STRUCTURE, REGENERATION AND PRODUCTIVITY OF MANGROVES IN THAILAND

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ABSTRACT

STRUCTURE, REGENERATION AND PRODUCTIVITY
OF MANGROVES IN THAILAND

By

Sanit Aksornkoae

Mangrove structure, regeneration and productivity were studied at Amphoe Khlung, Changwat Chantaburi, Thailand. Community structure varied from the edge of the estuary to inland sites, with *Rhizophora candelaria*, *R. mucronata*, and the palm, *Nypa fruticans*, the dominant species along estuary and channel edges.

Avicennia and *Bruguiera* were associated with *Rhizophora* but they formed a more distinct zone further inland. On areas adjacent to the *Avicennia* and *Bruguiera* zone which have drier soils and are less subject to tidal inundation, *Xylocarpus obovatus*, *X. moluccensis* and *Excoecaria agallocha* become the dominant species. Within this zone, *Ceriops* and *Lumnitzera* are usually found to colonize those areas with a low topographic relief and soils high in clay content. *Melaleuca leucadendron* reaches its highest dominance further inland on drier and more elevated sites which are less subject to tidal flooding. The fern, *Acrostichum aureum*, occurred throughout the mangrove area but was most dense on disturbed sites.

Species diversity, density and stem-volume varied between forest zones. The *Rhizophora*, *Avicennia* and *Bruguiera* zone had the highest density but lowest diversity and stand-volume (30 to 35 m^3/ha). The intermediate zone, occupied by *Xylocarpus*, *Excoecaria*, *Ceriops* and *Lumnitzera* had the highest species diversity and stand volume (120 m^3/ha). Drier sites dominated by *Melaleuca leucadendron* were intermediate in diversity, density and stand-volume (50 to 84 m^3/ha).

Monthly height-growth and mortality of 4 planted commercially important mangrove species over a one-year period (October, 1974, to September, 1975) were recorded. *Rhizophora candelaria*, *R. mucronata* and *Bruguiera conjugata* grew most rapidly during the first three to four months following planting (6-7 cm/month). Growth rates decreased during June and July (2.5-3 cm/month) but then again increased in August and September (3-5 cm/month). Initial growth of *Avicennia alba* was slow but gradually increased to a monthly maximum of 2 cm during August and September.

The annual number of leaves and top growth produced for *R. candelaria*, *R. mucronata* and *B. conjugata* was between 10 to 34 leaves and 40 to 67 cm, while *A. alba* produced only 6 to 16 leaves, and 14 to 25 cm of top growth. *Rhizophora* and *A. alba* exhibited their greatest height-growth on sites adjacent to the estuary edge, while *B. conjugata* grew best on areas approximately midway between the edge of the estuary and the inland side. Annual species mortality was highest in _B. conjugata_ (9%) and _A. alba_ (8%) and lowest in _R. candelaria_ (5%) and _R. mucronata_ (4%).

Growth rates and net primary production were estimated for seven different aged _Rhizophora candelaria_ plantations (3, 6, 9, 11, 12, 13 and 14-year-old). Diameter increment was greatest in the 6-year-old stand (0.92 cm/yr) and lowest in the 3 and 11-year-old plantations (0.15-0.17 cm/yr). Annual height-growth increment was highest in the 13 and 14-year-old stands (2.0 m) and the least in the 3-year-old plantation (0.6 m). The annual height increment in the remaining plantations was 0.9 m.

The total stem-volume increment of the 3, 6, 9, 11, 12, 13 and 14-year-old plantations was 0.7, 9.2, 17.9, 11.5, 47.7, 20.3 and 58.7 m^3/ha/yr respectively. Commercial volume was approximately 90% of the total volume. Estimated dry-weight for each plantation (3 to 14-year-old) was 21, 50, 93, 116, 149, 167 and 188 metric tons/ha respectively. While total tree weight increased with age, crown canopy weight (branches and leaves) remained nearly constant in the 12 and 13-year-old plantation (43 metric tons/ha). Prop root weight increased with age until 9 years (18 metric tons/ha) and thereafter was nearly constant up to age 14 years with the average value of 21 metric tons/ha. The total dry-weight increment for each plantation (3 to 14-year-old) was estimated to be 7, 10, 14, 12, 33, 18 and 21 metric tons/ha/yr respectively.

Relationships between total tree weight, stem, branch, leaf and prop root weights and stem-volume with DBH and D^2H were investigated. A better correlation existed between D^2H and tree dry-weight and stem-volume than between DBH and tree dry-weight and stem-volume.

Soil samples taken in each plantation to a depth of 6 cm showed that soil texture was primarily silt loam. Soil pH varied from 5.2 to 6.0. Organic matter levels varied between 15-28%. The phosphorus content for all plantations did not vary greatly, ranging from 3.3 to 7.6 ppm. The amounts of potassium ranged from a low of 693 ppm to a high of 1166 ppm. Cation exchange capacity is quite similar, ranging from 6.0 to 9.0 meq/100 gm soil. Chlorinity also showed no great variation between sites with values being from 2 to 2.5%.

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INTRODUCTION

Mangroves: General Background

The term "mangrove" generally embodies two different concepts (Du, 1962). It refers to an ecological group of evergreen plant species belonging to several families but possessing marked similarity in their physiological characteristics and structural adaptations to similar habitat preferences. It also implies a complex of plant communities fringing the sheltered tropical shores. Such communities usually have a border of trees which are normally species of Rhizophora associated with other trees and shrubs growing in the zone of tidal influence both on the sheltered coast itself and inland lining the banks of estuaries.

Schimper (1903) defined "mangrove" to include the formation below the high tide mark. Consequently, he and many others have used the term "tidal forest" as a synonym of "mangrove forest." However, the true mangrove may form only a part of the whole intertidal zone. They often occur above and below the intertidal zone as well as on coasts where there are no tides at all (Davis, 1940; Richards, 1952).

Chapman (1970) stated that the global distribution of mangrove vegetation has been represented by two major groupings, the mangrove of the Old World or Indo-Pacific region, and those of the New World and West Africa. The distribution of the former extends from East Africa, up the Red Sea, around India, Southeast Asia, the Philippines, and up to Southern Japan, to Australia, New Zealand, and Oceania as far East as Samoa. The New World mangroves occupy the Atlantic coast of Africa and the Americas, along with a small area on the Pacific Coast of Central and South America.

In Thailand, Banijbatana (1957) explained that the mangroves occur on the sheltered muddy shores and low lying boggy ground of river and stream estuaries along both banks of the Gulf of Thailand and on the West Coast of the peninsula. The total area that is occupied by mangroves is approximately 164,539 ha. About four-fifths of this area ia located on the West Coast of the peninsula bordering the Indian Ocean. The remaining area is found on the East Coast (22,780 ha) and West Coast (6,580 ha) of the Gulf of Thailand. The distribution of mangroves and other major forest types in Thailand is illustrated in Figure 1.

Impact of Man Upon Mangroves

Mangroves are very important to the economy of many countries. In Thailand, the population depends entirely on firewood and charcoal for fuel because no coal or adequate electric power exists. Mangroves supply a large part of this need. Although mangrove bark is not widely used for tanning purposes, locally it is used for the preservation and perhaps dyeing of fishing nets. In some parts of Thailand, where the

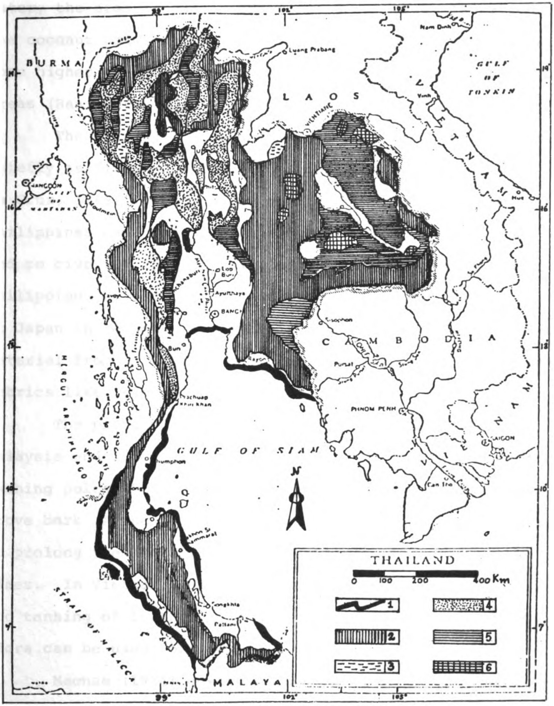

Figure 1. Forest types of Thailand: 1) Mangrove forest, 2) Evergreen forest (Tropical and Hill), 3) Coniferous forest, 4) Mixed deciduous forest, 5) Deciduous Dipterocarps Forest, 6) Savannas.

mangrove forest is dry and seldom inundated by brackish sea water, the area is easily converted to coconut plantations. The coconut palms raised on such coastal areas normally produce higher yields and better quality nuts than in other areas (Banijbatana, 1957).

The utilization of the mangroves in the Philippines, chiefly as firewood and tanbark, has long been recognized (de la Cruz, 1969). Mangrove forests in some parts of the Philippines have been completely removed for charcoal-making and to give way to fishpond construction. Recently, the Philippines have exported Rhizophora and other related species to Japan in response to Japanese demands for "bakawan," a raw material from Rhizophora used in manufacturing wash and wear fabrics like nylon and polyester.

The principal uses of mangrove in Burma, Vietnam, Malaysia and Indonesia are for firewood, charcoal, stakes and fishing poles (Cobban, 1968). In Malaysia and Burma, mangrove bark is used for preserving fish lines. Tannin is said to prolong the life of Malay fishermen's clothes by three times. In Vietnam, the bark is used for dyeing of clothes and tanning of leather. In addition, some of the mangrove flora can be used for medicinal purposes (Cobban, 1968).

Macnae (1974) described the significance of mangroves to fisheries production in Southeast Asia. Mangroves support a characteristic fauna which include crabs, penaeid prawn juveniles, and various molluscs and fish. Many species of penaeid prawn are dependent upon mangrove forests for shelter durin

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during their juvenile development. In some areas, a correlation between certain penaeid species and mangroves appears to hold and one might say: "no mangroves: no prawns." Many commercially important fish utilize the mangrove waterways as nursery ground. The fertility of mangrove soil for plant growth is also important in relation to the construction of shrimp and fish-culture ponds in mangrove areas.

Hesse (1961) reported that the reclamation of coastal *Rhizophora* mangrove swamps for the cultivation of rice is becoming important in West Africa. Many areas of mangroves in Mexico have been felled primarily for fence posts and charcoal (Thom, 1967). Borman (1917) mentioned that mangroves were planted to prevent erosion of railway embankments in Florida. The mangroves in this area are also utilized to maintain the environmental quality and high productivity of desirable fisheries (Snedaker and Lugo, 1973). In addition to these uses, the mangroves also indirectly act as the agent for reclaiming land from the sea (Banijbatana, 1957; Davis, 1940).

Gaps in Our Knowledge of Mangroves

The ecology of mangroves has not been as widely studied as the ecology of inland forests because the mangroves are often relatively less economically important to a country, occupy less area than inland forests and often times are physically more difficult to work in.

In West Africa, most research done on mangrove soil composition and dynamics has not been concerned with soil effects upon mangrove growth or succession but rather with their effects on rice yields (Hart, 1959; Thornton and Giglioli, 1965; Doyne, 1937; Hesse, 1961).

In Australia, mangrove ecology has been intensively studied. Attention has been focused on the interactions among vegetation, soil and climate, and the significance of species interaction (Clarke and Hannon, 1967; 1969; 1970; and 1971). But these studies have thus far not examined such functional aspects as nutrient cycling and productivity.

The most intensively studied mangrove are in South Florida (Snedaker and Lugo, 1973; Lugo et al., 1974; Lugo, Sell and Snedaker, 1974; Pool and Lugo, 1973; Snedaker and Pool, 1973; Davis, 1943; and Ervink, 1973). Study objectives here have been centered around the maintenance of environmental quality and high productivity of desirable fisheries.

Despite the fact that mangroves are important to the economy of several Southeast Asia countries, only a few published reports are available (e.g. Watson, 1928, for the mangroves in Malaysia; Du, 1962; Vu Van Coung, 1964; National Academy of Sciences, 1974, in Vietnam; de la Cruz and Banaag, 1967, and de la Cruz, 1969, in the Philippines; Banijbatana, 1957, and Kongsangchai, 1973, in Thailand, Noakes, 1951; 1957 in Malaysia). This lack of knowledge on the ecology of mangroves, especially in Thailand, results from scarcity of research staff and funds (Banijbatana, 1957).

In Thailand, the mangrove forest plays a very important economic role. This results primarily because of the:

1. Potential for mangrove exploitation and its ultimate effect on the ecosystem;
2. Apparent close relationship between the presence of mangrove forest areas and the accompanying high productivity of the associated coastal waters;
3. Growing interest in aquaculture programs associated with the mangroves;
4. Increased demand for land and for the reclamation of coastal areas involving mangrove forests.

Such potential uses raise many significant questions about the management of the mangrove ecosystem in Thailand. These include:

1. What is the actual extent of the mangrove area and what are the structural and functional characteristics of the mangrove ecosystem?
2. How can the mangroves be intensively managed for timber, tannins, and charcoal production?
3. What relationships exist between the fisheries within and near the mangroves areas and the actual functioning of the mangrove ecosystem?

The answers to these questions are not available at the present time. The investigation reported here can provide some answers to these questions.

The objective of this investigation is to provide information on the mangrove ecosystem of Thailand, both as to its structure and productivity. Based on these data, preliminary recommendations can be made as to the wise management of this forest resource.

DESCRIPTION OF THE STUDY AREA

Location

The study was located in the mangrove forests at Amphoe Khlung, Changwat Chantaburi on the Northeastern coast of the Gulf of Thailand. The area is between 12° and 13° north latitude; and between 102° and 103° longitude, east of Greenwich. The area is approximately 19,000 ha (or 119, 355 rais) and is representative of a very well developed mangrove forest in Thailand. The study area and extent of mangrove forest at Amphoe Khlung, Changwat Chantaburi is shown in Figure 2.

Vegetation

More than 27 genera of trees and other plants are commonly found in the mangroves at Amphoe Khlung. Among these genera, *Rhizophora* is the most abundant and has the widest geographical distribution. The most dominant and valuable species normally belong to the Rhizophoraceae while the accessory species consist of several unrelated families. They are:

Family	Scientific Name
Rhizophoraceae	*Rhizophora candelaria*, *R. mucronata* *Bruguiera cylindrica*, *B. conjugata* *Ceriops roxburghiana*, *Kandelia rheedii*
Sonneratiaceae	*Sonneratia caseolaris*, *S. alba*

AMPHOE KHLUNG, CHANGWAT CHANTABURI

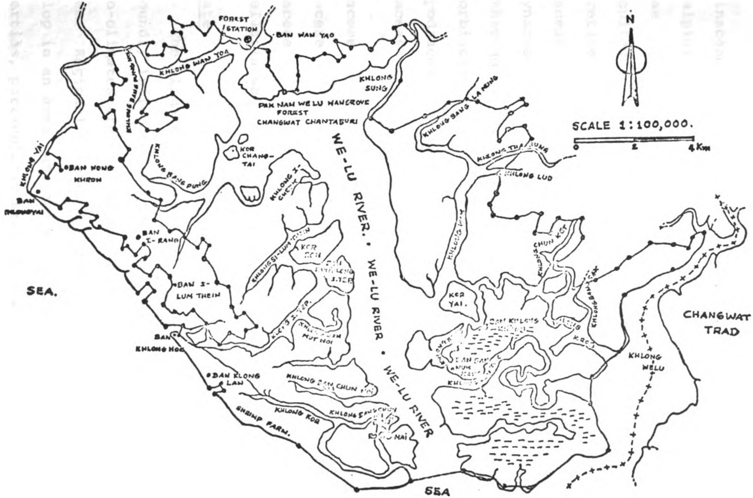

Figure 2. Mangrove forest at Amphoe Khlung, Changwat Chantaburi.

Verben

Meliac

Myrsin

Caesal

Palmae

Stercu

Combre

Myrtac

Apocyn

Acanth

Euphor

Polygo

Rubia

Malva

Laura

Ebena

Flage

Clima

Profo

Micro

Syste

Devel

Prope

Tempe

Sitio

Verbenaceae	*Avicennia alba*, *A. officinalis*, *Clerodendrum inerme*
Meliaceae	*Xylocarpus obovatus*, *X. moluccensis*
Myrsinaceae	*Aegiceras corniculatum*
Caesalpiniaceae	*Caesalpinia didyna*, *Intsia retusa*
Palmae	*Nypa fruticans*, *Phoenix paludosa*
Sterculiaceae	*Heritiera littoralis*
Combretaceae	*Lumnitzera racemosa*
Myrtaceae	*Melaleuca leucadendron*
Apocynaceae	*Cerbera odollam*
Acanthaceae	*Acanthus ebracteatus*, *A. ilicifolus*
Euphorbiaceae	*Excoecaria agallocha*
Polypodiaceae	*Acrostichum aureum*
Rubiaceae	*Litosanthes biflora*, *Scyphiphora hydrophyllacea*
Malvaceae	*Hibiscus tiliaceus*, *Thespesia populnea*
Lauraceae	*Cassytha filiformis*
Ebenaceae	*Diospyros ferrea*
Flagellariaceae	*Flagellaria indica*

Climate

The climate at Amphoe Khlung, Changwat Chantaburi, is profoundly influenced by the monsoon but both regional and micro-climates are undoubtedly important in the mangrove ecosystem. Regional climate dictates which plant species may develop in an area, whereas micro-climate determines soil properties, particularly salinity, which is effected by temperature-rainfall interaction. It also influences competition between species. The regional climate needs to be considered in relation to the original establishment of the present vegetative patterns but the micro-climate provides conditions for seedling development in established communities and therefore influences the maintenance of existing patterns.

Regional climatic data for Changwat Chantaburi were obtained from records kept by the Meteorological Department, Ministry of Prime Minister. Data for 1951 to 1970 are presented in Figure 3. Micro-climate data are fragmentary, and have not been presented in detail.

Temperature -- Mean monthly temperatures vary between 25°C and 29°C. Highest values occur from February to May, when temperature may exceed 33°C. Minimum temperatures of about 20°C occur in December and January.

Rainfall -- The highest rainfall in Changwat Chantaburi generally occurs from May to October, with September being the wettest month (590 mm). The least rainfall occurs from November to April, with December and January being the driest months of the year (11 and 13 mm respectively).

Atmospheric moisture -- Relative humidity is generally lowest from November to April, with an average value of about 77%. This results from the high temperatures and low rainfall during these months. The mean monthly value for the remaining six months is about 87%.

Evaporation -- In Changwat Chantaburi, evaporation is most extreme from November to April when rainfall is at its lowest and temperatures are rising to their monthly maximums.

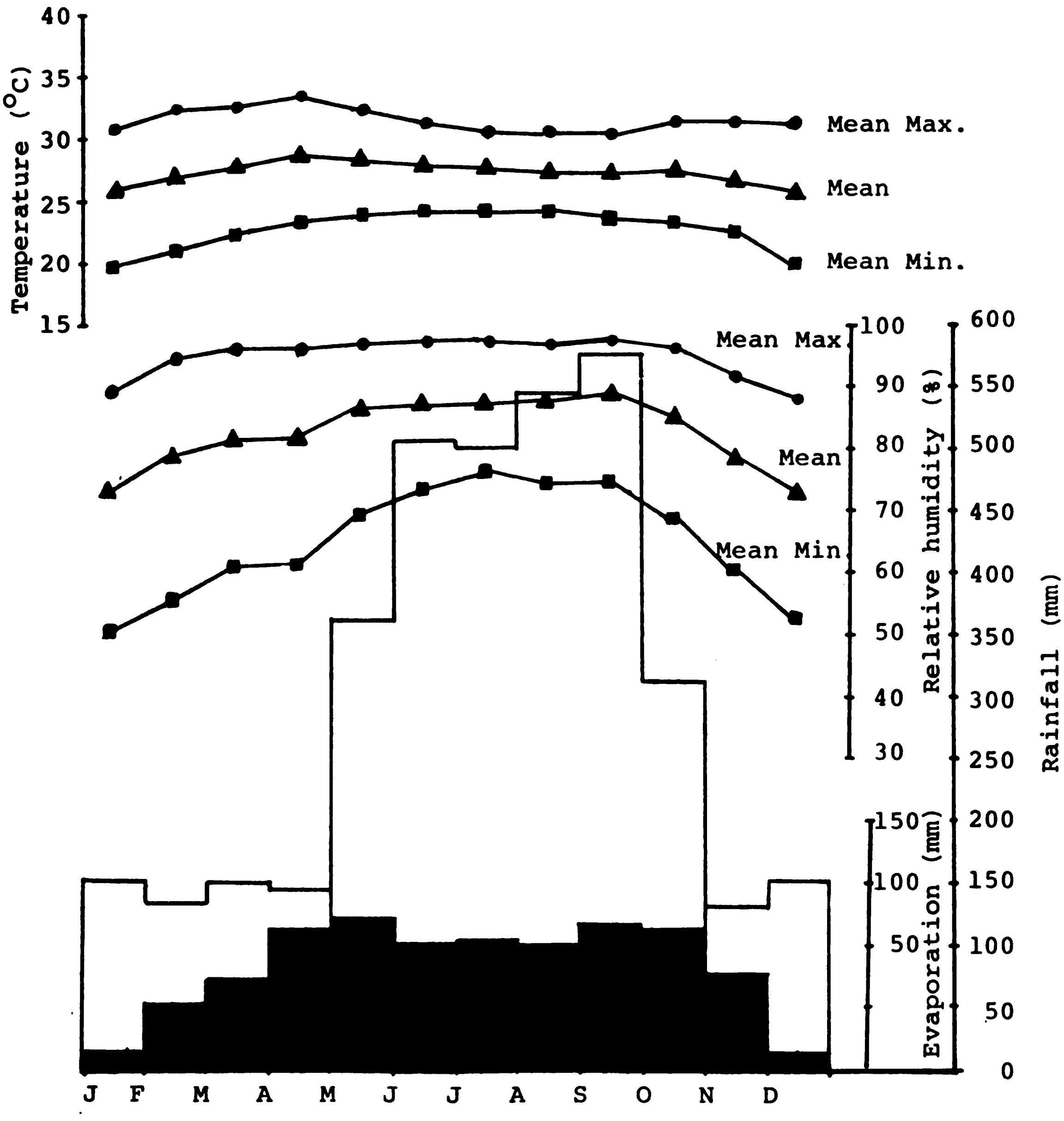

Figure 3. Climatological data at Changwat Chantaburi, 1951-1970 (from Meteorological Department, Ministry of Prime Minister, Bangkok, Thailand).

The highest evaporation values, 151 mm, occur in December and January, and the lowest in August, 102 mm.

Soils

Surface soil properties of samples taken at varying distances from estuary to land in the mangrove community at Amphoe Khlung, Changwat Chantaburi, are presented in Table 1.

The physical characteristics vary with distance from estuary to land. Sand content increases and is silt and clay percentage decrease in the more landward zones. However, soil textures are essentially all sandy loams throughout the study site except in the zone at the edge of the estuary where it is a loam.

pH -- The surface soil in the more landward zones tends to be more acid than those nearest to the estuary. The pH of the inland soils remains relatively constant, 3.6 to 3.9. Soils at the estuary bank have a pH of 4.3.

Cation eschange capacity -- All cation exchange capacities seem to be relatively low, with the highest value being about 11 meq/100 gm soil at the estuary bank. The lowest value is about 4.0 meq/100 gm soil at the landward areas. This reflects the relatively low level of organic mater content in these soils. The organic matter of the surface soil was found to be greater at the estuary edge than inland, where the values range from about 12.5 to 2% respectively.

Soil chlorinity -- Soil chlorinity is primarily dependent upon the physiography of the land and the frequency

Table 1. Surface soil properties in the mangrove community at Amphoe Khlung, Changwat Chantaburi in 1975.

Distance from estuary to land, m	Sand %	Silt %	Clay %	Texture	pH	C.E.C. meq/100 gm soil	O.M. %	N %	P ppm	K ppm	Cl^- %
0	47.6	37.8	14.6	loam	4.3	10.95	12.49	0.62	10.0	118.0	1.69
20	61.2	21.9	16.9	sandy loam	3.6	6.12	5.38	0.27	5.1	132.5	0.94
60	58.1	21.9	20.0	sandy loam	3.9	11.20	9.01	0.45	6.1	139.8	0.98
100	72.5	20.2	7.3	sandy loam	3.7	6.90	4.32	0.22	5.4	135.8	0.82
140	68.9	20.9	10.2	sandy loam	3.8	4.00	2.14	0.12	2.8	190.0	0.42

of tidal flooding. The chlorinities of the surface soils at different distances from the estuary varied from the highest occurring at the estuary bank, 1.69%, to the lowest concentration, 0.42% at 140 m from the bank.

Nitrogen, phosphorus and potassium content of the surface soils indicate that where nitrogen and phosphorus decrease in the more landward zones, the potassium content, in contrast, increases.

A comparison of surface soil properties of natural mangrove communities at different locations in Thailand is shown in Table 2. The studies included in Table 2 have found soil textures to vary from sandy loam to clay loam along with various soil chemical properties.

Tides

The daily rise and fall of water regulates many features of the mangrove community, e.g. floristic zonation, soil and water properties, and faunal distribution. Tides at Changwat Chantaburi, as recorded by the Hydrographic Department, Royal Thai Navy, in 1974-1975 are diurnal, with an average amplitude of 2.4 m for spring tides and 0.6 m for neap tides. The entire mangrove area is generally under water at high spring tides but the water at neap tides barely reaches the fringes of the trees.

Table 2. A comparison of surface soil properties of natural mangrove communities at different areas in Thailand.

Location	Sand %	Silt %	Clay %	Texture	Bulk Density gm/cc	pH	O.M. %	N %	P ppm	K ppm	C.E.C. meq/ 100 gm soil	Cl^- %	Reference
Amphoe Kabur, Ranong	62.5	27.7	9.8	Sandy loam	0.86	4.4	5.84	0.29	10	210	-	0.65	Senisrisanti-1975
Amphoe Takoapa, Pang-nga	56.1	29.5	14.4	Sandy loam	0.78	3.3	9.38	0.47	2	157	-	0.95	Senisrisanti-1975
Amphoe Meong, Krabi	14.5	66.3	19.2	Silty clay	0.67	5.2	10.71	0.55	12	900	-	1.70	Senisrisanti-1975
Amphoe Seekoa, Trang	60.3	28.4	11.3	Sandy loam	0.66	3.2	7.25	0.36	3	163	-	1.04	Senisrisanti-1975
Amphoe Kantang, Trang	58.7	30.3	11.0	Sandy loam	0.97	4.5	7.56	0.38	6	448	-	0.60	Senisrisanti-1975
Amphoe Langoo, Satul	21.0	49.6	29.4	Clay loam	0.67	3.7	11.37	0.57	10	474	-	1.99	Senisrisanti-1975
Amphoe Khlung, Chantaburi	-	-	-	-	0.30	5.5	12.80	0.64	2.2	-	-	-	Zinke, 1975
Amphoe Kraburi, Pang-nga	65.7	21.3	13.0	Sandy loam	-	4.0	4.80	0.24	4.5	151.5	6.9	0.69	Kongsangchai-1973
Amphoe Khlung, Chantaburi	61.6	24.5	13.9	Sandy loam	-	3.9	6.67	0.34	5.9	143.2	7.8	0.97	Aksornkoae, 1975

MANGROVE COMMUNITY STRUCTURE

Introduction

Mangroves are characteristic of tropical and subtropical coastline vegetation. They occupy the upper and intertidal zones of seashores, lagoons, and river estuaries. Mangrove habitats are a complex of many factors interacting so closely that it is very difficult to differentiate the effect between them and/or on the mangrove vegetation. The relationships of mangroves to their environment have been a subject of interest to ecologists and botanists for a long time. The objective of this part of the investigation is to describe the structure of the mangrove ecosystem especially dealing with species zonation, diversity and stem-volume.

Review of Literature

Mangrove Forest Types

Classification procedures for mangrove vegetation have received little attention. Snedaker and Pool (1973) classified the mangrove forests of southern Florida into five main types: basin forest, riverine forest, fringe forest, overwash forest and dwarf forest. Type distinction was based on the apparent differences in species composition and gross structure of the mangrove forests. These appear to be strongly controlled by local patterns of tides and terrestrial surface drainage.

Zonation

In most mangroves, different species dominate certain bands or zones which are clearly delimited from the others. This characteristic zonation pattern results from differences in the rooting and growth of seedlings resulting from competitive advantages which each species has along a gradient from below the low water to above the high water lines (Kuenzler, 1968).

Macnae (1968) reviewed the three zonation schemes that have been proposed for the mangroves of the Indo-Pacific region. One was based on frequency of inundation (Watson, 1928), another on soil salinity (de Hann, 1931), and a third on the generic name of the dominant trees (Walter and Steiner, 1936). Similar schemes have been applied to the mangroves of the New World by David (1940) and de la Cruz (1969) who compared the zonation of mangrove stands in the eastern and western hemisphere.

Factors That Effect Zonation

Physical and Chemical Soil Factors

The physical and chemical aspects of the soil play an important part in mangrove zonations. According to Macnae (1968), the soil of Rhizophora forests is usually soft. Macnae and Kalk (1962) report that in Mocambique, Rhizophora prefers wetter, stickier soils. Steenis (1958) points out that Rhizophora mucronata is a typical species of deep soft mud while Gledhill (1963) found it, along with Avicennia marina and Brugueira gymnorrhiza, growing in sandy areas in

Aberdeen Creek. Although Avicennia marina was also found in muddy substrata, Rhizophora was found by Gledhill (1963) to be typical of riverside swamps on deep silt, which is consistent with Jordan's (1964) findings that Rhizophora is specific for fresh, soft silty soils while Avicennia germinans colonizes the more firm and sandy soils along the coastal areas in Sierra Leone.

Certain species of mangroves grow only in well-drained soils (Macnae, 1968). These include Xylocarpus spp, and such mangrove associations as Osbornia octodonta and Pemphis acidula. Avicennia marina, particularly at its distributional limits, becomes taller in the better drained soils of the creek edge than further inland. It develops on beaches where the substratum is relatively firm due to partial tidal wave action. According to Macnae and Kalk (1962), Avicennia prefers a low slope angle from the beach and can tolerate sandy soils in the landward edge or muddy in the seaward fringe. Carter (1959) states that as the soil profile changes from coastal accretion to firmer mud, conditions become unfavorable for Avicennia and more favorable for Bruguiera. Chapman and Ronaldson (1958) pointed out that Avicennia grows taller on the well-drained banks close to streams in New Zealand.

Further inland, the Avicennia stand passes into a forest of Bruguiera cylindica which characteristically develops on stiff blue clay soils with a shallow humus layer and a well-marked surface drainage but no creek. Bruguiera parviflora is an "opportunist" species which frequently becomes established in a cleared area and then may act as a nurse tree to the colonization of Rhizophora spp or other Bruguiera spp (Watson, 1928). Bruguiera cylindrica and B. parviflora form a 15-20 m high understory in the Rhizophora forests of Southeast Asia (Macnae, 1968). Macnae (1968) also found that Bruguiera forests of Southeast Asia frequently support a herb-layer of the fern Acrostichum spp.

Generally, species of Ceriops develop into dense thickets or as undergrowth on the well-drained soils. In Southeast Asia, Ceriops tagal and Ceriops decandra form an understory in the Rhizophora forest (Macnae, 1968). The Nypa association constitutes one of the most important features of the mangrove throughout the Southeast Asiatic and Indo-Malaysian regions. It occurs in waterlogged soils (Macnae, 1968). The fern Acrostichum is widely distributed in marshy, brackish habitats, usually associated with mangroves (Chapman, 1970).

Drew (1974) stated that the fern Acrostichum aureum may reach a height of 3-4 m under favorable conditions in South Vietnam. This fern is associated with the palm Phoenix paludosa and the mangrove species of Excoecaria agallocha, Derris trifolia or Ceriops spp. The fern population tended to increase on the upland sites where the soil is drier (Vu-Van-Cuong, 1964).

Navalkar and Bharucha (1948, 1949) describe the chemical and physical factors of the mangrove soil in India. Cause and effect relations of zonation are not explicitly stated. However, Navalkar and Bharucha (1950) concluded that neither calcium carbonate, humus nor pH play an important part in determining plant associations. They felt the main considerations are related to amounts of exchangeable bases in the soil.

The role of organic matter in mangrove soils or within specific species zonation has received little study. The most comprehensive study was made by Giglioli and Thornton (1965). Their studies showed that the organic carbon content (1.724 x % organic carbon = % organic matter) of mangrove soils is derived from water-borne residues, leaf litter and decomposing root material. The organic carbon content of soils under young *Rhizophora* was found to be 8.7% while that under old *Rhizophora* was between 3.3% and 5.7%. These values are less than the 11.9% organic carbon found under *Rhizophora* by Hesse (1961). Hesse also showed the organic carbon under *Avicennia* to be approximately 5.5%.

A great deal of information exists on the pH of mangrove soils, mostly those under *Rhizophora*. The soil under *Rhizophora* is generally reported to be slightly more basic than under *Avicennia* when in a saturated state. The acidity difference is reversed, however, and more marked upon soil drying. Hesse (1961), found the pH of *Rhizophora* soils in Sierra Leone, West Africa, to be 6.6 as compared to 6.2 in the soil under *Avicennia*. Upon soil drying under aerobic conditions, the pH of *Rhizophora* soils fell to 4.6 while that of *Avicennia* soils decreased to but 5.7.

Thornton and Giglioli (1965) in a study of the mangrove swamp of Keneba, Lower Cambia River basin, found the pH of soils under Rhizophora to be approximately 5.0 while under Avicennia the pH was 6.0 or above. Tomlinson (1957) also reported low pH values for soils under Rhizophora of the mangrove forest in Sierra Leone. Zinke (1974) found that Rhizophora in South Vietnam occurred on soils with a pH of 7.2. Other chemical soil properties that may have an effect on the zonation of mangrove forest are related to levels of nitrogen, phosphorus and sulphur. Hesse (1961) analyzed mangrove soils for total nitrogen, ammonia nitrogen and nitrate nitrogen under Rhizophora, Avicennia and recently deposited tidal alluvium. He found that the total nitrogen, ammonia nitrogen and nitrate nitrogen under Rhizophora was approximately 0.4400%, 1 ppm and 1 ppm oven dry weight and under Avicennia to be 0.3900%, 8 ppm and 2 ppm respectively. The total nitrogen, ammonia nitrogen and nitrate nitrogen concentration of the recently deposited tidal alluvium were 0.3500%, 13 ppm and 1 ppm respectively.

Sulphur is readily evident in the soils of mangrove areas. The presence of hydrogen sulfide gas is quite noticeable upon removal of mangrove mud. Analysis of alluvium showed total sulphur to be 0.244% oven dry weight, soils under Rhizophora had 2.224% sulphur content and soils under Avicennia had 0.577% sulphur (Hesse, 1961). Thornton and Giglioli (1965) found differences in the total free sulphur between the soils under young and old Rhizophora and

Avicennia. In the young *Rhizophora* soils the amount of free sulphur increased sharply below the 6" level with the surface concentration being 2 mg/g soil and the underlying soil containing from 6-8 mg/g. Old *Rhizophora* soils also increased in free sulphur from a surface value of 4.5 mg/g to 7.8 mg/g at lower levels. The *Avicennia* soils decreased in free sulphur from 9 mg/g at the surface to 6-8 mg/g throughout the profile.

Soil Water Salinity

Soil water salinity, a saline quality of soil and water, is another important factor influencing species zonation within the mangrove forest. Mangroves occur in regions of high, low or variable salinity. Salinity appears to be of importance not because the salt is essential for growth but because it reduces competition from other species (Kuenzler, 1968). This has been shown by Borman (1917), who grew species of *Rhizophora*, *Avicennia* and *Laguncularia* for two to three years in salt-free water or soils.

According to Davis (1940) the conclusions regarding the importance of salinity in mangroves are as follows: 1) Salinity fluctuates widely with seasonal rainfall; 2) Most of the mangroves are tolerant of a wide range of salinity. A brackish condition is most favorable for optimum growth. 3) Zonation corresponds to seasonal salinity averages of the soil solution and surface water; 4) The soil solution usually is more saline and fluctuates less than the surface water; 5) The highest salinity is found where the water level is close to the soil surface, and with a consequent high rate of evaporation; 6) Saline conditions of both surface water and soil water extend farther inland than the normal range of the tide. The low topographic relief of the land prevents rapid salt leaching.

Macnae (1968) gives the salinity tolerances of several of the mangrove species. *Avicennia marina* appears to have the widest range of tolerance, with growth possible in almost fresh water or in soils with a water salinity exceeding 30‰. According to Jordan (1964) the *Avicennia* zone soils of Sierra Leone have a higher salinity because they are more permeable. *Sonneratia alba*, *Sonneratia apetala*, and *Sonneratia griffithii* are all found on the seaward fringe and would seem to prefer waters of near normal salinity. *Sonneratia caseolaris* only grows where the salinity is less than 10‰.

Species of *Bruguiera* usually grow in those portions of the mangroves with salinities less than 25‰. *Bruguiera porviflora* reaches optimal growth with salinity levels of 20‰. *Bruguiera sexangula* prefers soils with a salinity of 10‰ or less. *Bruguiera gymnorhiza* has a salt tolerance of 10-25‰. Species of *Ceriops*, particularly *Ceriops tagal*, will survive and grow where salinities exceed 30‰.

According to Watson's (1928) classification scheme, two types of *Rhizophora* forest occur in Malaya, Thailand, Southeast Asia, and the wetter parts of the Indonesian archipelago. *Rhizophora mucronata* lies behind a seaward fringe and passes backward and upstream along side a channel, river, or creek where water salinity of around 20‰ or more overflows the banks. It gives way to *Rhizophora apiculata* when water of salinity of less than 15‰ floods the forests. Chapman (1944) showed that on the Jamaican shoreline, *Rhizophora mangle* had a high optimum salt tolerance. Savory (1953) said that in West Africa, *Rhizophora racemosa* has often been reported to grow well in fresh water conditions but *Rhizophora mangle* has only been found associated with salt-swamp.

The different mangrove species have fairly specific tolerances. Outside these ranges, it appears that salinity acts as a limiting factor for growth (Steenis, 1958).

Drainage and Soil Moisture

The drainage characteristics of the soil influences the establishment and successional development of the mangrove forest. Drainage regulates such ecologically important factors as soil water chlorinity (Giglioli and King, 1966) and pH (Thornton and Giglioli, 1965; Hart, 1959). Chapman and Ronaldson (1958) have suggested that the height of *Avicennia marina* in New Zealand is controlled by the drainage of the underlying soil. Different genera of mangrove trees have been shown to require different soil drainage regimes. Thom (1967) found that *Avicennia* requires a higher, drier, and more compact soil than either *Rhizophora* or *Laguncularia*. On the other hand, he found *Bruguiera* to prefer only waterlogged soils.

Giglioli and King (1966), measuring soil moisture, found that the surface soil under old Rhizophora had a moisture content from 43% to 196% (% by wt dry soil). Clarke and Hannon (1967) found their surface soils to have a moisture range of from 28.6% to 143.3% (% by wt dry soil). They also found the subsurface soil moisture to vary from 29.5% to 98.2% (% by wt dry soil) while Giglioli and King (1966) give no value but remarked that the underlying clays of Rhizophora soils have a more constant soil moisture content than the surface soils.

Frequency of Tidal Flooding

Frequency of tidal flooding is one of the most significant factors that help regulate species zonation of mangrove forest. Macnae (1968) states that the zones of trees in mangrove are associated with rising ground level and the resulting decrease in frequency of tidal flooding. This relationship forms the basis for Watson's (1928) inundation classes and for de Hann's (1931) water zone with salinity. Zone width is a function of the slope of the shore and the range of the tide.

The following is a summation of Macnae's (1968) description:

> "Although the rate of rise and fall of the tide is highest when it is crossing the flats, the fact that it is crossing these flats causes a slowing down of the current and allows deposition here. When

the water has reached the upper flats within the mangrove the flow is further impeded by the obstruction caused by the trees and their pneumatophores. The region where those are most thickly developed is in the seaward fringes of *Avicennia* and of *Sonneratia* and within the *Rhizophora* forests, and these appear to be the region of greatest decomposition. Beyond the seaward fringes the bank of accretion sometimes slopes quite steeply, down to the mean sea-level. The soft, ill-consolidated soils are always waterlogged, and are reached by all or almost all tides. The soils are firm and well-consolidated at a point where tidal water no longer reaches them. The boundary between these soft and firm soils lies towards the upper margins of the *Rhizophora* forest."

The actual mechanisms by which the frequency of tidal flooding limits growth are not discussed. They are perhaps associated with species differences in requirements for successful seedling establishment and with soil changes related to silt deposition.

Species Diversity

There are a few studies of species diversity of mangrove forests reported in the literature. Snedaker and Lugo (1973) determined the diversity index of the mangrove at Rookery Bay forest in South Florida. Diversity indices (H) were calculated by using the Shannon index for general diversity equation where $H = -\Sigma pi \log pi$ or $-\Sigma(\frac{Ni}{N}) \log (\frac{Ni}{N})$ (H is Shannon index; Ni is importance value for a specific species; N is total of importance values for all species and pi is importance probability for each species which is equivalent to $\frac{Ni}{N}$) (Odum, 1971). They found that the diversity indices from five plots were 0.4472, 0.4896, 0.2894, 0.3695 and 0.3228. The lowest value was where the black mangrove was dominant and highest value was found in the ecotone between the red and black mangrove. In general, diversity was relatively low in all plots.

Materials and Methods

The natural mangrove community at Amphoe Khlung, Changwat Chantaburi was selected for the study area. In the past, the area has been selectively cut but there has been no disturbance since approximately 1970. Ten transect lines, each approximately 100 to 150 m long, were established from the estuary to the land throughout the mangrove area. Distance between transect lines was variable depending upon species zonation and distribution.

A 5 x 20 m plot was laid out at 10 m intervals along each and at right angles to the transect lines. Trees within each plot larger than 5.5 cm in diameter at 10 cm above the root collar for *Rhizophora* and at breast height for other species without prop roots were measured as follows:

a. number of individuals by species was determined by actual count.

b. diameter at 10 cm above the root collar and at breast height (dbh) was obtained by using a diameter tape.

c. total height was measured by using a regular meter tape and Haga altimeter.

Trees smaller than 5.5 cm at 10 cm above the root collar for Rhizophora and at breast height for other species within the plot were classified as seedlings. The number of seedlings by species for each plot was counted.

The species of undergrowth was also recorded for each plot.

The importance value for each tree species was calculated by the summation of the percentages of relative density, relative frequency and relative dominance, where:

$$\text{relative density} = \frac{\text{No. of individuals of species x}}{\text{Total of individuals of all species}} \times 100$$

$$\text{relative frequency} = \frac{\text{Frequency of species x}}{\text{Sum of frequency values for all species}} \times 100$$

$$\text{relative dominance} = \frac{\text{Basal area of species x}}{\text{Total basal area of all species}} \times 100$$

Frequency is defined as the probability of finding the species in any one plot. Basal area is the cross-sectional area of the tree at 10 cm above the root collar for Rhizophora and at the breast height for other species.

The Shannon index for species diversity was determined with the following equation:

$$H = -\sum \left(\frac{Ni}{N}\right) \log \left(\frac{Ni}{N}\right)$$
$$= -\sum Pi \log Pi$$

where:

Ni = importance value for a specific species

N = total of importance values for all species

Pi = importance of probability for each species $\left(\frac{Ni}{N}\right)$

Comparison of the actual measured stem-volume of 180 trees of different size-classes with the volume estimated geometrically, assuming mangrove stems approximate either a cylinder or cone, indicated that estimates assuming conical geometry were in error by only -17% whereas estimates assuming cylindrical geometry were in error by about +65%. Tree stems were, therefore, assumed to approximate cones in geometry. The total stem-volume of each tree was obtained by multiplying the basal area (cross-sectional area), measured at 10 cm above the root collar for *Rhizophora*, and at breast height for other species, by one half the total height. This estimate was then increased by 17% to adjust for the known error in assuming conical geometry.

Results and Discussion

Plant Zonation

The mangroves at Amphoe Khlung, Changwat Chantaburi, extend upwards just above the level of high water of neap tides almost to that of high water of ordinary spring tides. Different species tend to dominate certain bands or zones which are clearly demarked from the others. However, there are occasionally some areas where over-lapping does occur (Figure 4 and 5). These different zonation patterns may result from differences in species adaptations to adverse site factors such as: waterlogged soils, salinity, poor soil aeration, and strong prevailing seashore winds. Such adaptations are: the presence of stilt roots, pneumatophores, thick and leathery leaves with thick cuticle, water storage tissue, deep seated chlorenchyma, salt-secreting glands, fruits and seed capable of floating in water for a number of days without deterioration, and vivipary (Venkatesan, 1966).

The distribution of mangrove trees in this area can be described in the following manner. Along the margin of the estuaries and channels running through the mangrove, and where the soil surface is waterlogged and very muddy, pure stands of _Rhizophora_ are found with roots arching into the water (Figure 6). The two common species are _Rhizophora candelaria_ and _R. mucronata_. The former tends to be the more abundant and has a wider distribution than the latter. Occasional trees of _Rhizophoras_ may also occur in the wetter, muddier areas in the middle of the thickets of other species. _Nypa fruticans_ is also sparsely found in this zone but mostly along the stream margins.

The belts or zones of _Bruguiera_ and _Avicennia_, variable in width, occur behind the zone of _Rhizophora_. _Avicennia_ tends to be distributed in a well-defined zone, whereas _Bruguiera_ has a wider distribution and is occasionally found among the _Ceriops_. Both _Avicennia_ and _Bruguiera_ are seldom

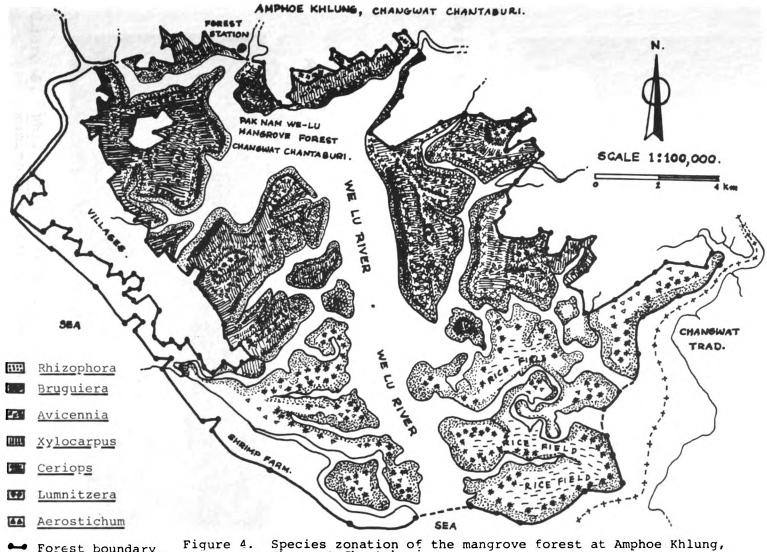

Figure 4. Species zonation of the mangrove forest at Amphoe Khlung, Changwat Chantaburi.

Figure 5. Aerial view of the zonation of the mangrove forest at Amphoe Khlung, Changwat Chantaburi.

Figure 6. Rhizophora zone along the estuary margin of the mangrove forest at Amphoe Khlung, Changwat Chantaburi.

found in the *Rhizophora* zone where the water level is near the soil surface. The associate species sparsely occurred within this zone are *Heritiera littoralis*, *Thespesia populnea*, *Intsia retusa* and *Hibiscus tiliaceus*.

The sites behind the *Avicennia* and *Bruguiera* zones that are more elevated and drier, and subject to less frequent tidal inundation, are occupied by *Xylocarpus*. The two common species found in this area are *Xylocarpus obovatus* and *X. moluccensis*. The former species has a wider distribution and is more abundant throughout the drier area than the latter species which has a more well-defined zone. The associate species occasionally found within this zone are *Excoecaria agallocha*, *Sonneratia spp*, *Acathus spp*, *Lumnitzera* and *Ceriops*. The fern, *Acrostichum aureum*, is found sporadically covering a vast area in the *Xylocarpus* zone where forest has been severely disturbed by cutting (Figure 7). *Phoenix paludosa* also grow sparsely in this zone (Figure 8).

Occasionally, the drier sites behind the zone of *Bruguiera* are colonized by *Ceriops* and *Lumnitzera*, with the former species the more common of the trees (Figures 9 and 10).

On the landward side, where the area becomes flooded during only extreme high tides, there will be a mixed community dominated by *Melaleuca leucadendron* (Figure 11). Associated species are *Flagellaria indica*, *Caesalpinia didyna*, and *Cherodendrum inerme*. This zone delimits the

Figure 7. Acrostichum aureum, a fern associated with a Xylocarpus stand at Amphoe Khlung, Changwat Chantaburi.

Figure 8. Phoenix paludosa growing in the mangrove forest at Amphoe Khlung, Changwat Chantaburi.

Figure 9. A Ceriops thicket in the mangrove forest at Amphoe Khlung, Changwat Chantaburi.

Figure 10. Lumnitzera in the mangrove forest at Amphoe Khlung, Changwat Chantaburi.

Figure 11. Melaleuca leucadendron growing on the inland side of the mangrove forest at Amphoe Khlung, Changwat Chant-

Figure 12. Acrostichum aureum located inland on a cut-over associated with Melaleuca leucadendron, in the mangrove forest at Amphoe Khlung, Changwat Chantaburi.

margin of the mangrove forest and other grades into the inland forest.

The fern, Acrostichum aureum, plays an important role in the mangrove ecosystem particularly in relation to the mangrove regeneration (Noakes, 1951). At Amphoe Khlung, Changwat Chantaburi, this fern occurs throughout the whole mangrove forest but especially in open areas (Figure 12). The reason is that this fern can respond rapidly to full sunlight (Noakes, 1951). It is also frequently found associated with Xylocarpus (Figure 7), Melaleuca leucadendron (Figure 11), and Phoenix paludosa and various halophytic species as shown in Figure 8. Drew (1974) found that on the somewhat higher and drier site which receive less flooding from high tide, the size of Acrostichum aureum was considerably larger than in the lower elevated area.

Species Diversity

Diversity indices (H) were calculated for 0.1 ha plots located at different points from the estuary bank towards the stand (Table 3). The lowest value (0.3073) was found at the estuary edge where the Rhizophora is dominant. The highest value, 0.8030, corresponds to the area between the estuary edge and landward area. At landward area, the highest value was 0.5915. The diversity value for the whole study was 0.8790. These values indicate that plant diversity in this mangrove forest is relatively higher than the mangrove stand in Florida where the diversity value was 0.4070 (Snedaker and Lugo, 1973).

Table 3. Species diversity and density of mangrove trees in different areas from the estuary to the land at Amphoe Khlung, Changwat Chantaburi.

Distance from estuary to land, m	Species diversity $H=-\sum pi \log pi$	Number of Individuals per 0.1 ha										
		Rhizophora candelaria	*R. mucronata*	*Brugueira conjugata*	*Avicennia alba*	*Xylocarpus obovatus*	*X. moluccensis*	*Ceriops roxberghiana*	*Lumnitzera spp*	*Melaleuca leucadendron*	*Excoecaria agallocha*	Total
5	0.3073	180	46	2	-	-	-	-	-	-	-	228
20	0.4081	171	38	2	5	-	-	-	-	-	-	216
35	0.5042	82	-	81	28	1	-	-	-	-	-	192
50	0.6762	70	-	86	7	5	8	7	-	-	-	183
65	0.8030	56	-	25	-	49	7	25	3	-	3	168
80	0.7214	9	-	35	-	43	-	31	10	2	10	140
95	0.7139	12	-	30	-	34	-	27	14	5	3	125
110	0.5915	-	-	-	-	45	-	45	23	20	2	135
125	0.5667	-	-	-	-	45	-	47	17	25	-	134
140	0.5804	-	-	-	-	21	-	56	37	29	-	143

Study area total 0.8790

The importance values of the dominant species of mangrove forest at Amphoe Khlung, Changwat Chantaburi, were determined and plotted against the distances from the estuary to the land (Figure 13). The major species were *Rhizophora candelaria*, *R. mucronata*, *Bruguiera conjugata*, *Avicennia alba*, *Xylocarpus obovatus*, *X. moluccensis*, *Ceriops roxburghiana*, *Lumnitzera spp*, *Melaleuca leucadendron* and *Excoecaria agallocha*. Figure 13 indicates that the importance values of *Rhizophora candelaria* and *R. mucronata* were highest at the edge of the estuary (204 and 73 respectively) and tended to decline to zero at approximately 100 and 30 m from the edge of the estuary respectively. *Bruguiera* had a very low value (6.7) at the edge of the estuary, and reached a peak where the importance value was 115 at about 50 m, and then gradually declined to zero at approximately 100 m. *Avicennia* had a well-defined zone between about 15 to 55 m and had the highest value (104) at 35 m from the estuary bank. *Xylocarpus obovatus* had a low importance value (4.6) at 35 m from the edge of the estuary and then increased to a peak (132) at around 95 m, and declined to 65 on the landward side. *X. moluccensis* was found approximately between 40 to 70 m from the edge of the estuary with the average importance value of 22. The distribution of *Ceriops* was similar to *Lumnitzera* since they were found about 50 m from the edge of the estuary with the importance values of 17 and 40 respectively. Both species gradually increased in the importance values (98 and 91

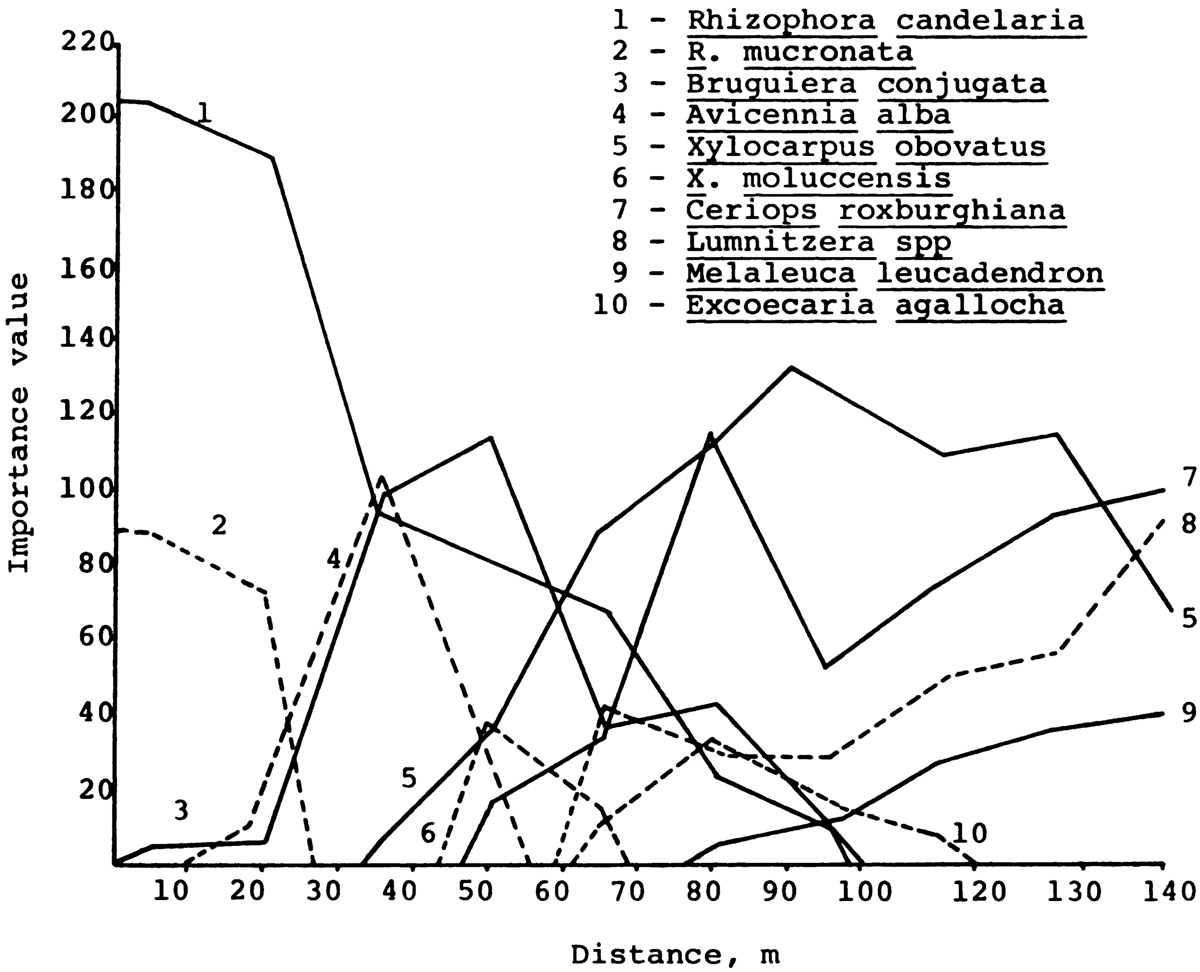

Figure 13. Importance values of main species of mangrove forest at Amphoe Khlung, Changwat Chantaburi, as related to distance from the estuary to the land.

respectively) at 140 m, but the importance value of Ceriops markedly fell off somewhat at about 95 m (50) and then increased up to a value of 98 at 140 m from the estuary bank. Excoecaria had a well-defined zone found approximately between 60 to 115 m from the edge of the estuary with the average importance value of about 16. Melaleuca leucadendron had low importance value (7) at about 75 m and then the value gradually increased and reached to 40 on the inland side.

Stand Volume

The stand volume of the mangrove forest was determined at the different plot areas from the estuary edge towards the forest (Figure 14). Volumes are variable throughout the area, but data indicate that the values tend to increase from the mangrove margin to the area between the mangrove edge and the landward sites, then the volumes decrease on the areas nearest to the inland side. Stand volume in each area is dependent upon tree size, density and species composition. Volumes at the mangrove-water edge, approximately 30 to 35 m^3/ha, due to the small tree sizes and relatively comprises few species. The area at the landward side has a higher stand volume, about 50 to 84 m^3/ha. The highest stand volume, approximately 120 m^3/ha, is found in the middle zone where the area is composed of more species of larger size.

Noakes (1957) reported that the volume for the best stand in Malaya, the Perak Mangrove, is about 248 m^3/ha. The volume from the average Malayan mangrove forest is much less

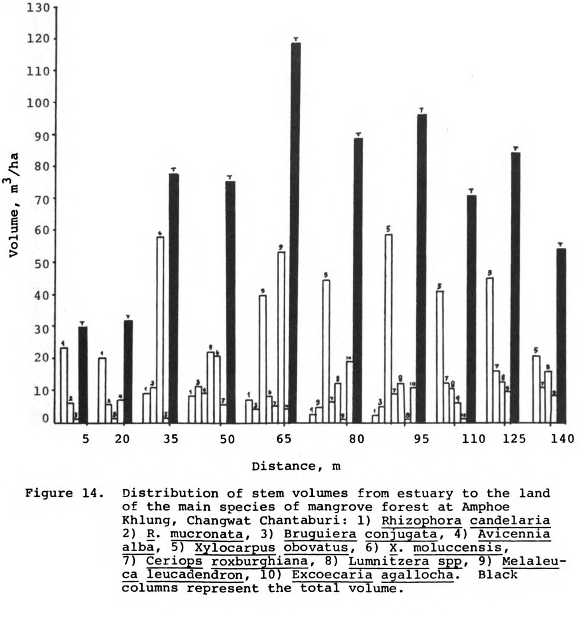

Figure 14. Distribution of stem volumes from estuary to the land of the main species of mangrove forest at Amphoe Khlung, Changwat Chantaburi: 1) *Rhizophora candelaria* 2) *R. mucronata*, 3) *Bruguiera conjugata*, 4) *Avicennia alba*, 5) *Xylocarpus obovatus*, 6) *X. moluccensis*, 7) *Ceriops roxburghiana*, 8) *Lumnitzera spp*, 9) *Melaleuca leucadendron*, 10) *Excoecaria agallocha*. Black columns represent the total volume.

than this amount. Noakes found that in the Selangor mangrove, volumes were only 110 m^3/ha.

MANGROVE REGENERATION

Introduction

No studies have been done in Thailand on mangrove regeneration and the growth rate of the various tree species. This information is urgently needed because:

1. The Thailand Royal Forest Department has recently changed the cutting system for the mangrove working plan from "Shelterwood Cum Minimum Girth" system to a "Clear Cutting in Alternate Strip" system (Bumroongrad, 1974). Strips that are cut will be replanted, and therefore, basic knowledge on regeneration is needed.
2. Vast areas of cleared mangrove forests in Thailand need to be planted, as soon as possible. These abandoned areas resulted from past logging operations, tin mining and/or shrimp farming.
3. While natural regeneration of mangrove is excellent when compared to other forest types, survival is often unsatisfactory because of many destructive factors (Boonyobhas, 1975). Factors that play a significant role in influencing mangrove regeneration are man's interference, competition from the ferns (*Acrostichum aureum*), crab activity, deep flooding,

and amount of slash. These factors have been discussed by Noakes (1951) and Du (1962). Therefore artificial regeneration is important in areas where natural regeneration is inadequate.

The results provide information on: 1) species suitability to site, 2) growth rates related to species and distances from the estuary edge to the land, and 3) time of the year in which maximum growth occurs for each species.

Review of Literature

Mangrove Reproduction, Dispersal and Establishment

Reproduction

A striking feature of the trees included in the "mangrove" family is their method of reproduction. Each species exhibits a certain degree of vivipary; that is, the seed germinates while still on the tree rather than after it has fallen.

From the time of flower fertilization, the red mangrove requires about three months for the hypocotyl to appear (Bowman, 1917). However, Guppy (1906) stated that a period of 15 weeks elapses from time of fertilization until the radical appears. Davis (1940) reported that it takes from 70 to 90 days for the hypocotyl to ripen from the fruit. Bowman (1917) found the rate of hypocoty elongation of *Rhizophora mangle* to be 4.7 cm in 34 days.

In *Rhizophora* a full year may pass from the time of fertilization until the seedling is released (Bowman, 1917).

Guppy (1917) believed this interval to be from nine to ten months for mangroves in the West Indies. When fully developed and before falling, the seedling may reach a length of 30 to 60 cm in Rhizophora and 15 to 20 cm in Bruguiera (Du, 1962). In contrast to the red mangrove, the seeds of Avicennia are released immediately upon completion of germination (Bowman, 1917).

Although mangrove seed production has been shown to occur the year around, Davis (1940) has shown that in mangrove forest in Florida, the peak seed production of Rhizophora occurs in August. Avicennia and Laguncularia seedlings appear to peak somewhat later in September. Khan (1961) found that fruit of Avicennia in West Pakistan matured towards the end of July or early August. In the mangrove forest in Thailand, Kongsangchai (1973) found that the viviparous seedlings of Rhizophora matured during July to September. Salinity of the surrounding water appears to influence the ability of the mangrove to reproduce. Thom (1967) observed that under conditions of low salinity, Rhizophora failed to reproduce in the mangrove forest of Mexico.

Dispersal

When the seedling is dropped from the mangrove tree it can either stick directly in the mud below or be carried away by the tide. Although Dale (1938) observed a large amount of regeneration beneath the parent mangroves in Kenya, Egler (1948) stated that Rhizophora seedlings do not grow in the mud directly below the parent tree because: 1) the curve of the hypocotyl prevents it from directly entering the soil, 2) it normally strikes water rather than mud, and 3) if it did strike soil the probability is high that it would be floated out on the next tide. Ding Hu (1958) noted that most seedlings of *Rhizophora*, *Bruguiera*, and *Ceriops* in the Perak mangrove forest in Malaya were from local trees and did not come from great distances. Although tides and winds are reported to be more effective than water currents in carrying seedlings inland (Davis, 1940), currents are the source of outward seedling dispersal for if the seedlings are buffeted about excessively the plumule is broken and the seedling dies (Bowman, 1917). How far the seedling is transported away from the mother tree depends on its shape, size and the amount of obstruction. Watson (1928) described the seedlings of *Rhizophora* as being ill-suited for water dispersal due to the long hypocotyl and its tendency to be hindered by nearshore objects.

Seedlings have been observed to float in the water for several months to a year, during which time top growth and secondary roots may still develop (Davis, 1940; Multer and Multer, 1966). However, Chapman (1966) reported that such seedlings show neither root development nor other signs of growth. *Avicennia* seedlings, have been observed to survive about 3 months afloat but not much longer if not rooted (Davis, 1940). The actual length of time that a seedling will float depends on the age of the seedling and the salinity of the water. Stephens (1962) has found that the higher the salinity of water, the longer the seedlings will float.

Establishment

Many researchers have examined the various reasons for the ability of mangroves to colonize a particular area. Davis (1940) states that the establishment of plants depends mostly on tide, waves, submergence and sedimentation. The main factors for ecological preference according to Steenis (1958) are: 1) soil type, 2) salinity, and 3) resistance to currents and surf. Clarke and Hannon (1970) conclude that the position in the habitat, time within tidal flow, and seedling age will determine whether seedlings become established.

Once the mangrove seedling has reached a shore where growth may develop, very specific circumstances must occur for successful establishment. If the seedlings developed secondary roots while afloat, its chances for establishment are markedly reduced (Chapman, 1966). Egler (1948) says that two days of root growth are necessary to bind seedlings to the substrate so that they will not be dislodged on the following tide.

Some Factors Involved in Mangrove Establishment

Salinity

Salinity appears to play only a minor role in influencing mangrove establishment (Steenis, 1958; McMillan, 1971). Mangroves were at one time considered to be obligate halophytes but this is untrue. Davis (1943) reported that

Rhizophora mangle lived for six years in a greenhouse with only fresh water. This indicates that it can probably adapt to fresh water. Steenis (1958) found *Acanthus ilicifolus* and *Acrostichum aureum* growing naturally in water analyzed to be fresh. Although they do not absolutely require saline conditions for growth, mangrove species do, for the most part, fare better in salt water. Clarke and Hannon (1970) found that *Avicennia*, at the 0 to 2 leaf-stage of seedlings, requires sea water for optimum growth, particularly for root development. Their studies showed that 20% sea water at the 2 to 4 leaf-stage, with seedlings becoming more tolerant to a higher salinity at the older stages. Moog (1963) observed that *Avicennia germinans* was regulated by salt variation. He found that in salt pools containing a higher concentration of salt (than sea water), *Avicennia germinans* was dwarfed and the trees grew but 2 cm/year. While Stern and Voight (1959) reported the early development of *Rhizophora* be favored by high salinities, Macnae and Kalk (1962) found *Rhizophora* growing only on waterlogged soils where the range of salinity was below that of normal sea water. Morrow and Nickerson (1973) reported that *Rhizophora mangle* survived only in areas where salinity approximates that of sea water, and where sea water is free to exchange with the ocean at each tide.

Turbulence and Depth of Water

Turbulence inhibited root and seedling development in *Avicennia germinans*, when seeds were artificially tumbled for 12 weeks (McMillan, 1971). However, once stabilized, the seeds developed rapidly. Water turbulence, if not severe, may actually assist in mangrove establishment. Grossland (1903) described mangrove seedlings established in the cracks of rocky substrata resulting from the motion of water currents carrying the seedlings into the laden cracks.

Water depth is one of the more significant considerations in mangrove establishment. Although seedlings of *Rhizophora* may survive a year or longer while totally submerged, they usually do not become established in water depths greater than 60 cm (Stephens, 1962). Davis (1940) found that *Avicennia* and *Laguncularia* did not establish themselves in water depths greater than 16 cm. *Avicennia* seedlings with over 6 cm top growth can withstand nearly constant submergence but fail to develop if totally submerged. *Laguncularia* seems to be able to withstand some submergence but consistent data are unavilable (Davis, 1940). From field observation in the mangrove forest at Amphoe Khlung, Thailand, the fern *Acrostichum aureum* sporelings were totally submerged to a depth of 0.8 to 1 m without apparent injury.

Light

Mangrove species normally have high light requirements (Macnae, 1968; Du, 1962). Snedaker and Lugo (1973) found that when the tree canopy was opened and light transmission was high, mangrove seedling density increased. Clarke and Hannon (1971) established that the growth of *Avicennia* was most likely to be limited by light, at the seedling stage. Deep shade reduced the shoot growth of *Avicennia* and full light produced yellow and spotted leaves in contrast with the dark green leaves produced at lower light intensities. Total growth was greatest in full light, but the plants were not as healthy and mortality was higher than in plants grown under less intense light conditions.

Waterlogging

Rhizophora of Inhaca Island, Mocambique, grew only on waterlogged soils (Macnae and Kalk, 1962) whereas total water immersion of very young *Avicennia* seedlings resulted in high mortality rates, seedlings with 2 to 4 leaves were not affected by waterlogging (Clarke and Hannon, 1971). Carey and Frazer (1932) state that *Avicennia* adapts its growth to waterlogged areas by virtue of its viviparous nature. The National Academy of Sciences (1974) reported that *Rhizophora* and *Ceriops* seedlings planted by hand in defoliated areas in South Vietnam grew and survived between 80 and 85% in the more moist or waterlogged areas than those seedlings planted in the higher and drier areas where seedlings survived only 50 and 66% respectively.

Temperature

The only work reported on the effect of temperature on mangrove seedling development was by McMillan (1971). He found that the optimum temperature for rooting of *Avicennia germinans* along the Texas coast to be 18°, 24° and 30°C, with temperatures below and above this range being inhibitory for root development. He also stated that, temperatures of 39°- 40°C for a 48 hour period were lethal to stemless seedlings but not seedlings with stems and roots.

Growth of Mangrove Seedlings

Few studies exist on the growth characteristics of mangrove seedlings. Stephens (1969) found that early growth is very rapid in mangroves, with 60 cm height-growth occurring in the first year. *Rhizophora* and *Avicennia* may produce 12 to 13 leaves with 15 to 60 cm of top growth and 4 to 14 leaves with 8 to 22 cm of top growth in the first year respectively.. *Laguncularia* is the slower growing of the three, producing 4 to 8 leaves with 5 to 20 cm height-growth in the first year (Davis, 1940). Khan (1961) found that the first pair of *Avicennia* leaves appeared in four to six days and the second pair of leaves in about 20 days after the two cotyledons dried out. Salvage (1972) planted *Rhizophora* seedlings on an undisturbed beach in Little Saratosa Bay, Florida, and found that the first pair of leaves were formed after a month. Red mangrove seedlings in Rookery Bay, Florida, grew at the rate of 0.1 cm/day (Snedaker and Lugo, 1973).

A few studies have been done in an attempt to cultivate mangrove seedlings away from their natural habitat. Patil (1964) grew *Bruguiera* and *Rhizophora* at Allahabad, India, and found the best growth response when seedlings were grown in a solution where the concentration of sodium and magnesium chloride were relatively high though still less than in sea water. From the stage at which the seedling hypocotyls drop to the ground to the stage of development attained, *Bruguiera* produced a second pair of leaves while *Rhizophora* had only produced the first pair of leaves. In Florida, Salvage (1972) found that 10 weeks after planting *Rhizophora* in different mediums (filter fiber, Spanish moss and sea grass), the seedlings had produced the first leaf set. Height growth was not recorded.

Materials and Methods

The natural mangrove forest study site at Amphoe Khlung, Changwat Chantaburi covers an area approximately 120 m long from the estuary edge to the land and 20 m in width. All trees occurring in this area were cut and removed, a fence was constructed around the planting site. The study was carried out from October, 1974, to September, 1975. A split plot design was used for data analyses with three factors being examined: species, distance from the edge of the estuary to the land, and time of the year.

The four commercially valuable mangrove species selected for study were *Rhizophora mucronata*, *R. candelaria*, *Bruguiera conjugata* and *Avicennia alba* (Figure 15). One hundred mature seedlings for each species were collected after falling from the parent tree and inserting them into the ground at a 1 x 1 m spacing. Planting occurred from the edge of the estuary to the land by using a randomized block design with 5 replications (Figure 16).

Figure 15. **The unknown aged seedlings of four mangrove species.** From left to right: Rhizophora mucronata, R. candelaria, Bruguiera conjugata and Avicennia alba.

Figure 16. Nine-month old seedlings of four mangrove species planted with 1x1 m spacing from the edge of the estuary to the land at Amphoe Khlung, Changwat Chantaburi (October, 1974, to June, 1975).

Distances from the edge of the estuary to the land were stratified into 20 - 5 m intervals (0-5, 6-10, ... 91-95 and 96-100 m). Five replications were used for each distance interval.

Initial seedling heights by species were measured to the nearest 0.1 cm. Total height of the same seedling was recorded at the end of each month over a 1 year period. The actual monthly height-growth was obtained by substracting the initial height from the total height measured at the end of each month. The number of new leaves produced each month was also recorded. Mortality of each species was recorded at the end of each month.

Results and Discussion

Species Growth

The height-growth of 100 planted *Rhizophora candelaria*, *R. mucronata*, *Bruguiera conjugata* and *Avicennia alba*, was measured monthly. Measurements were averaged for each species and expressed in both monthly total height and as increment over a one-year period (October, 1974, to September, 1975). Data are presented in Figures 17 and 18.

On the basis of height-growth response, these species may be grouped into two categories. The first is represented by *Rhizophora candelaria*, *R. mucronata* and *Bruguiera conjugata*, where the average monthly total height-growth, and average monthly increment were very similar (Figures 17 and 18). The growth of *Rhizophora candelaria* and *Bruguiera conujugata*,

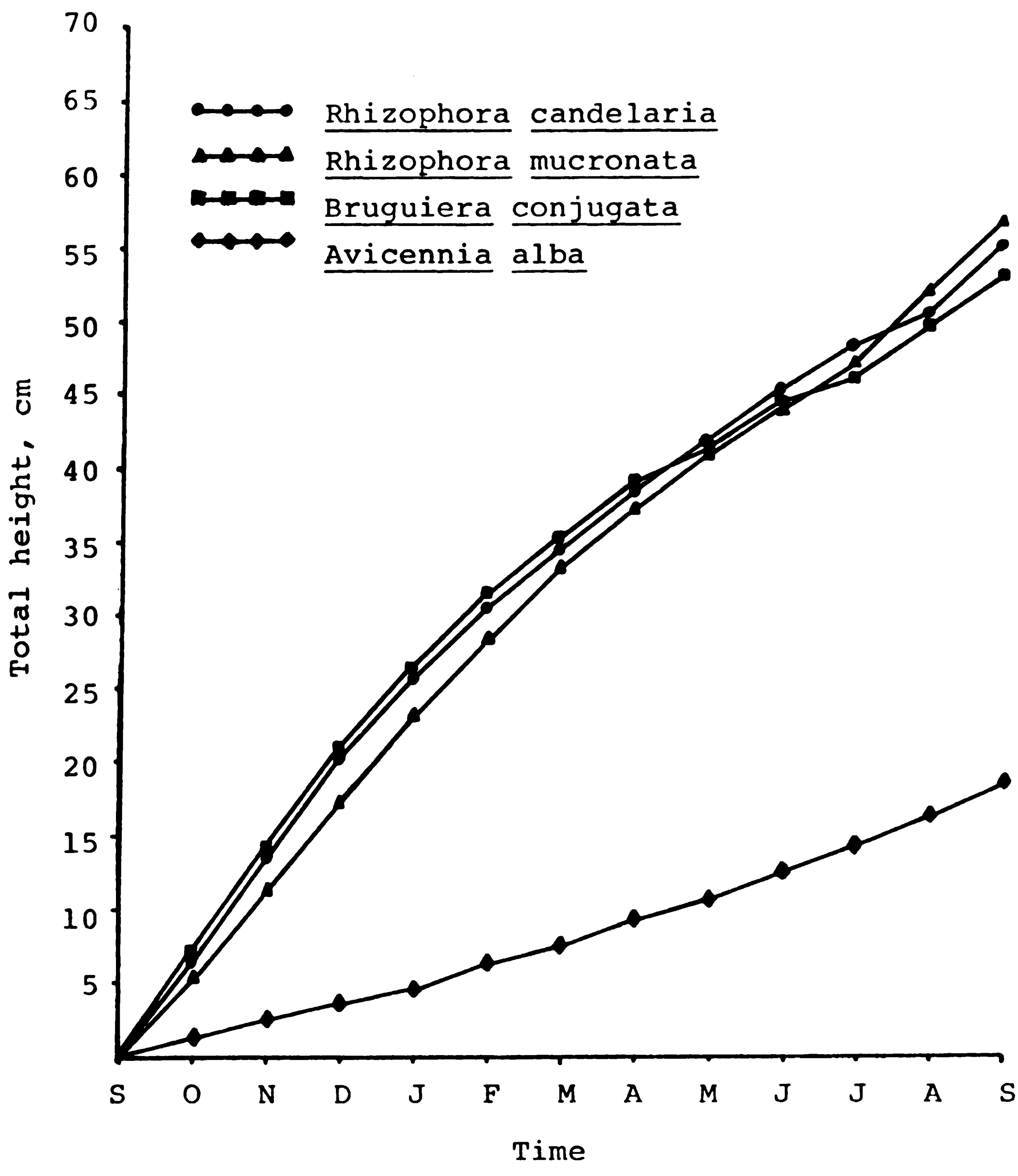

Figure 17. Total annual height growth of four mangrove species, October 1974, to September, 1975.

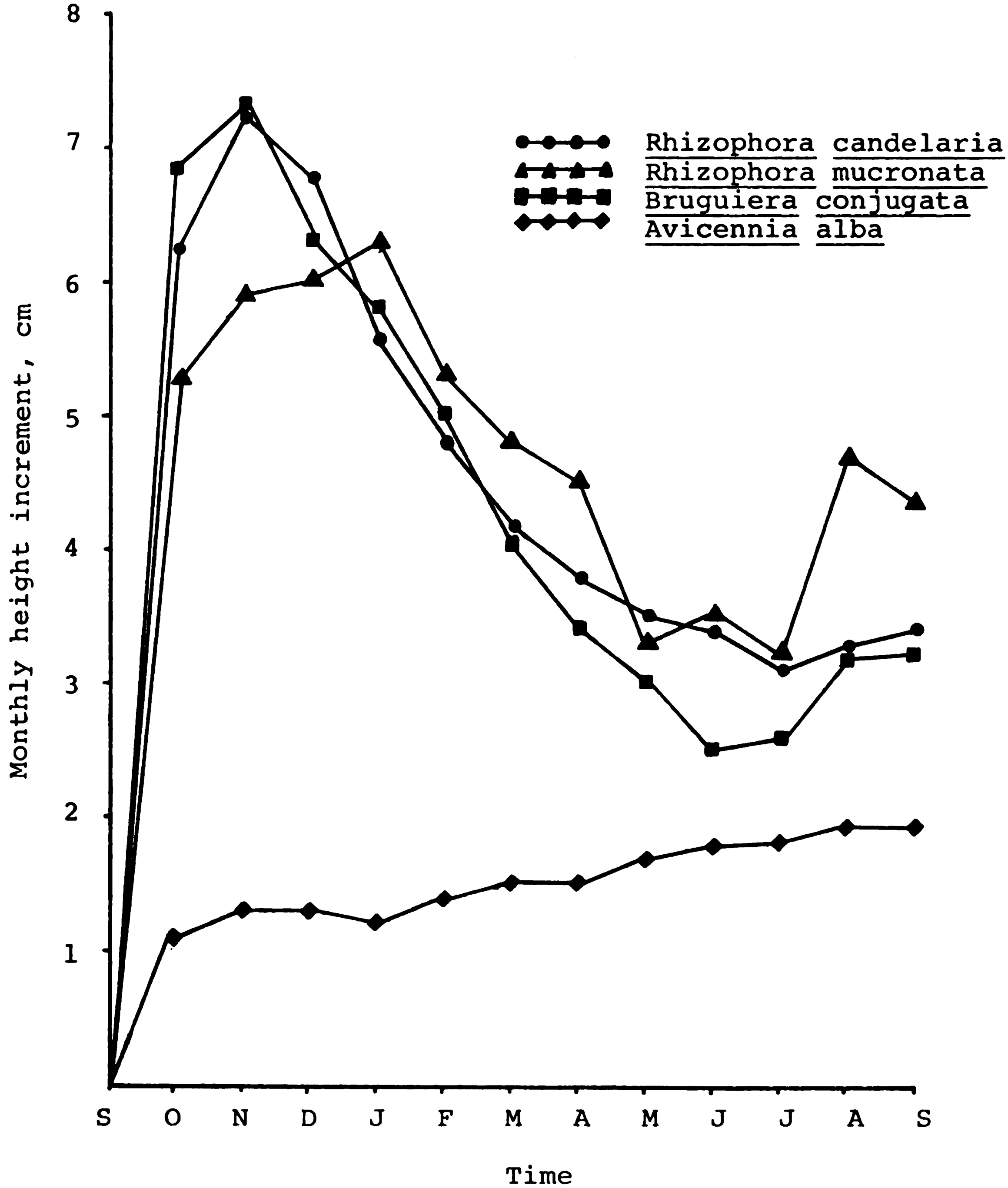

Figure 18. Average monthly increment of height growth of four mangrove species, October 1974, to September, 1975.

started soon after planting (in the end of September, 1974) and continued at a rapid rate during the first three months (October to December). The average height-growth increment at this time was approximately 6.7 and 7.0 cm/month. Growth then gradually decreased until the minimum rate was reached in about July for *R. candelaria* (3.1 cm) and June for *B. conjugata* (2.5 cm) respectively. Both species resumed a faster rate of growth again at that time until an average increment of 3.4 and 3.2 cm/month respectively was attained in September.

Rhizophora mucronata growth started with a high growth rate in October after planting and reached a peak in January (Figure 18). The height-growth rates from October to January were approximately 5.3, 5.9, 6.0 and 6.3 cm/month respectively. This rate than gradually declined, dropping to a minimum increment of 3.2 cm in July. Height growth then increased in August and September when the growth rates were about 4.7 and 4.3 cm respectively.

The second height-growth response class is represented by *Avicennia alba*. Growth began at a slow rate (1.1 cm) in October after planting and gradually increased up to September when the maximum height-growth increment was approximately 2.0 cm (Figure 18).

The rapid height-growth increment of *Rhizophora candelaria* and *Bruguiera conjugata* during October to December, and in *R. mucronata* from October to January was probably achieved by the relatively large quantity of reserve food stored in the hypocotyl (Figure 15). These food reserves were quickly utilized when growth began following planting in the end of September, and resulted in the rapid formation of shoot tissues.

The decrease of height-growth from January to June in Rhizophora candelaria, to July in Bruguiera conjugata, and that of R. mucronata beginning in February probably occurred because of: 1) the depletion of food reserve in the hypocotyl and 2) as the result of branch and leaf development. Branch initiation of R. candelaria and R. mucronata occurred in April, with subsequent prolific leaf development. The increases in number of branches and leaves resulted in a lower height-growth increment during this period. There was no corresponding branch establishment in B. conjugata during the period of May to June. Leaf development took place directly from the stem, however, and a reduction in height-growth therefore took place.

The resumption of height-growth from July to September in B. conjugata and August to September for both Rhizophoras is probably due to the establishment of a well-developed root system. However, no studies have been done on the root development of these mangrove species.

The height-growth increment of Avicennia alba deviated from the other mangrove species in that it gradually increased continuously from October to the end of one year. There were no branches developed during the first year but one pair of leaves was produced each month. A probable reason for the initial increase in height-growth increment in

A. alba, as contrasted to the other mangrove species, was an earlier development of an extensive root system. Macnae (1968) found that *A. alba* begins to develop a root system shortly after the seedlings drop to the soil surface.

Growth With Distance From Estuary

The height-growth patterns of the four mangrove species planted from the edge of the estuary to the landward side are presented in Figure 19 for the entire study year. These data indicate insignificant differences between the total height-growth for *Rhizophora candelaria*, *R. mucronata* and *Bruguiera conjugata*.

Rhizophora candelaria grew best in the areas from the estuary edge up to approximately 55 m inland. Here the average height-growth was 61.0 cm, while the poorest average height-growth, 41.0 cm, occurred in the area nearest the landward side. Between 60 to 100 m from the edge of the estuary, the average height-growth was 51.0 cm.

The best average height-growth for *R. mucronata*, 60 cm, and *B. conjugata*, 55 cm, occurred on the sites between the edge of the estuary and about 75 m inland. Further inland, the total height-growth decreased to an average height-growth of 49.0 cm for both species.

Avicennia alba was the slowest growing of the four species. The best average height-growth of 25 cm was on sites nearest the estuary edge, while the height-growth was about 20 cm when located between 10 to 50 m inland. The

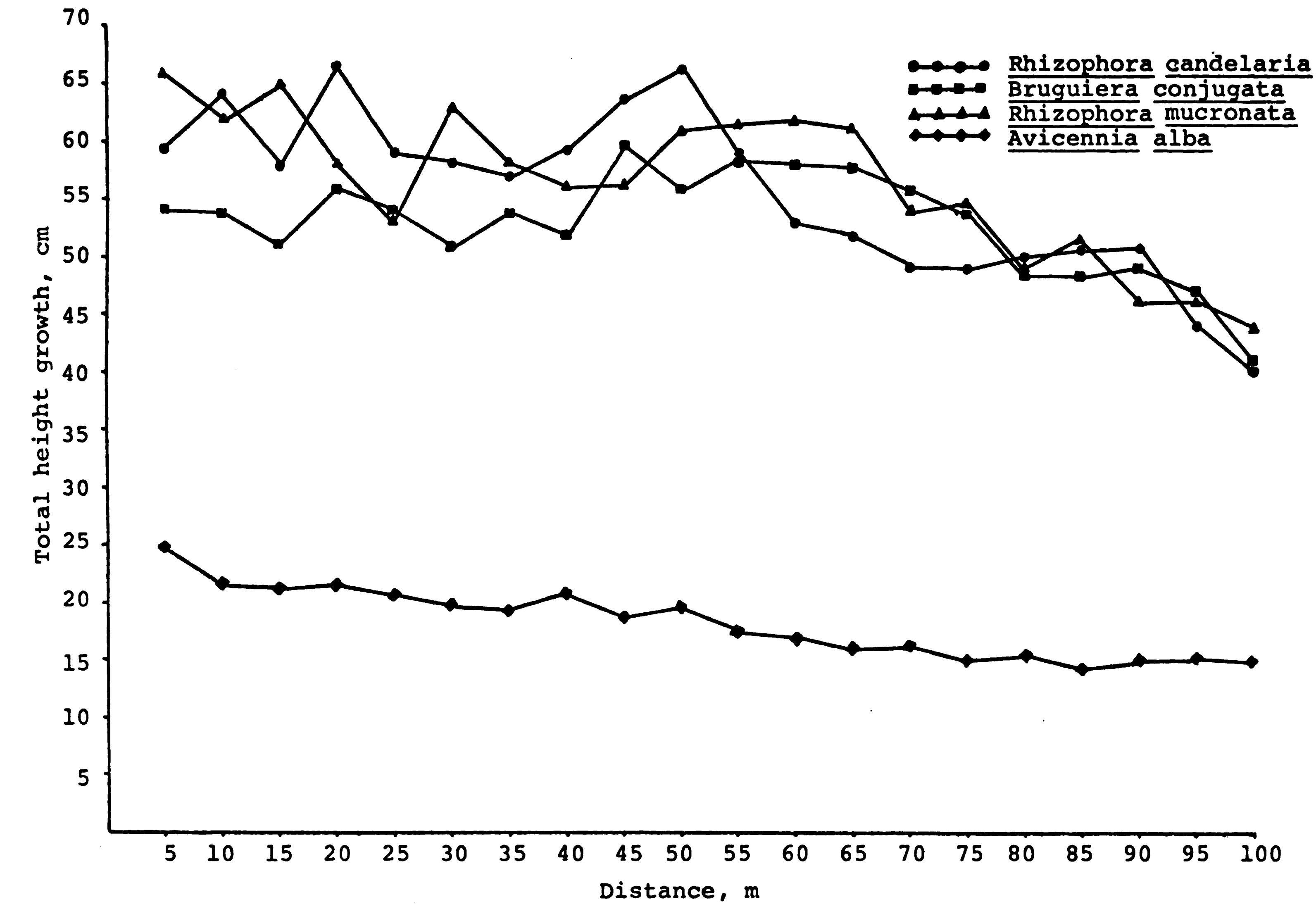

Figure 19. Annual total height growth of four mangrove species with distance from estuary edge to inland side, October, 1974, to September, 1975.

poorest growth occurred on sites more than 55 m away from the estuary, where the average height-growth was 16.0 cm.

In all cases, total height-growth was greatest in the areas adjacent to the edge of the estuary. These particular mangrove species appear to be best suited to those sites that are commonly inundated, waterlogged, poorly aerated and containing high levels of chlorinity and nutrients.

Mortality

It was observed that *Bruguiera conjugata* and *Avicennia alba* had the highest mortality rates of the four species, with values of 9% and 8% during the first year respectively. The two *Rhizophora* species suffered less mortality, with 5% and 4% occurring in *R. candelaria* and *R. mucronata* respectively. The highest mortality rates for both *Rhizophora* and *B. conjugata* occurred from June to August while for *A. alba*, it was in December to March (Table 4). Mortality for all species was greatest in the inland areas with 3%, 2%, 5% and 5% occurring in *R. candelaria*, *R. mucronata*, *B. conjugata* and *A. alba* respectively. The least amount of mortality for *R. candelaria* (1%), *R. mucronata* (0%) and *A. alba* (1%) occurred in the area near the edge of the estuary, while for *B. conjugata* (1%), it was in the area midway between the edge of the estuary and the landward side. The mortality of *B. conjugata* in the area near the edge of the estuary was 3%. In the area midway between the estuary edge and the landward side, the mortality of *R. candelaria*, *R. mucronata* and *A. alba* was 4%, 2% and 2% respectively.

Table 4. Percent of mortality of the four mangrove species planted from the estuary edge to the land at Amphoe Khlung, Changwat Chantaburi.

Distance from the estuary edge to the land, m	*R. candelaria*			*R. mucronata*			*B. conjugata*			*A. Alba*		
	0-50	50-75	75-100	0-50	50-75	75-100	0-50	50-75	75-100	0-50	50-75	75-100
October	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	2
January	0	0	0	0	0	0	0	0	0	0	1	0
February	0	0	0	0	0	0	0	0	1	0	0	1
March	1	0	0	0	0	0	0	0	0	1	1	1
April	0	0	0	0	0	1	0	0	0	0	0	0
May	0	0	0	0	0	0	1	0	1	0	0	0
June	0	1	0	0	1	0	0	0	0	0	0	1
July	0	0	2	0	1	0	1	1	1	0	0	0
August	0	0	1	0	0	1	1	0	2	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
Total	1	1	3	0	2	2	3	1	5	1	2	5

MANGROVE PLANTATION PRODUCTIVITY

Introduction

This investigation examines the above-ground biomass (weight of living plant material), as one step in assessing the net primary productivity of the mangrove plantations. The present study forms a part of Thailand's contribution to International Biological Program (IBP).

Knowledge of the standing crop of a plant community is the necessary biological basis of any attempt to manage the productivity of that community. Therefore, this investigation explored possible correlation between: plantation age and plant component biomass; diameter and height measurement relationships with total biomass and stem volume. Such information should be useful in determining suitable mangrove harvest rotation systems. Results of this study will also provide a reference point for evaluating changes that have occurred in other mangrove plantations in Thailand.

Review of Literature

Very little work has been done thus far carried out on mangrove photosynthesis and respiration. Golley *et al*. (1962) studied the structure and metabolism of a mangrove swamp in Puerto Rico. They found that total photosynthesis and leaf respiration were each estimated to be 8 gc/m^2/day or about 16 g organic matter/m^2/day. This is a high rate of gross production. Lugo et al. (1973) measured CO_2 exchange for all four of the South Florida mangrove forest tree species (*Rhizophora mangle*, *Avicennia nitida*, *Laguncularia racemosa*, and *Conocarpus erecta*). Measurements were done by compartment (trunks, prop roots, pneumatophores, seedlings, and shade and sun leaves) and on a diurnal basis in order to establish magnitudes and possible zonation of photosynthesis and respiration. The hourly rates of net daytime photosynthesis and nighttime respiration were the same between species, but the red mangrove had a higher total daytime net photosynthesis for the same light intensity. In general, red mangrove leaves exhibited a higher photosynthetic capacity than those of black mangrove. The white mangrove leaves were the least productive of the three. Sun leaves were found to have higher net daytime photosynthesis and lower nighttime respiration than shade leaves. Due to their higher nighttime respiration, shade leaves seem to have a higher gross photosynthesis than sun leaves. Miller (1972) found a higher net photosynthesis in the shade leaves of the upper canopy than in the lower canopy of mangrove in South Florida. On a surface area basis, trunks have as much respiration as shade leaves, and prop roots and pneumatophores have the least respiration (Lugo et al., 1973).

Lugo *et al*. (1973) compared the metabolism of mangroves at Rookery Bay in Florida, with the red mangroves in Puerto Rico. The Rookery Bay forest was characterized by a greater-than-one ratio of gross photosynthesis to total respiration (P/R) in contrast to the Puerto Rico forest which had a ratio of 0.8.

Several parameters have been identified as important regulators of mangrove productivity. These can be grouped into two principal factors (Lugo and Snedaker, 1974) and subdivided into the following seven categories (Carter *et al*., 1974 in Lugo and Snedaker, 1974).

1. Tidal Factors
    a. Oxygen transport to the root system.
    b. Physical exchange of the soil water solution with the overlying water mass, removal of toxic sulfides and the reaction of reducing the total salt content of the soil water.
    c. Tidal flushing interaction with the surface water particulate load, influencing the rate of sediment deposition or erosion within a given area.
    d. Vertical motion of the ground water table transporting the nutrients regenerated by detrital food chains into the mangrove root zone.

2. Water Chemistry Factors

a. Total salt content governs the osmotic pressure gradient between the soil solution and the plant vascular system, thus effecting the transpiration rate of leaves.

b. A high macro-nutrient content of the soil solution may maintain a high productivity in mangrove ecosystems despite the low transpiration rates caused by high salt concentrations in sea water (Kuenzler, 1968).

c. Allochthonous macro-nutrients contained in wet season surface runoff may dominate the macro-nutrient budgets of mangrove ecosystems (Lugo et al., 1973).

Method of estimating primary productivity by terrestrial plant communities have been reviewed by Kira et al. (1967). These depend on either a harvest technique, in which repeated biomass measurements are made at specific intervals, or a photosynthetic technique, in which the photosynthetic rate of a single leaf is linked with vertical distribution of leaf area and light intensity. Kira concluded that, especially for non-seasonal communities such as tropical forests in which growth ring analysis is difficult, gross productivity can best be estimated by calculating biomass increment derived from repeated estimates of biomass of the same stand, substracting the losses by litter fall (measured with litter trap) and grazing and parasitism (they regard these latter sources as of minor importance) and adding an estimate of community respiration.

The variability in the biomass data may be attributable to age, stand history, or structure differences (Lugo and Snedaker, 1974). While no data are available on the biomass of known-aged mangrove plantations, several publications have reported on the biomass of unknown-aged mangrove forests (Golley et al., 1962; Golley et al., 1974 in Lugo and Snedaker, 1974; de la Cruz and Banaag, 1967; and Snedaker and Lugo, 1973) (Table 5).

Direct biomass measurement by weighing of a reasonably wide area of the type of forest is unrealistic and impracticable. An indirect method of biomass estimation utilizes the relationships that can often be made between tree weight and other growth parameters which can be measured over a large sample area (Sabhasri and Wood, 1967).

Such relationships, termed allometric, formulate the relation between the weights of two different parts of an organism, x and y as:

$$y = Ax^h$$

$$\text{or } \log y = \text{Log } A + h \log x$$

where y and x are measured quantities of a particular individual and A and h are specific constants.

Kittredge (1944, 1948) was one of the first to apply the allometric relationship of leaf weight to stem diameter in the estimation of forest biomass. Ovington and Madgwick (1959) used a similar method in studying the distribution of

Table 5. Mangrove forest biomass estimates (kg dry-weight/ha).

Location Mangrove Type	Panama[1]	Puerto Rico[2]	Philippines[3]	Florida[4] Overwash Area 1	Florida[4] Overwash Area 2	Florida[5] Riverine Area 1	Florida[5] Riverine Area 2	Florida[6] Fringe Area 1	Florida[6] Fringe Area 2	Florida[6] Fringe Area 3	Florida[7] Scrub	Florida[8] Inland	Florida[9] Succession
Leaves	3,550	7,780	13,319	7,263	6,946	3,810	9.510	5,934	5,843	7,037	712	4,990	2,215
Fruit & Flowers	21	-	-	20	236	148	0.4	28	210	131	-	78	-
Stems & Branches	-	12,740	-	-	-	16,770	27,670	17,000	19,120	18,550	3,959	-	5,908
Wood	159,209	27,960	24,346	70,380	70,480	62,850	133,660	40,960	65,150	109,960	-	18,090	-
Prop Roots	116,432	14,370	-	51,980	41,920	14,640	3,060	22,270	27,200	17,190	3,197	25,810	-
Pneumatophores	-	-	8,271	-	-	-	-	-	-	-	-	-	-
Subsurface Root	189,761	49,970	-	-	-	-	-	-	-	-	-	8,010	14,068
Litter	102,106	-	-	17,310	13,990	42,950	33,930	22,730	60,250	98,410	1,140	-	323
Total Above Ground Biomass Excluding Litter	279,212	62,850	45,936	129,643	119,218	98,218	173,900	86,192	117,523	152,868	7,868	48,968	8,123

[1] Golley, F. B. *et al.* (1974).
[2] Golley, F. B. *et al.* (1962).
[3] de la Cruz, A. A. and J. F. Banaag (1967).
[4, 5, 6, 7, 8, and 9] Snedaker, S. C. and A. E. Lugo (1973).

organic matter and plant nutrients in a Scotch pine plantation. In Thailand, such relationships have been established by Ogino _et al_. (1964) in estimating the standing forest crops in the northeast, and by Ogawa _et al_. (1965) and Yoda (1967) on three main types of forest vegetation including a stand of dry evergreen forest near Doi Inthanon in Northern Thailand and by Sabhasri _et al_. (1968) on the estimation of dry evergreen forest in the northeast. They concluded that a better correlation exists between tree weight and D^2H (where D is the diameter of the tree at the breast height and H is its height) than between the weight and diameter at breast height.

Materials and Methods

The mangrove plantations in Amphoe Khlung, Changwat Chantaburi were planted in 1960, 1961, 1962, 1963, 1965, 1968 and 1971 so that the ages of these plantations now are 14, 13, 12, 11, 9, 6 and 3 years old respectively. The approximate locations of these study sites are shown in Figure 20. _Rhizophora candelaria_, the most commercially valuable mangrove tree species, was planted with a 1 x 1 m spacing using mature seedlings. Site preparation involved the complete removal of all trees from the area. None of the plantations have been thinned since planting, and all occupy relatively undisturbed sites (Figures 21-24).

Thirty trees were randomly sampled from each plantation. Diameter was measured to the nearest 0.1 cm by using

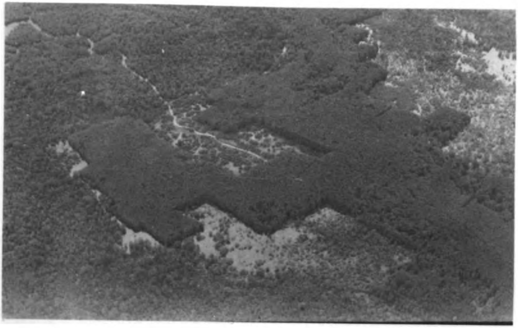

Figure 21. Aerial view of several mangrove plantations at Amphoe Khlung, Changwat Chantaburi, 1974.

Figure 22. Three-year old mangrove plantation, Rhizophora candelaria.

Figure 23. Nine-year old mangrove plantation, Rhizophora candelaria.

Figure 24. Fourteen-year old mangrove plantation, Rhizophora candelaria.

a diameter tape. Total and commercial height (commercial height refers to the usable portion of the tree stem which is the length from the stump base to 4.0 cm upper stem diameter) was measured following the harvest to the nearest 0.1 m by using regular meter tape.

Prior to felling, all prop roots were removed from the stem at ground level. Each tree was measured stem diameter at ground, 10 cm and 130 cm (diameter at breast height) above the ground. After cutting, stem diameter was measured at two meter intervals to calculate stem taper.

To obtain the fresh weight, stems were cut into two meter sections, leaves were collected by hand, green and dead branches were separated as were the prop roots, and each component weighed with a 60 kg capacity scale to the nearest 0.1 kg. Figures 25-28 illustrate the weighing technique.

Stem, branch, leaf and prop root sub-samples were oven-dried at 105°C for 24 hours to correct green weights to oven-dry weights. The total and commercial stem volume for each tree was calculated by using Smalian's formula (Bruce and Schumacher, 1950). The relationships between dbh, D^2H, tree dry-weights by component, and stem volume were calculated.

Three surface soil samples (0-6 cm) were collected from each mangrove plantation at three randomly selected sites. All samples were analyzed at the soil laboratory of Agricultural Chemistry Division, Department of Agriculture, Thailand, for soil texture, pH, organic matter, N, P, K contents, cation exchange capacity (C.E.C.) and soil chlorinity. Soil particle

Figure 25. Field weighing a 2 m tree stem section.

Figure 26. Separation of component parts with subsequent weighing.

Figure 27. Determination of root weight in the field.

Figure 28. Field weighing of branch and twig components.

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sizes were determined by the pipette method (FAO, 1970). pH values were measured by a Redox-pH meter. The determination of organic matter was carried out by using Walkley and Black's rapid titration method (Walkley and Black, 1934). Cation exchange capacity (C.E.C.) was obtained by using the sodium saturation method as modified by Chapman (1965). The Kjeldahl method was used to determine the total nitrogen content. Phosphorus value was determined by using the method of Bray II (Jackson, 1967). Potassium content was determined by using NH_4OAc as described in Jackson (1967). The chloride ion value was obtained by the water soluble method (Jackson, 1958).

Results and Discussion

A summary of average values, based on 30 trees from each age group of mangrove plantation (*Rhizophora candelaria*), for diameter at breast height (dbh), total height, volume and weight is shown in Table 6. Tables 7 and 8 summarize the data of total and commercial volumes and weight per unit area of the different aged mangrove plantations. Graph of oven dry weight as related to age of mangrove plantations is given in Figure 29. The results of several allometric pair combinations are summarized in Tables 9 and 10. Analysis of soil properties with regard to some aspects of fertility are presented in Table 11.

D.B.H.

The relationship between diameter at breast height (dbh) and age in Table 6 indicated that the diameter increment of the

Table 6. Average growth parameters per tree for 3 to 14-year old mangrove plantations (*Rhizophora candelaria*), at Amphoe Khlung, Changwat Chantaburi.

Ages	DBH	Height	Volume (cm^3)		Green weight (kg)					Oven dry weight (kg)				
(Year)	(cm)	(m)	Total	Commercial	Stem	Branches	Leaves	Prop root	Total	Stem	Branches	Leaves	Prop root	Total
3	0.44	1.87	218.6	-	0.98	0.83	1.56	1.38	4.75	0.47	0.37	0.62	0.62	2.08
6	3.21	4.30	2985.1	-	3.60	2.42	2.77	2.39	11.18	1.73	1.09	1.10	1.08	5.00
9	4.94	6.64	8383.3	7236.4	9.24	3.97	4.10	3.94	21.25	4.11	1.79	1.63	1.78	9.31
11	5.28	8.20	10685.7	9430.5	12.32	4.41	4.61	4.13	25.47	5.94	1.98	1.84	1.87	11.63
12	5.88	9.15	15458.8	13802.0	17.99	4.99	4.98	4.56	32.52	8.63	2.25	1.98	2.07	14.93
13	6.37	10.31	17492.5	16583.6	21.65	5.13	5.05	4.50	36.33	10.38	2.31	2.02	2.03	16.74
14	6.97	12.32	23363.2	22046.7	28.01	3.36	3.53	5.06	39.96	13.59	1.51	1.40	2.29	18.79

Table 7 . Total and commercial volumes for 3-to-14-year old mangrove plantations (*Rhizophora candelaria*), at Amphoe Khlung, Changwat Chantaburi.

Age	total volume m^3/ha	commercial volume m^3/ha
3	2.1	-
6	29.8	-
9	83.8	72.3
11	106.8	94.3
12	154.5	138.0
13	174.9	165.8
14	233.6	220.4

Table 8. Green and oven dry weight for 3 to 14-year old mangrove plantations (*Rhizophora candelaria*), at Amphoe Khlung, Changwat Chantaburi.

Ages	Green weight, metric tons/ha					Oven dry weight, metric tons/ha				
	Stem	Branches	Leaves	Prop root	Total	Stem	Branches	Leaves	Prop root	Total
3	9.8	8.3	15.6	13.8	47.5	4.7	3.7	6.2	6.2	20.8
6	36.0	24.2	27.7	23.9	111.8	17.3	10.9	11.0	10.8	50.0
9	92.4	39.7	41.0	39.4	212.5	41.1	17.9	16.3	17.8	93.1
11	123.2	44.1	46.1	41.3	254.7	59.4	19.8	18.4	18.7	116.3
12	179.9	49.9	49.8	45.6	325.2	86.3	22.5	19.8	20.7	149.3
13	216.5	51.3	50.5	45.0	363.30	103.8	23.1	20.2	20.3	167.4
14	280.1	33.6	35.3	50.6	399.6	135.9	15.1	14.0	22.9	187.9

Table 9. Allometric relations between DBH, weights, and volume for a *Rhizophora candelaria* plantation.

	W_T	W_S	W_B	W_L	W_R	V_S
h	0.7652	1.1411	0.9349	0.3999	0.4647	0.7795
log A	0.5252	-0.0231	-0.2113	-0.0763	-0.0742	-2.5052
r	0.9423	0.9367	0.9575	0.9196	0.9586	0.8401
r^2	0.8880	0.8775	0.9168	0.8457	0.9190	0.7058

W_T = Total dry-weight

W_S = Stem dry-weight

W_B = Branch dry-weight

W_L = Leaf dry-weight

W_R = Prop root dry-weight

V_S = Stem-volume

Table 10. Allometric relations between D^2H, weights, and volume for a *Rhizophora candelaria* plantation.

	W_T	W_S	W_B	W_L	W_R	V_S
h	0.2959	0.4421	0.2393	0.1514	0.1786	0.6276
log A	0.3826	-0.2374	-0.3175	-0.1445	-0.1586	-3.4305
r	0.9637	0.9597	0.9543	0.9207	0.9740	0.9955
r^2	0.9287	0.9210	0.9106	0.8476	0.9486	0.9910

W_T = Total dry-weight

W_S = Stem dry-weight

W_B = Branch dry-weight

W_L = Leaf dry-weight

W_R = Prop root dry-weight

V_S = Stem-volume

Table 11. Surface soil properties of the 3-to-14-year old mangrove plantations at Amphoe Khlung, Changwat Chantaburi.

Age (year)	Sand %	Silt %	Clay %	Texture	pH	Organic matter %	N %	P ppm	K ppm	C.E.C. meq/100 gm soil	Chlorinity %
3	14.3	72.8	12.9	Silt loam	5.9	20.4	1.02	7.6	924	8.25	1.45
6	33.2	51.9	14.9	Silt loam	6.0	15.5	0.78	4.4	770	5.88	1.95
9	20.3	64.6	15.1	Silt loam	5.6	28.3	1.42	5.8	1122	8.19	2.28
11	14.8	61.8	23.4	Silt loam	5.9	26.1	1.31	3.8	1166	7.29	1.99
12	29.1	63.2	7.7	Silt loam	5.8	19.8	0.99	3.3	693	6.23	1.34
13	32.6	53.9	13.5	Silt loam	5.2	28.4	0.43	4.2	1056	9.43	2.41
14	43.2	46.8	10.0	loam	5.2	22.7	1.14	3.5	979	9.15	2.42

3-year-old plantation was 0.15 cm/yr. The average diameter increments of the 6, 9, 11, 12, 13 and 14-year-old plantations were 0.92, 0.58, 0.17, 0.60, 0.49 and 0.60 cm/yr. The greatest net annual diameter increment occurred in the 3 to 6-year-old plantations. Annual increments were lowest in the 3 and 11-year-old plantations.

Height

The total heights of 3, 6, 9, 11, 12, 13 and 14-year-old plantations were 1.87, 4.30, 6.64, 8.20, 9.15, 10.31 and 12.32 m respectively (Table 6). The annual height increment of the 13 to 14-year-old plantations was the highest (2.01 m). The 0 to 3-year-old plantation had the lowest annual increment (0.62 m).

Volume

Both total and commercial volumes of the different aged plantations tended to increase with age but the annual increment of each age class was different (Tables 6 and 7). From the data in Table 7, total volume increments for the 3, 6, 9, 11, 12, 13 and 14-year-old plantations were 0.7, 9.2, 17.9, 11.5, 47.7, 20.3, and 58.7 m^3/ha/yr respectively. The annual volume increment decreased when the plantations were approximately 11 and 13-years-old.

Weight

Increases in total biomass occurred with an increase in plantation age (Tables 6 and 8). The total oven-dry weight increment of the 3, 6, 9, 11, 12, 13 and 14-year-old plantations was 6.93, 9.73, 14.37, 11.60, 33.06, 18.10 and 20.5 metric tons/ha/yr respectively.

The green and oven-dry weights of the different tree components (stem, branches, leaves and prop root) illustrated in Table 6 and Figure 29 indicate that stem weight increased with age. Canopy weight, derived from the summation of branch and leaf weights, showed increases with plantation ages up to 12 years old. Canopy weight was almost constant at age 12 and 13 years but decreased at age 14 years. Prop root weights tended to increase with age until about 9 years old and thereafter remained nearly constant. The average 3-year-old plantation has a total oven-dry biomass of 20.8 metric tons/ha. Approximately 23% of this is in stem wood, 18% in branch, 29% in leaf and 30% in prop root. The average 14-year-old plantation has a total oven-dry biomass of 187.9 metric tons/ha. Approximately 72%, 8%, 8% and 12% of this are in stem wood, branch, leaf and prop root respectively. The average 6 to 13-year-old plantations have the total oven-dry biomass between 50 to 167 metric tons/ha with approximately 35 to 62% to be in stem wood, 14 to 22% in branch, 12 to 22% in leaf and 12 to 21% in prop root.

The biomass estimates of this study, on known-aged plantations, can be compared to those reported for natural stands elsewhere but of unknown-aged. For example, a mangrove forest in Florida had a total dry weight of approximately 126 metric tons/ha (Snedaker and Pool, 1973). This is nearly comparable to the 116 metric tons/ha found in the 11-year-old

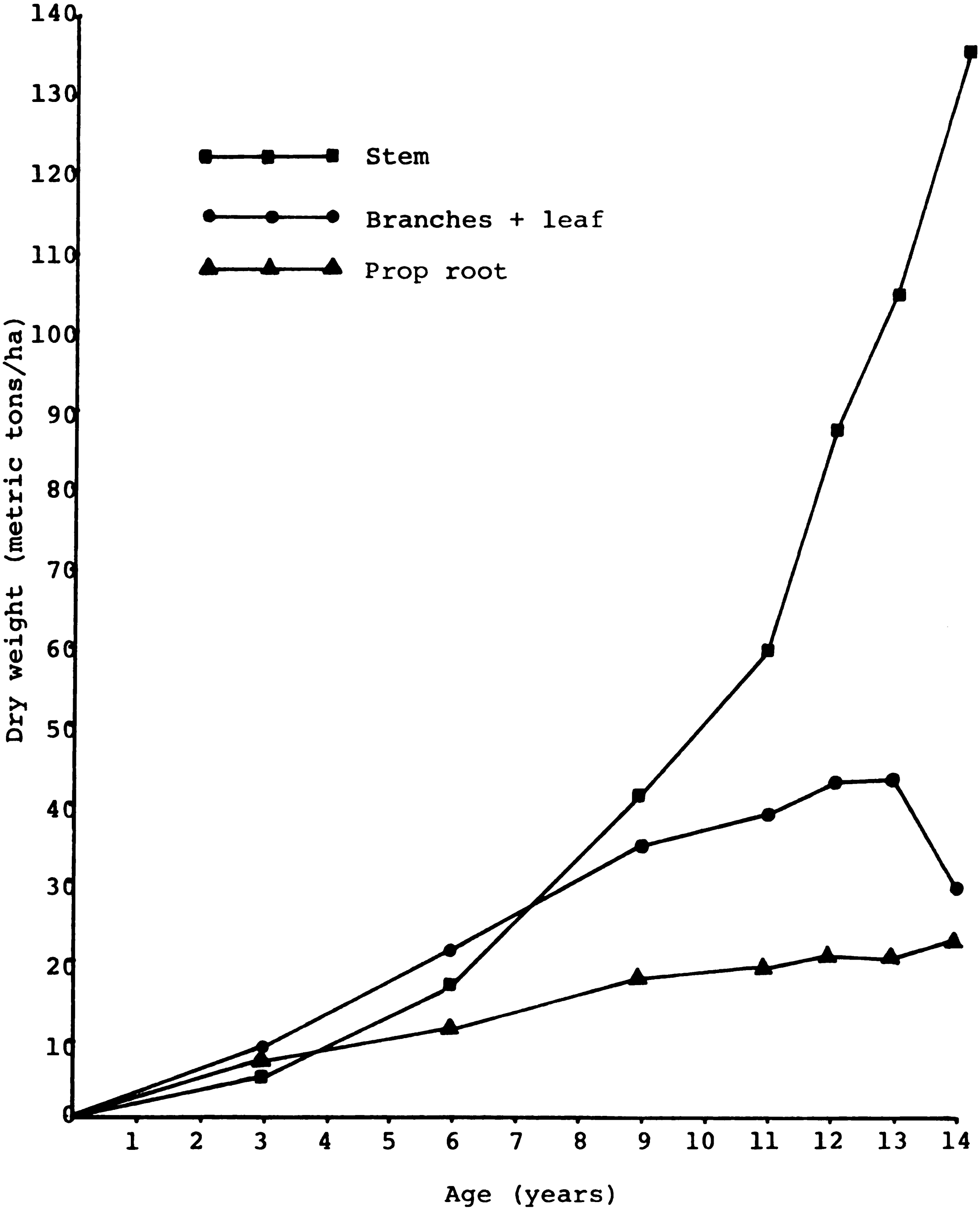

Figure 29. Dry weight by plant component with age of mangrove plantation.

plantation in this study. Golley *et al.* (1962) found the total dry-weight of the mangrove forest in Puerto Rico to be 63 metric tons/ha. The total dry-weight of the 6-year-old study plantation was 50 metric tons/ha. Although the ages of the natural stands in Florida and Puerto Rico are unknown, it is of interest to see that their biomass equivalents can be reached in 6 to 11 years in Thailand.

Analysis of Allometric Relations

The results of several allometric pair combinations for *Rhizophora candelaria* are presented in Tables 9 and 10. These relationships are:

1. Total dry weight (W_T) against DBH.
2. Stem dry weight (W_S) against DBH.
3. Branch dry weight (W_B) against DBH.
4. Leaf dry weight (W_L) against DBH.
5. Prop root dry weight (W_R) against DBH.
6. Stem volume (V_S) against DBH.
7. Total dry weight (W_T) against D^2H.
8. Stem dry weight (W_S) against D^2H.
9. Branch dry weight (W_B) against D^2H.
10. Leaf dry weight (W_L) against D^2H.
11. Prop root dry weight (W_R) against D^2H.
12. Stem volume (V_S) against D^2H.

In each allometric relationship, h indicates the slope of the regression line and log A indicates the value of y when x = 1. The coefficient of determination, r^2, showing the regression equation for the relationships between different growth parameters against D^2H, were usually higher than those relationships existing between growth response and just DBH. The results presented in Tables 9 and 10 can be utilized for determining total weight, branch, stem, and leaf weights and stem volume when the DBH and/or D^2H are known.

The applicability of these regression equations must be used with caution, especially if attempting to extrapolate their uses to other mangrove species sampled at other times and located in other areas. They proved to be inaccurate, for example, when used to compare the values found by Golley *et al.* (1962) who estimated total biomass for various sized *Rhizophora mangle* in Puerto Rico. Total dry-weight of a tree 5.3 cm in dbh and 8.6 m in height was determined to be 16.3 kg while this study's regression equation estimated a value of 12.5 kg. This is an underestimate of 22.0%. Golley *et al.* (1962) estimated that a small tree, 2.7 cm dbh and 5.2 m tall, had a total biomass of 4.5 kg, while these equations generated a value of 7.0 kg. This is an overestimate of 36.0%.

Physical and Chemical Soil Properties

Soil samples from the surface 6 cm were randomly collected from three locations within each mangrove plantation and analyzed for several properties (Table 11). Chemical properties investigated included nitrogen, phosphorus and potassium levels, as well as soil pH, cation exchange capacity, and soil chlorinity. Physical properties consisted of soil texture and organic matter content.

The soil textures for all plantations was silt loam except for the loam soil of the 14-year-old plantation. Soils are moderately acid, with a pH range between 5.2 and 6.0. Organic matter levels varied between 15% (6-year-old stand) and 28% (13-year-old stand). The phosphorus content for all plantations is quite similar, ranging from 3.3 to 5.8 ppm, except in the 3-year-old plantation with a value of 7.6 ppm. The amounts of potassium range from a low of 693 ppm in the 12-year-old stand to a high of 1166 ppm in the 11-year-old plantation, but the differences are insignificant.

The cation exchange capacity between sites varied slightly, from 5.88 to 9.43 meq/100 gm soil. The soil chlorinities are higher in the 9, 13 and 14-year-old stands with the values of 2.28, 2.41 and 2.42%, but are lower in the 3, 6, 11 and 12-year-old plantations where the values are 1.45, 1.95, 1.99 and 1.34% respectively. The reason for this is that the extent of sea water inundation differs between each area.

SUMMARY AND RECOMMENDATIONS

Summary

Mangrove Community Structure

The mangrove community at Amphoe Khlung, Changwat Chantaburi, consists of more than 27 genera of trees and other plants, but only a few are dominant in the structure of the ecosystem. *Rhizophora candelaria* and *R. mucronata* are the dominant plants found both on the banks of the brackish estuaries and on the edges of the channels running through the forest. Soils of this site are usually waterlogged, and much wetter, muddier, and less acid than other areas more inland.

The area behind the *Rhizophora* zone is generally colonized by *Avicennia* and *Bruguiera*. These species may occur sparsely in the *Rhizophora* zone, with *Avicennia* more abundant in the area of *Rhizophora* than *Bruguiera*.

Xylocarpus obovatus, *X. moluccensis* and *Excoecaria agallocha* commonly occupy the areas adjacent to the *Avicennia* and *Bruguiera* zone, wherever the soils are drier, and less subject to frequent tidal inundation. In areas that are flat and soils are high in clay content *Ceriops* and *Lumnitzera* may occasionally colonize the site. Of these two species, *Ceriops* commonly occurs in thickets but the latter species is sparsely distributed.

Areas of high elevation that are infrequently inundated by salt water tidal flooding during extreme high tides are dominated by Melaleuca leucadendron. A palm, Nypa fruticans, is a plant characteristically found on the estuary edge where the area is flooded by all tides. Another palm, Phoenix paludosa, and the fern, Acrostichum aureum, are commonly established in the intermediate zone between the inundated mangrove and the non-flooded site. Acrostichum is widely distributed, occurring most commonly wherever mangrove forests have been severely disturbed by cutting. It also appears sparsely throughout the whole range of mangrove forest.

Species diversity varied from the edge of the estuary towards the mangrove forest. The sites along the banks of the estuaries where Rhizophora, Avicennia and Bruguiera are dominant have the highest density with the lowest species diversity. The intermediate zone between inundated mangrove and unflooded sites, where the area is occupied by Xylocarpus, Lumnitzera and Excoecaria, has the greatest species diversity with approximately sixteen tree species, but the number of individuals is low. On the landward side, where the area is flooded only by extreme high tide and occupied by Melaleuca leucadendron, eight associated species occurred with low density. The diversity value (H) found in this mangrove forest was 0.8790.

Stand volume varied from the edge of the estuary to the landward side, with the lowest stand volume (approximately 30 to 35 m^3/ha) occurring on the area where Rhizophora, *Avicennia* and *Bruguiera* are dominant. The intermediate area between the inundated mangrove and the unflooded forest occuped by *Xylocarpus*, *Ceriops*, *Lumnitzera* and *Excoecaria* produced the highest stand volume (about 120 m^3/ha). On the landward side, dominated by *Melaleuca leucadendron*, stem volume (approximately 50 to 84 m^3/ha) was between those two areas.

Mangrove Regeneration

The height-growth and mortality of four planted mangrove species, *Rhizophora candelaria*, *R. mucronata*, *Bruguiera conjugata* and *Avicennia alba*, was recorded monthly over a one-year period (October, 1974, to September, 1975).

1. Growth of all species began shortly after planting in October. The height-growth increment of *Rhizophora candelaria*, *R. mucronata* and *Bruguiera conjugata* all started rapidly in the first three to four months (October to January) with average values of 6.7, 5.9 and 7.0 cm/month respectively. The minimum growth rate was in July for *R. candelaria* (3.1 cm) and *R. mucronata* (3.2 cm) and in June for *B. conjugata* (2.5 cm). Following this period of reduced growth, the height-growth increment of *B. conjugata* once again increased in July while the increment of the two species of *Rhizophora* increased somewhat later, in August until September. *Avicennia alba* grew very slowly

after planting but gradually increased with a maximum rate of height-growth of 2.0 cm occurring in August and September.

2. After one year of growth, Rhizophora candelaria produced 10 to 26 leaves with 40 to 67 cm of top growth; R. mucronata produced 12 to 34 leaves with 44 to 66 cm of top growth and B. conjugata produced 10 to 28 leaves with 41 to 60 cm of top growth. Avicennia alba was the smallest of the species, producing 6 to 16 leaves with 14 to 25 cm height-growth.
3. Total height-growth in Rhizophora candelaria, R. mucronata and Avicennia alba was greatest in sites adjacent to the estuary edge and decreased further inland. Maximum height-growth for R. candelaria, R. mucronata and A. alba was about 67, 66 and 25 cm, while minimum growth was 40, 44 and 14 cm respectively.
4. The greatest height-growth in Bruguiera conjugata (60 cm) occurred approximately in areas midway between the estuary edge and the landward side. The minimum height-growth was in the area nearest the landward side (41 cm).
5. Species mortality in a 1-year-old plantation of Bruguiera conjugata and Avicennia alba was 9% and 8% respectively. All other species had little or no mortality.

Mangrove Plantation Productivity

Growth rate and primary production of seven different age groups of Rhizophora candelaria plantations (3, 6, 9, 11, 12, 13 and 14-year-old) were estimated. Thirty trees were randomly sampled from each plantation. Trees were felled, and dbh and tree heights recorded. Stem, branches, leaves and prop roots were separately weighed and biomass computed on an area and age class basis.

1. The highest annual diameter growth increment, 0.92 cm/yr, was found in 6-year-old plantation. The 3 and 11-year-old stands showed the lowest annual diameter increment, 0.15 and 0.17 cm/yr respectively. The annual diameter increments of the remaining age groups ranged from 0.49 to 0.60 cm/yr.
2. The annual height increment of the 13 to 14-year-old stand was the highest (2.0 m) while the 3-year-old plantation had the lowest annual height increment (0.6 m). The annual height increments of 6, 9, 11, 12 and 13-year-old stands were similar with value being approximately 0.9 m.
3. The total stem volume increment of the 3, 6, 9, 11, 12, 13 and 14-year-old plantations was 0.7, 9.2, 17.9, 11.5, 47.7, 20.3 and 58.7 m^3/ha/yr. The commercial volume was approximately 90% of the total volume.

4. The total oven-dry plant biomass presented for each plantation age was approximately 21.0, 50.0, 93.0, 116.0, 149.0, 167.0 and 188.0 metric tons/ha for 3, 6, 9, 11, 12, 13 and 14-year-old respectively. While the total weight increased with age, the weights of the crown canopy (branches and leaves) and roots were slightly different. Crown canopy weight was almost constant in 12 and 13-year-old plantations but decreased at age 14 years due to a high degree of natural prunning. Prop roots weight increased with age until approximately 9 years, thereafter root weight was nearly constant to 14 years of age. This may be due to space limitations imposed upon the prop root in the plantations. The total dry-weight increment for each plantation (3 to 14-year-old) was estimated to be 7, 10, 14, 12, 33, 18 and 21 metric tons/ha/yr respectively.
5. The relationship between total weight, stem, branch, leaf and root weights, and stem-volume with DBH and D^2H were established. There was a better correlation between D^2H (D is diameter at breast height and H is total tree height) and tree dry-weight and stem-volume than between DBH and tree dry-weight and stem-volume. Such relationships can be utilized for estimating total weight, branch, stem and leaf weights and stem-volume for only <u>Rhizophora</u> tree species in Thailand when the DBH and/or D^2H are known.

6. Surface soil samples to a depth of approximately 6 cm taken from different aged mangrove plantations were examined for various physical and chemical properties. Soil textures were primarily silt loam with the 14-year-old stand having a coarser textured loam soil. Soil pH values did not show any marked change among the different locations with values ranging from 5.2 to 6.0. The nitrogen content of soils is directly proportional to the amount of organic matter. The surface soil samples had a nitrogen content ranging from 0.8 to 1.4% with organic matter ranging from only 16 to 28%. The phosphorus content was found to vary between plantations with the lowest (3.3 ppm) in the 12-year-old plantation and the highest value (7.6 ppm) in the 3-year-old stand. Surface soil in the 11-year-old plantation had a higher potassium content than the other plantations, with values ranging from 693 to 1166 ppm. Cation exchange capacity did not vary greatly between plantations with values ranging from 6.0 to 9.0 meq/100 gm soil. Chlorinity also showed no great variation between sites with values being from 2.0 to 2.5%.

Recommendations

The wise management of the mangrove ecosystem depends upon a comprehensive ecological knowledge of this forest type. Thus far, mangrove management in Thailand has been based primarily upon economic returns, with little regards given to any importance of environmental considerations. The objective of the Thailand Royal Forest Department is to manage this resource on a sustained yield basis, with due emphasis being given towards effective environmental quality control.

The recommendations reported are based on preliminary investigations done in the mangrove forest at Amphoe Khlung, Changwat Chantaburi. Although they are only directly applicable to the development of this particular mangrove area, it is felt that they may also be utilized in the management of mangrove forests located elsewhere in Thailand. These recommendations are:

1. In order to increase the yields of naturally occurring *Rhizophora*, which is currently the major high-value mangrove species, the other less commercially desirable species such as *Avicennia*, *Xylocarpus*, and *Lumnitzera* should be removed. Such removal will encourage the natural regeneration and high growth rate of *Rhizophora*.
2. An intensive use study of *Avicennia*, *Xylocarpus* and *Lumnitzera* should be undertaken to learn of what use can be made of them. The promotion of

the greater use of these additional mangrove species would reduce the intensive demand now being made of *Rhizophora*.

3. For implementation of the "Clear Cutting in Alternative Strips" system now advocated for the mangrove forest of Thailand, both *Rhizophora candelaria* and *R. mucronata* should be the species selected for planting in the cleared strips. Not only are these two species important in the economy of Thailand, but they also have a high growth rate and a low mortality rate. *Bruguiera* is another species with high growth rate potentials, but it suffers higher mortality losses and is therefore a less desirable species to plant than *Rhizophora*. *Avicennia* cannot be recommended for the reforestation of cut-over mangrove forests because of its relatively slow growth and low survival qualities. It can be recommended, however, for planting of estuary shorelines subject to erosion since it has a rapid root development.
4. It has been the practice to plant mangrove species in areas away from the estuary edge which are often much drier than is optimum for good growth and survival. On such sites, channels or small water-ways should be constructed that would allow sea water to flood these areas. The results would be an increase in growth and a reduction in

mortality. An alternative would be to remove and burn the often occurring fern, *Acrostichum aureum*, and plant the areas with both *Rhizophora* species and *Bruguiera*, but for best results, such plantings should be made on areas where channel construction has taken place.

5. To intensify the management of the mangrove forest, an immediate and massive tree planting program must be undertaken to avoid a serious timber supply deficit. Plantations are strongly recommended since they produce a much higher stem-volume in a shorter period of time than occurs in natural forests. Estimates of what the investment costs of such a massive tree planting program would be made.

6. The desirability of such silvicultural treatments as thinnings in mangrove plantations must be evaluated. Preliminary study results indicate that a first thinning should be made about 8 to 9 years after planting. A second thinning might be required at age 12 years. To determine the most advantageous time for a thinning operation, additional experimental trials should be made in several locations. A 15-year rotation may be appropriate for a mangrove plantation based upon present day uses made of such wood. The intensity of such thinnings also needs to be determined,

based on just what the number of trees to be left should be. Other timber stand improvement methods such as spacing trials should also be made. In addition, comparison studies should be started between timber yields of natural stands and plantations. In all cases, economic constraints of such operations must be considered.

7. The most striking gap in the mangrove research program centers around the functioning of the ecosystem. Such functions as nutrient cycling, energy flow and biological regulations have been largely neglected. Moreover, the monitoring of micro-environmental changes in the mangrove forest is still lacking. A thorough research effort needs to be developed to collect such data.
8. Finally, an applied research program is needed to formulate a multiple-use policy for the mangrove forests of Thailand. The productivity of fisheries, wildlife conservation and soil reclamation potentials should all be given high research priority positions in the future.

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