200 m	2.3	0.2	2.2	0.5
Large Streams >200 m	11.7	--	14.3	--
Totals	85.5	14.5	84.8	15.2

(25 cm), and bluish-gray and anaerobic (without oxygen) below 10 in. (25 cm). A soil profile showed many root channels and crab holes, which served to drain water into subsurface channels that discharged into nearby erosion channels or drainage ditches. Crabs were particularly numerous. The site was visited during a heavy rainstorm, during which standing pools of brown, muddy water were observed as well as muddy runoff water from the bare areas. Surface runoff and the resultant sheet erosion can be caused by a decrease in permeability of the soil from compaction, along with the leaching of the surface of the saline soils by rainwater.

We approached Site #1 from the Long-Tau River on a South Vietnamese Navy PFC (Patrol Craft, Fast). As the tide was low, we stopped in the mud below a 10-13 ft (3-4 m) bank. At the top of the bank, the general impression of the area was that of a vast mud flat sparsely covered by vegetation. Numerous stumps of cut trees and the lack of trash such as tree trunks and branches on the ground indicated that the trees had been cut and removed, probably for firewood and charcoal. (See Figure 1 for generalized diagram of the defoliated area of the Rung-Sat Special Zone.)

Along the edge of the bank running inward for about 165 ft (50 m) were grassy mats of Paspalum vaginatum with some Fimbristylis dichotoma, Cyperus javanica, and Diplachne fusca. Several clumps of the thorny shrub Azima sarmentosa and the vine Wedelia biflora formed thickets 3.3-5.0 ft (1.0-1.5 m) high. Some patches of Acrostichum aureum were also present. Scattered throughout the grassy mats were seedlings of Ceriops (probably C. decandra) 4 in. (10 cm) high. These seedlings were probably washed in as seeds six to eight months before and trapped by the grass. One plant of Sonneratia caseolaris 3.3 ft (1 m) high was

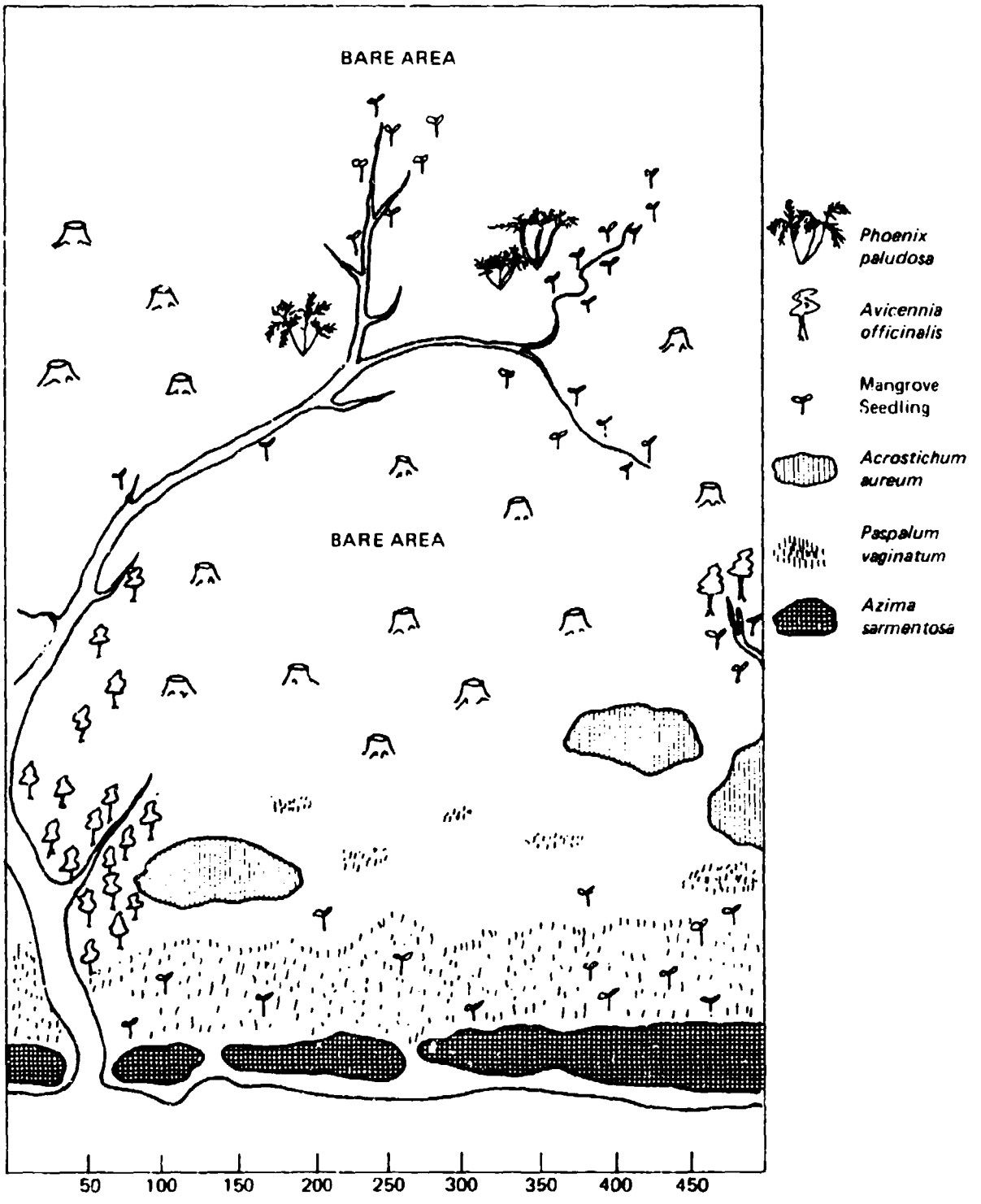

Fig. 1 Generalized Diagram of the Defoliated Area of the Rung Sat Special Zone

observed. An extensive area of the ground was completely barren 55-110 yd (50-100 m) inland from the river bank.

A return visit to the same area on August 30, 1972 revealed several features of interest. The young plants of Ceriops formerly observed were not evident. The Sonneratia had now grown to 10 ft (3 m) in height. Three transects 33 ft (10 m) wide and extending 330 ft (100 m) from the river bank inland to the barren areas gave counts of 23, 12, and 9 seedlings (mostly Ceriops but also Rhizophora). The same observations were made when the area was visited on December 16, 1972. Seedlings were less abundant on this date; it was estimated that there was less than 1 seedling per 120 square yd (100 m^2). The seedlings were present exclusively in the grassy area; none were seen in the barren area further inland. Moreover, most seedlings did not seem larger than those observed almost a year earlier. Thus, it is possible that although the seedlings germinate and pass the earliest stages of development, they do not become permanently established. Apparently the young seedlings had been unable to develop into plants--either because of the adverse environmental conditions such as heat, low pH (acid), or dryness--or because of destruction by crabs.

Site #2. This site was visited on January 31, April 11, and December 16, 1972. It is located at the junction of Rach-Toc-Roi and Tac-Binh-Cau on the west bank 2640 yd (2400 m) northwest of the hamlet of Xom-An-Thit.

The site is completely cleared of mangrove trees; however, numerous stumps indicate a former dense mangrove stand. Near the river bank, thickets 3.3-5.0 ft (1.0-1.5 m) high of the spiny shrub Azima sarmentosa

with Pluchea indica and Acrostichum aureum were observed. Mats of Paspalum vaginatum with Diplachne fusca extended from the river bank inland for 66-330 ft (20-100 m). Paspalum was observed in flower; however, it seems to colonize vegetatively from rhizomes. Again, in these grassy mats several seedlings of Ceriops (probably C. decandra) and Avicennia officinalis were found scattered throughout. The grassland probably plays an important part as a filter or trap preventing mangrove seedlings from being washed into the interior.

Patches of the fern Acrostichum aureum were observed, with fronds reaching a height of 20-40 in. (50-100 cm). Wedelia biflora and Pluchea indica were also present. Except for a few clumps of the palm Phoenix paludosa, the soil was totally barren 110 to 220 yd (100-200 m) inland from the river bank. Species of plants with small seeds such as Paspalum, Diplachne, and Fimbristylis could be transported to these areas. The soil may have undergone chemical modification such as a decrease in pH, which would prevent growth of plants. People interviewed in a nearby village, Nga-Ba-Dan-Xay, said that the soil has a high concentration of alum, like the soils in the Plain of Reeds. Crabs (Uca and Sesarma) were abundant in the area and may well feed on the seeds and small seedlings.

Six months after the first observations were made, the site was visited again. The Azima sarmentosa thickets had not changed; however, many new seedlings of this plant were found nearby. New seedlings of Avicennia marina were recorded together with seedlings of the vine Derris trifolia. The barren areas were still without vegetation; no mangrove seedlings were recorded. Ceriops seedlings were estimated during

the December 16, 1972 visit to average one per 12 square yd (10 m^2).

Site #3. This site was located on the west bank of the Dua River, 4400 yd (3960 m) south of the hamlet Xom-An-Thit, and was visited on the same days (January 31, April 11, and December 16, 1972) as Site #2.

The vegetation was similar to that of Site #2, with the exception that there were no Azima sarmentosa thickets on the river banks. Azima mixed with Acrostichum and Phoenix occurred inland. In the conspicuous grassy mats of Paspalum vaginatum, seedlings and young plants of Ceriops and Avicennia were found. Observations made six months later showed an increase in the number of seedlings of both species as well as new seedlings of Scyphiphora, Bruguiera, and Derris. Acrostichum aureum formed dense patches in this area.

Site #4. Site #4 was located on the west coast of the southern end of Thanh-An Island bordered by the Nga-Bay River, an area that has been heavily sprayed as it lies along the main shipping channel to Saigon. It was first sprayed in March 1965; spray missions over the area followed in 1966 and 1967.

At this site, the high banks observed in the first three sites were absent. Because the land surface is lower, it is probably inundated each month and is cut by many small streams. Azima and Wedelia thickets, so prevalent at the first three sites, were found only infrequently on a few higher ridges. Scattered patches of Paspalum vaginatum were also present. The higher ground at this site was dry and the soil cracked in a block-like pattern that may have provided an inhospitable environment for plants. Adjacent to these higher areas, patches of Acrostichum aureum were found. Many large stumps of Ceriops, 330 ft (100 m) inland from the

channel, indicate a former dense mangrove stand. Considerable numbers of Ceriops plants 3.3-5 ft (1.0-1.5 m) high were observed. A small number of Rhizophora plants with well-developed prop roots indicating an age of 4-5 years were found near the shore. Several large Avicennia trees were scattered in the area, probably survivors with new regrowth together with seedlings of Sonneratia and Bruguiera. Clumps of mature Phoenix paludosa, 16.5-23 ft (5-7 m) high, plus young plants of Phoenix, 3.3-6.6 ft (1-2 m) high, were noted in the lower area a considerable distance from the channel.

Soil erosion at this site was estimated from the position of the roots of Avicennia. Several of the larger trees that had survived had older horizontal cable roots exposed above the surface and newer subsurface cable roots with pneumatophores. The older cable roots are assumed to have been below the ground and to have borne pneumatophores at the time of herbicide spraying. The difference in the levels of the soil surface now and at the time of spraying indicates that some 4-6 in. (10-15 cm) have been eroded away. Once-buried Ceriops roots now elevated above ground and grass clumps on columns 4 in. above the surrounding bare soil are also positive evidences of accelerated erosion.

Site #5. Site #5, visited only once on August 31, 1972, was located on the east bank of the Nga-Bay River, about 80 yd (75 m) east from Nha-Ba-Diong-Xai strong point and extending about 220 yd (200 m) along the river bank and 121 yd (110 m) inland.

The site was largely bare; the western end was disturbed by traffic from the strong point (empty shell cases and other refuse). Patches of Paspalum vaginatum occurred approximately 44 yd (40 m) inland, with some smaller patches of Fimbristylis polyteschoids and Cyperus malacensis.

Wedelia and Avicennia were absent, however. Small Acrostichum and grasses of growing Phoenix were observed. In the entire area of 24,000 yd^2 (20,000 m^2) some 36 Ceriops seedlings with 2-3 leaf pairs were found in the grassy portion.

CA MAU PENINSULA

The southern tip of SVN, the Ca-Mau Peninsula, was almost entirely covered with dense mangrove forests up to 1968. Several large rivers, the Bay-Hap, Cua-Lon, Dam-Dai, and Bo-De, drain the interior sections of the Peninsula and also bring in salt water from the sea by a dense network of drainage streams that run in all directions.

Up to 1928 there was indiscriminate cutting of the mangrove for charcoal from the logs and tannin from the bark. French foresters established forest reserves in 1928 and started to manage the mangrove systematically. In 1934 a major program was established: cutting was regulated by law, canals were dug, and denuded areas were replanted, all with the aim of managing the mangrove for the charcoal and tannin industries. During the next 15 years, 38,000 hectares were replanted, mainly with Rhizophora apiculata. Moquillon (1949?) discusses the management of the Ca-Mau mangroves and the production of charcoal and tannin.

Thus, prior to the arrival of the American forces in the Ca-Mau Peninsula, the mangrove forests were mainly even-age stands of Rhizophora apiculata with some Bruguiera parviflora. These trees often reached 100 ft (30 m) in height and 3.3 ft (1 m) in diameter. In areas where there was a build-up of sediments near the shore, Avicennia alba and Excoecaria agallocha were the first colonizers, followed by Rhizophora apiculata and Bruguiera

parviflora seedlings, which rapidly took over. Recorded measurements show that Rhizophora has an annual growth of 3.3 ft (1 m) in height and 0.28 in. (7 mm) in diameter and it has been calculated that it would take up to 30 years before newly-deposited silt initially colonized by Avicennia could be replaced by Rhizophora. In addition to Rhizophora, Ceriops tagal could also be grown as pure stands. Inland pure stands of Nypa palm line the small streams where the salinity is lower than the large streams leading to the sea.

Bare or grassy swamps can be found in the interior. There Rhizophora trees disappear because of stagnant, brackish water diluted by rain accumulation of decaying organic matter, and because of diminished salinity and a rise in temperature.

Present State of the Ca-Mau Peninsula

Herbicides were first used in the Ca-Mau Peninsula in 1962 when the Cua-Lon and Bay-Hap Rivers, the canals between them, and targets along the Ong-Doc River were sprayed. The major spray missions were carried out in 1967 and 1968 as described in Section II, Part A of the Report on the Effects of Herbicides in South Vietnam, and the damaged areas of the Peninsula still stand out in 1972. The map of the present state of the Ca-Mau Peninsula shows that 52 percent of the area is bare of mangrove trees (see Figure IV C-10, Part A of the Report on the Effects of Herbicides in South Vietnam).

Ground Observations in the Cau Mau Peninsula

Site #1. This site, visited on October 11, 1971, was located 12

miles (20 km) west of Nam-Can on the south bank of the Cua-Lon River. The site includes untreated mangrove forest and an area sprayed with Agent Orange on December 7, 1967. The area along the banks of the Cua-Lon River was also sprayed in June 1963 and in October 1964 with Agent Purple (3 gal/acre). In the sprayed area there were many dead tree snags, stumps plus wood debris on the ground. The dead trees as well as the vegetation in the unsprayed area suggest that dense mature mangrove forest of Rhizophora once covered the area.

A considerable amount of revegetation had occurred along the river edge. Rhizophora apiculata and Bruguiera parviflora were particularly prevalent. These plants along the river edge were 3.3-5.0 ft (1.0-1.5 m) in height. Dense, even-aged stands of Avicennia, 3.3-6.6 ft (1-2 m) high, covered the mud from the river bank to 22-23 yd (20-30 m) inland. In 10 quadrats of one square meter an average of 45.7 seedlings/m^2 were counted--mainly Avicennia, but with some Bruguiera and Rhizophora. Beyond this distance, the ground looked completely bare. Several examples of Rhizophora and Avicennia with dead branches in the crown but with abundant regrowth were observed. In one case the Rhizophora was in fruit. Several mature Excoecaria trees in full leaf and in flower were observed in areas where all the Rhizophora and Avicennia had been killed by the herbicides. This observation suggests that Excoecaria may be a more resistant tree. Also, several large Avicennia were observed to be fruiting heavily within the sprayed area. As in the Rung-Sat, these living trees occurred in linear patterns, a fact suggesting that they may have received a lower dose of herbicide at the edge of the spray run.

Site #2. This site was located 3 miles (5 km) northeast of Nam-Can on the west bank of the artificial canal Kinh-Ngang. The area was sprayed with Agent Purple on September 20-21, 1962, with Agent Orange on April 8, 1970, and with Agent White on March 11 and April 21, 1970. The banks of the canal were also sprayed in 1962. The whole area was under 12 in. (30 cm) of water at the time of our visit (October 12, 1972), so that observations on the soil could not be made. However, large crab mounds rising above the water were frequent, especially around dead tree stumps.

Inspection of the nearby unsprayed area showed that the mangrove community was composed of mixed species, including Avicennia, Rhizophora, Bruguiera, and Ceriops. The trees were 16.5-23.0 ft (5-7 m) high. Fifty-five yd (50 m) inland from the canal was a large, open area with dead stumps, so presumably the area had been heavily logged and not defoliated. Further from the canal a dense, almost pure stand of Rhizophora rose to about 33 ft (10 m) high. Many of the mangrove trees were fruiting and flowering.

In the sprayed area, the edge of the canal primarily contained Avicennia seedlings, but a few mature plants were also present. Fifty-five yd (50 m) inland there was a large open area supporting patches of Paspalum vaginatum with tufts of Cyperaceae, groups of dead and living Rhizophora, groups of Avicennia, some 33 ft (10 m) high, and scattered Excoecaria. Stumps left by woodcutters were visible. These stumps with prop roots were decaying rapidly and crumbled when stepped upon. A few Rhizophora seedlings had become established in the Paspalum. Behind this area were larger dead standing trees, with an occasional group of Phoenix that had survived.

NATURAL RECOVERY OF THE AREA OF DESTROYED MANGROVE FORESTS

While there is no doubt about the extent and the degree of damage caused by the herbicides, there is considerable comment and disagreement in the literature on the recovery of the mangrove communities. For example, Tschirley (1969) thought that reestablishment might occur in 20 years. His statements were based on observations of regeneration in 1968 of areas defoliated in 1962 and on a timetable for establishment of Rhizophora-Bruguiera forest of 20 years from McKinley (1957). In contrast, Westing (1971) states

> Herbicidal attack appears to prevent the reestablishment of any new plant community, true mangrove, rear mangrove, or otherwise. How permanent this exclusion is remains to be seen. All that I can say now is that a sprayed area appears to be impervious to recolonization by plants for at least 6 years, and that no clear evidence of recolonization has been observed anywhere by us or others.

Orians and Pfeiffer (1970) also felt that Tschirley's estimate of time for recovery may be somewhat low. In fact, they suggest that reestablishment of the original forest may be impossible except along the edges of the river channels and backwaters. Meselson and co-workers (1970) have indicated that essentially all mangrove vegetation was killed by spraying and that preliminary ground and aerial inspection in 1970 showed little or no recolonization by mangrove tree species after three or more years. They did not discuss natural revegetation but stressed the urgency of replanting mangrove species.

Success of natural regeneration in the mangrove forest seems to depend upon a number of environmental and physiological factors. These include depth of water, frequency of flooding, soil moisture (on high areas),

salinity of water and mud, nutrient availability and pH status of soil, previous occupants of the area, presence of debris on the mud surface, predation by crabs, and presence of adequate seeds and seedlings for restocking.

From observation and data gathered on site, depth of water, salinity and pH of the water and mud, temperature of the mud surface as well as nutrients appear to be in the normal range for plant growth and should not limit regeneration (see Chapman 1966, Davis 1940, Macnae 1966, Watson 1928). The situation may be different in relatively elevated areas, which are flooded only at highest tides. Here, presumably because of insufficient leaching, higher salinity levels (up to 50 ppm as compared to 24-32 in small nearby creeks) and also higher soil temperatures may be unfavorable for the establishment of seedlings.

Soil nutrients were found to be in a range that should not limit plant growth; in fact, the nutrient content of the soil in completely bare regions in the Rung-Sat was higher than in a nondefoliated mangrove on the Ca-Mau Peninsula, suggesting that the nutrient status of the soil was not the reason for the failure of any extensive revegetation.

The Committee made herbicide determinations in Rung-Sat soil and experimented with spraying selected plots and then planting seedlings at different times after herbicide application. These investigations showed that while there are residues (2,4,5-T and picloram) in the Rung-Sat, they are far below levels that would inhibit seedling establishment. In fact, seedlings could be successfully planted as early as 3 weeks after a herbicide treatment equivalent to the dose from one herbicide mission.

The experiments indicated also, however, that the size of the denuded area affects the establishment of mangrove seedlings. Seedling survival on a relatively large area completely cleared of vegetation by hand (with no subsequent herbicide application) was poorer than on small plots cleared within an undefoliated mangrove (survival of Rhizophora seedlings after 34 to 35 weeks, between 71 and 79 percent versus 3 to 4 percent.[a]) Supporting this conclusion is the observation that the seedlings that were found in defoliated areas in the Rung-Sat were mainly among grass, rather than on completely bare soil. The following table presents data from various sites in the Rung-Sat and Ca-Mau Peninsula obtained by Committee members:

Site	Treatment	Temp. (°F)	pH	Salinity (‰)	Tide
Rung-Sat (North)	canal water	80	--	16	ebb
Rung-Sat (Central)	canal water	--	--	22	--
Song-Cau-Lon	defoliated marsh	92	6.5	22	high
Song-Cau-Lon	defoliated marsh	90	6.0	21	high
Kinh-Ngang	defoliated marsh	80	6.0	21	high
Kinh-Ngang	undefoliated marsh	82	6.0	20	high
Kinh-Ngang	canal water	80	6.0	27	high
Kinh-Ngang	canal water	80	6.5	22	high
Vung-Tau	sea water	--	--	33	--

In the Ca-Mau area, large quantities of stems, roots, and other trash were present on the mud surface in the bare areas, and relatively few seedlings were encountered. Trash may act as a filter preventing mangrove seeds and seedlings from reaching inland areas and also providing a hazard to young seedlings (movement of trash by tides breaking, damaging seedlings) that had become established (Watson 1928, Walker 1938). On

[a] See Zinke, P.J. Effect of herbicides on soils in South Vietnam, Part B of the Report on the Effects of Herbicides in South Vietnam, for further discussion of soils.

the levees abundant regeneration has occurred. In the Rung-Sat area, bare mud flats with stumps were observed, with large amounts of trash present in the tidal creeks. North of the village of Dong-Hoa, standing dead trees and trash are still abundant. Less trash occurred in this area where woodcutters had removed the stems. Moquillon (1949?) states that trash requires about 2 years for breakdown. Our observations indicate that after 3 years the trash is still present but appears to be rapidly decaying.

The availability of seeds and seedlings for revegetation of the sprayed areas appears to be a critical factor. A large number of seedlings of Bruguiera and Rhizophora were observed in floating trash on the Cua-Lon River in the Ca-Mau Peninsula, and many plants of Avicennia, Bruguiera, Rhizophora, and Excoecaria were observed in fruit in the nearby nonsprayed areas. These observations suggest that adequate seeds and seedlings are available for regeneration in the Ca-Mau area. In contrast, relatively few seeds or seedlings were observed floating in the canals of the Rung-Sat. The major seed source is the northeastern area, which was not sprayed but has been heavily cut over by woodcutters. Distribution over the Rung-Sat from this area would be exceedingly slow. Crabs, which were observed to be numerous both in Ca-Mau and the Rung-Sat, may destroy mangrove seedlings colonizing the sprayed areas. The Committee observed some damage to seedlings by crabs in plantings carried out near Vung-Tau. Dixon (personal communication 1972) reports that crabs (Sesarma) ringbark seedlings and can cause severe damage in new plantations. Watson (1928) and Macnae (1966) also report damage by crabs to mangrove regeneration.

In the sprayed areas in the Ca-Mau, the river and canal banks inland

to 220 yd (200 m) are being stocked with the desirable mangrove species Rhizophora and Bruguiera, which should flower in four years. Inland from the canal and river banks, the process of revegetation is slower, probably due to the trash on the ground preventing seedling distribution. In two or three years from the present, it is likely that the trash will have decayed and seedling dispersal over the area by water should be possible. Thus, these areas may develop into mature forests in 25-30 years.

The Rung-Sat is a different case. The major seed sources are not near. If allowed to develop, the living Avicennia and Ceriops, which were apparently more resistant to herbicides than other mangrove tree species, will produce seeds that will help to recolonize the area. Given normal development, these plants should flower and fruit in a few years and will help supply seeds and seedlings. However, it appears that as soon as young trees grow to pole size they are cut and removed for firewood. The number of generations required to restock successfully the entire Rung-Sat must remain speculative. Since Rhizophora and Bruguiera seed sources are very scarce, a typical mature mangrove forest may take decades.

ALTERNATIVES TO THE NATURAL REVEGETATION OF SPRAYED MANGROVE

If the sprayed areas are left untouched, they will eventually be covered with typical mangrove species. However, there are other courses, such as reestablishment of forests through planting or development of agriculture in suitable locations, conversion of land to agriculture and/or pasture, and establishment of large-scale saltwater fish ponds along the formed edge.

Mangrove forests in SVN have been managed in the past for charcoal,

firewood, and timber (Moquillon 194?). In the management of these forests, areas have been clear-cut, and where natural revegetation was too slow, replanting was performed. Seedlings of Rhizophora apiculata were collected from beneath mature trees or from the water and were pushed into the mud a few inches. In several days, these seedlings formed roots, developed leaves in 15 days, and grew over 3.3 ft (1 m) in one year. About 20,000 seedlings were required to plant 2.5 acres (1 ha).

To test various methods of replanting mangrove seedlings, trials were carried out during March and August 1972 on Thanh-An Island in the Rung-Sat. The island had been sprayed at least once and along the west coast several times. Seedlings of Rhizophora apiculata and Ceriops tagal gathered from trees in the unsprayed areas of the Rung-Sat were used in these tests. The planting tests were studied and evaluated in December 1972. The results indicate that Rhizophora and Ceriops seedlings planted by hand will survive and grow. Between 50-66 percent of the seedlings planted in the higher and drier areas survived; between 80-85 percent survived in moister, more suitable areas.

To test a quicker planting method, seedlings of both Rhizophora and Ceriops in various packages were dropped from a helicopter. Seedlings packaged with sand to which a slow-releasing fertilizer had been added were found to survive and to grow very rapidly. Other seedlings, packaged without fertilizer or with no packaging, did not fare as well. It is concluded that mangrove seedlings will survive and grow in the Rung-Sat but that hand planting seems to be the best method to ensure survival.

The drier and/or sandy soils in the Rung-Sat and the area where Phoenix paludosa and Excoecaria agallocha are found might successfully

be replanted with the nonnative Casuarina equisetifolia. This species is widely spread on the coast of the Indian and Pacific Oceans and has been much planted elsewhere. It grows well in brackish and acid soils. It is planted to hold sand from drifting in many coastal areas but also has value as a wood that is hard and durable for construction and burns quickly in cooking fires. Moquillon (1949?) discusses reforestation of silted uplands with Casuarina once diking was accomplished to prevent flooding from tides.

The sprayed areas could be converted to agriculture and/or pasture usage. Moquillon (1949?) has shown that excellent results can be expected from crops such as corn, sorghum, manioc, Cucurbitaceae, sweet potatoes, bananas, roseapple, etc., on organic silts found between mangroves and the "back mangrove" area. Areas that have been covered by Sonneratia caseolaris and Nypa fruticans--plants that indicate nonacid soils with a low content of sodium salts--could be transformed into rice paddies. Such areas south of Nha-Be and Ap-Bao-Sera have been managed in this way. Dikes would have to be built to protect the rice paddies from flooding by too-brackish water; paddies would be irrigated only by rainwater during the rainy season and would give only one harvest per year. Sonneratia caseolaris and Nypa palms would have to be planted along the dike to combat erosion and break the force of currents. Vu-Van-Cuong (1964) mentions such rice paddies along the Bien-Hoa-Phuoc-Thy Road, and the whole region in the quadrangle Nha-Be, Long-Thanh, Bien-Hoa, and Phu-Cuong, which is covered with rice paddies and orchards. Diked areas including rice paddies on the sprayed areas in the Ca-Mau Peninsula observed in the 1[illegible] aerial photography indicate that rice can be and is being grown in mangrove areas

sprayed with herbicides.

Sprayed areas where Rhizophora apiculata was dominant, especially toward the seaward face of the mangrove area, can be transformed into large ponds for raising fish and crayfish. Such fish-raising has been successful along the northern shores of Java and Manila Bay in the Philippines (Macnae 1966).

Areas in the Rung-Sat that exhibit marked erosion could be stabilized by Paspalum vaginatum. This is a creeping grass native to Africa and the Americas but now widely distributed throughout the tropics. It has been used effectively in Western Australia for the reclamation of salt-affected and eroded areas. Also, areas presently covered with this salt grass could be utilized as pasture. The grass is quite palatable to cattle and able to withstand light grazing (Barnard 1969).

CONCLUSIONS

1. The mangroves of SVN have been seriously affected by the military use of herbicides. About 36 percent of the mangrove area--262,347 acres (104,939 ha)--has been sprayed with resultant kill of vegetation. Some 14 percent of the Melaleuca woodlands, 59,260 acres (23,704 ha), has also been sprayed with herbicides. In the Rung-Sat, one of the two study areas, 57 percent of the overall surface area had been sprayed; this covered approximately 41 percent of the vegetation. In a transect across this area, 27 percent of the tree area remains after spraying. In the Ca-Mau, the second study area, 52 percent of the dense mangroves was sprayed, with a consequent destruction of the trees.

2. Many of the tree species of mangrove are very sensitive to the herbicides Agent Orange and Agent White applied at a rate of 3 gal/acre, and can be killed with one treatment. Avicennia, Ceriops, and Excoecaria were usually not killed with one treatment, but exhibit some top-kill and regrowth.

3. Air and ground observations have confirmed that increased sheet erosion has occurred in the dead mangrove areas of the Rung-Sat. Erosion of the river banks by the waves created by large ships passing through the shipping channels to Saigon were also observed.

4. The numerous observations made by the Committee suggest that mangrove regeneration is proceeding naturally in the Ca-Mau area where seedlings are well distributed over the sprayed areas. The areas inland from the river banks are revegetating more slowly. Delay in recolonization may be due to large quantities of trash on the ground, which restrict the movement of mangrove seedlings floating in the water, as well as the fact that high tides reach the higher ground inland less frequently. An adequate seed and seedling supply appears to be present to sustain revegetation and, in addition, isolated clumps of surviving trees within the defoliated forest are reproducing and will provide additional seed sources. Revegetation was also observed in the Rung-Sat area, but the speed of recovery is apparently proceeding at a much slower rate. One possible limiting factor to revegetation in this area is the lack of adequate sources of seeds and seedlings and continued intervention of woodcutters.

REFERENCES

Barnard, C. 1969. Herbage plant species. Division of Plant Industry, C.S.I.R.O., Brisbane.

Chapman, V.J. 1966. Some factors involved in mangrove establishment. In Scientific problems of the humid tropical zone deltas and their implications, UNESCO, pp. 219-25. 422 pp.

Davis, J.H. 1940. The ecological and geological role of mangroves in Florida. Carnegie Inst. Washington Publ. 517:303-412.

Fact sheet on forestry in Vietnam. March 1, 1969. Prepared jointly by Directorate of Waters & Forest and USAID Forestry Branch. 14 pp.

McKinley, T.W. 1957. The forests of free Vietnam: a preliminary study for organization, protection, policy and production. Forest Resources Advisor, USOM/Saigon. 93 pp.

Macnae, W. 1966. Mangroves in eastern and southern Australia. Aust. J. Bot. 14:67-104.

Maurand, P. 1943. L'Indochine forestiere. Gouvernement General de L'Indochine, Hanoi.

Meselson, M.S., A.H. Westing, J.D. Constable, and R.E. Cook. 1970. Preliminary report. Herbicide Assessment Commission, AAAS. 8 pp. (mimeogr.)

Moquillon, C. 1949? La foret de paletuviers de la Pointe de Camau. Rapport, Inspecteur Principal de la Classe des Eaux et Forets de l'Indochine, Saigon. 179 pp.

Orians, G.H. and E.W. Pfeiffer. 1970. Ecological effects of the war in Vietnam. Science 168:544-54.

Rollet, B. 1962? Memorandum on the vegetation of Vietnam south of parallel 17 north. (Defense Mapping Agency Topographic Center translation from French, Washington, D.C., 1972). 48 pp.

Tschirley, F.H. 1969. Defoliation in Vietnam. Science 163:779-86.

Vu-Van-Cuong-Humbert, F.S.C. 1964. Flore et vegetation de la mangrove de la region de Saigon-Cap Saint-Jacques, Sud Viet-Nam. Thesis, Univ. of Paris. 188 pp.

Walker, R.S. 1938. Regeneration of Klang mangroves. Malay. For. 7:71-76.

Watson, J.G. 1928. Mangrove forests of the Malay Peninsula. Malay. For. Rec. No. 6. 275 pp.

Westing, A.H. 1971. Ecological effects of military defoliation on the forests of South Vietnam. BioScience 21:893-98.