# THESIS

## MANAGEMENT OF PRIVATE MANGROVE (*Rhizophora apiculata*) PLANTATION FOR CHARCOAL PRODUCTION AT YEESARN SUB-DISTRICT, SAMUT SONGKRAM PROVINCE

MD. KAMRUL HASSAN

GRADUATE SCHOOL, KASETSART UNIVERSITY
2006

# THESIS APPROVAL

## GRADUATE SCHOOL, KASETSART UNIVERSITY

Master of Science (Tropical Forestry)

**DEGREE**

| Tropical Forestry | Interdisciplinary Graduate Program |
|---|---|
| **FIELD** | **PROGRAM** |

**TITLE:** Management of Private Mangrove (*Rhizophora apiculata*) Plantation for Charcoal Production at Yeesarn Sub-District, Samut Songkram Province

**NAME:** Mr. Md. Kamrul Hassan

**THIS THESIS HAS BEEN ACCEPTED BY**

______________________ **THESIS ADVISOR**

( Assistant Professor Vipak Jintana, Ph.D. )

______________________ **COMMITTEE MEMBER**

( Associate Professor Suree Bhumibhamon, D.F. )

______________________ **COMMITTEE MEMBER**

( Assistant Professor Chongrak Wachrinrat, Ph.D. )

______________________ **GRADUATE COMMITTEE CHAIRMAN**

( Associate Professor Suree Bhumibhamon, D.F. )

**APPROVED BY THE GRADUATE SCHOOL ON** 03 May 2006

______________________ **DEAN**

( Associate Professor Vinai Artkongharn, M.A. )

# THESIS

## MANAGEMENT OF PRIVATE MANGROVE (*Rhizophora apiculata*) PLANTATION FOR CHARCOAL PRODUCTION AT YEESARN SUB-DISTRICT, SAMUT SONGKRAM PROVINCE

**MD. KAMRUL HASSAN**

**A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Science (Tropical Forestry)
Graduate School, Kasetsart University
2006**

**ISBN 974-16-1594-9**

Md. Kamrul Hassan 2006: Management of Private Mangrove (*Rhizophora apiculata*) Plantation for Charcoal Production at Yeesarn Sub-District, Samut Songkram Province. Master of Science (Tropical Forestry), Major Field: Tropical Forestry, Interdisciplinary Graduate Program. Thesis Advisor: Assistant Professor Vipak Jintana, Ph.D. 106 pages. ISBN 974-16-1594-9

This research aimed to investigate the management of a mangrove plantation for charcoal production in Thailand. Private *Rhizophora apiculata* plantation at Yeesarn Sub-district, Samut Songkram Province was selected to be the study area. Silvicultural practices including site preparation, planting, maintenance and harvesting of the plantation were studied through interviewing the plantation owner. Fifteen temporary sample plots of 10 × 10 m were established to represent 15 age classes of the plantations i.e. 1-15 years. Survival of the trees was recorded. Total height (H) and diameter at breast height (DBH) were measured. The allometric equations were used to estimate the total biomass and volume of the plantation. Charcoal production was inquired through interviewing of the charcoal kiln operator. Physical properties of wood and charcoal were determined by sampling method and analyzed with statistical test. Financial return from 8 to 15 years old plantation was examined. The cost/benefit analysis was carried out with the given prices between 56,250 and 93,750 baht/ha, and interest rates at 6%, 8%, 10%, 12%, 14% and 16%.

The results indicated that the survival rates decreased with increasing age of the plantation. One year after planting 94% of the seedlings survived whereas only 35% remained in the 15 years old plantation. The current annual increments in DBH and H were found to be the maximum at 12 years old plantation with the values of 0.46 cm/yr and 0.80 m/yr respectively. Total biomass and wood volume of the 14 years old plantation were estimated to be the highest at 202 ton/ha and 181 $m^3$/ha, respectively. Densities and specific gravities of the wood significantly differed (P=0.00 and P=0.01, respectively) according to age of the trees i.e. 8 to 15 years. There were 8 charcoal production centers with 40 charcoal kilns in the area and produced approximately 2,003 tons of charcoal per year. The average yield of charcoal was 37% which constituted 33% lump charcoal and 3.73% brands charcoal. There were no remarkable differences between the yield of lump charcoal (P=0.78) and brands charcoal (P=0.51) from different kilns. The average density, moisture content and specific gravity of charcoal were 0.70 gm/$cm^3$, 4.42% and 0.78, respectively. There were no significant differences in density, moisture content and specific gravity of charcoal from different kilns (P=0.44, P=0.76 and P=0.52 respectively). Under the moisture free condition, percentage of volatile matter, fixed carbon and ash content of charcoal from *R. apiculata* wood were 31.6, 66.2 and 2.2%, respectively. Heat value of the charcoal was 6,800 kcal/kg.

The financial analysis revealed that at the minimum revenue level the *R. apiculata* plantation provided the NPV, B/C and IRR at 708.03 baht/ha, 1.04 and 8.36%, respectively. In maximum revenue level on the other hand, it provided the NPV, B/C and IRR at 711.47 baht/ha, 1.04 and 12.38%, respectively.

KHassan | V. Jintana | 28 / 04 / 06

Student's signature | Thesis Advisor's signature

## ACKNOWLEDGEMENT

I wish to express my indebtedness and deep sense of gratitude to my advisory committee chairman Dr. Vipak Jintana, Department of Forest Management, Faculty of Forestry, Kasetsart University, Bangkok for constant guidance, inspiration and encouragement, suggesting the problem, kind assistance, untiring supervision and critical reading of the manuscript. Without his assistance it would not have been possible for me to shape this work in the present form. I would like to express my sincere veneration to my advisory committee members Dr. Suree Bhumibhamon, Course Leader, Tropical Forestry (International Program), and Dr. Chongrak Wachrinrat, Associate Dean, Faculty of Forestry, for their valuable advice, guidance, comments and warm encouragement throughout this study.

My profound gratitude is extended to Dr. Roongreang Poolsiri, Head of Forest Soil Laboratory, for providing the facilities for soil analysis. I am extremely grateful to Mr. Songkold Jarusombuti, Head of Forest Products Department, for his valuable advice and allowing me to frequently use the laboratory. I am sincerely thankful to Dr. Damrong Pipatwattanakul, Department of Silviculture, Faculty of Forestry, Dr. Sonjai Havanond, Department of marine and Coastal Resources, Ministry of Natural Resources and Environment, and Dr. Wirachai Soontornrangson, Environmental Ecological and Energy Department, Thailand Institute of Scientific and Technological Research for sharing their experiences, deep appreciations and valuable advice. A note of thanks to Mr. Adrian Hillman, The Graduate School, Kasetsart University for editing some part of this manuscript.

Special thanks to Mr. Sai Saksareechai, village headman in Yeesarn of Samut Songkram province who spent his valuable time, providing accommodation, nice cooperation and giving valuable information during several times of my field visit. My heartfelt thanks go to the students of the Forest Faculty who helped me during the data collection in the field.

I would like to express my profound appreciation to Mr. Osman Gani, Chief Conservator of Forests and Mr. Iklil Mondol, Project Director, Forestry Sector Project, Bangladesh Forest Department for providing financial support for conducting this research and giving the opportunity to grow professionally.

Finally, I am very much obliged to my parents, brother, sisters and my wife Mita for their encouragement and moral support which served as inspiration while I was away from home and made me fulfill my dreams toward the attainment of this academic challenge.

Md. Kamrul Hassan
28 April, 2006

# TABLE OF CONTENTS

# TABLE OF CONTENT (cont'd)

## TABLE OF CONTENT (cont'd)

# LIST OF TABLES

# LIST OF TABLES (cont'd)

**Appendix Table** **Page**

# LIST OF FIGURES

# LIST OF FIGURES (cont'd)

# MANAGEMENT OF PRIVATE MANGROVE (*Rhizophora apiculata*) PLANTATION FOR CHARCOAL PRODUCTION AT YEESARN SUB-DISTRICT, SAMUT SONGKRAM PROVINCE

## INTRODUCTION

### 1. Background and Justification

Mangroves are trees and shrubs that grow in tropical and subtropical tidelands throughout the world. They are able to grow in salt water inundation because of specialized rooting structures (such as prop roots and pneumatophores), specialized reproduction (vivipary) and the ability to exclude or excrete salt. Mangrove forests are floristically less diversified. It may be attributable to their unique environmental conditions. According to Tomlinson (1986) there are 66 genus 114 species of mangrove plant species over the world, of which 9 genus 34 species are classified as the major components, 11 genus 20 species as the minor, and 46 genus 60 species as the mangrove associates. The major components are recognized because of their similar physiological characteristics and structural adaptations to habitat preferences. They play major role in the forest structure, forming an ecological zonation. The trees of genus *Rhizophora* are the most abundant components of mangrove forests (Chapman, 1976; Watson, 1928). They often form a pure stand. Under the genera *Rhizophora* the most morphologically distinctive species is *Rhizophora apiculata* in terms of flower number per inflorescence, inflorescence position, bracteole structure, petal indumentums and stamen number (Tomlinson, 1986).

The general geographic distribution of mangroves in different tropical regions is divided into three regions: Topical America, Tropical Africa and Tropical Asia. Based on the most recent estimation the areas covered by mangrove forests gave a total of 18.1 million worldwide which South and Southeast Asia having 41.5%, the Americas 27.1%, West Africa 15.5%, East Africa and the Middle East 5.5%, and Australasia 10.4% (Spalding *et al.,* 1997). Mangrove forests form an important part of the coastal ecosystem in tropical regions around the world. The mangroves in Southeast Asian region cover an estimated area of about 3.95 million ha. The region has the highest diversity of mangrove species in the world. In many countries of this region, mangrove forests provide employment opportunities and serve as a primary natural resource for livelihood of a considerable portion of coastal population. Mangrove forests have been traditionally utilized by local people for a variety of purposes such as charcoal, timber, firewood, wood chips, medicine, tannin, thatching materials, honey, fishes, prawns, shrimps, crabs and mollusks. In Many countries the mangrove forests are now of great national and international economic significance both in terms of direct resource utilization for forestry and fisheries, and also in terms of their potential for protecting coastlines and maintaining estuarine ecological balance. Wise management of mangrove resources is essential for sustainable use.

Mangrove charcoal production practices are found in many Southeast Asian countries such as Thailand, Peninsular Malaysia, Vietnam, and on the east coast of Sumatra of Indonesia. Although charcoal has traditionally been used for daily cooking by coastal villagers and rural household, in recent years it has been exploited as a commercial product particularly in Thailand, where now mangrove charcoal are exported to Malaysia, Hong Kong, Taiwan and Japan. High quality charcoal is characterized by high percentage of fixed carbon, low ash contain, low moisture content with high specific gravity. Mangrove charcoal is highly preferred mainly because of its special qualities that ordinary charcoal often does not possess, in particular the absence of fire bursting during use, strong burning over a long period and the handling convenience. High quality charcoal is produced from *R. apiculata* and *R. mucronata*. Other species like *Bruguiera* and *Ceriops* are also used for charcoal production (Chantarasena, 1985). In Thailand, mangrove for sustainable bio-energy in form of mangrove charcoal production through private venture can only found in Yeesarn Sub-district of Samut Songkram Province where *R. apiculata* plantation and charcoal making system has traditionally been practiced more than 60 years (Aksornkoae *et al*., 1992).

Private mangrove plantation in Yeesarn has arisen from the efforts and determinations of governors, provincial officers, local leaders and villagers are emphasized here as the model for sound management of mangrove forests in Thailand (Paphavasit *et al.,* 1997). In addition, *R. apiculata* plantation for charcoal production which is grown in large areas of mudflat in this region has long been recognized as the sources of income of the local people. It should be learned from this study that how the silvicultural management for *R. apiculata* are taking place, the trends of charcoal production and marketing systems, and to identify how people are getting benefits from *R. apiculata* mangrove plantations. So, Yeesarn of Samut Songkram Province has been chosen as a proper study area for collecting data on various aspects of management and utilization of private mangrove plantations.

## 2. Problem Statement

The mangrove areas of Thailand were approximately 367,900 ha in 1961 which covered 0.72% of the country area (Kongsangchai, 1996). Due to conversion of mangrove lands for aquaculture, mining, salt pan, urbanization, industry, agriculture, settlement and uncontrolled concessionaries, the mangrove areas have been depleted at an alarming rate with nearly one-forth of the mangrove lands have lost. Since 1961 these activities has led continuous reduced of the mangrove areas in Thailand. In the most recent year the mangrove areas of the country were estimated as 275,805 ha (RFD, 2004). In the wake of alarming decrease of mangrove forests, the government decided to ban all concessionaries from mangrove areas since 1999 and mangroves were kept under ‘National Forest Reserve Act’ 1964. Unfortunately, due to the rising population and rapid economic expansion in Thailand for the period of 1961 to 1991, mangroves have been primary target for development (Aksornkoae *et al.,* 1992). Moreover, the mangrove ecosystems are linked to the other ecosystems such that an understanding of the functions of mangroves in terms of nutrients, soil condition and vegetation would help implement the wise management of these resources into sustainable extent.

Samut Songkram is one of the Provinces of Thailand with pristine mangrove forests dating back before 1957. After the year 1958, the mangrove forests still remained intact. The local residents were dependent on these forests for fisheries and charcoal production. Mangrove (*R. apiculata*) plantation and *Nypa* palm plantation were common. This was the sign of mangrove reforestation efforts carried out in this Province in order to maintain their sustainable uses. The mangrove forests of this Province was 10,934 ha in 1961 and 8,240 ha in 1975. From the 1975 mangrove areas of Samut Songkram Province were started to degrade due to intensive shrimp farming (Paphavasit *et at.,* 1997). Since 1985 due to population growth along with high demands for mangrove utilization, these mangrove forests had been withdrawn from the forestry sector and declared under the agricultural development sector. The mangrove forests in these areas have been diminished due to forests clearance and land reclamation for other purposes especially for shrimp ponds, urban settlements, coconut and *Casuarina junghuhniana* plantations. These development pressures reduced the mangroves of the Province and reached only 1,276 ha in 2004 (RFD, 2004). Presently, the mangrove forests of Samut Songkram Province are mostly restricted to Yeesarn Sub-district which is under private sector. The owners of the plantation are responsible for management and utilization of the mangrove resources.

In recent years, due to the increasing demand of land for agriculture, aquaculture and industrial development, the rapid conversion of mangrove forest has resulted in environmental problems. Particularly in Yeesarn Sub-district, under Amphawa district of Samut Songkram Province where large scale conversion of private man-made mangrove plantation has taken place. The activities have expressed the concern about mangrove ecosystems and charcoal making systems. In addition the system provides an indigenous renewable energy source to those who can hardly afford any other energy sources. The residents of mangrove areas of Yeesarn have contributed to sustainable development of the system without much government support but their contribution have not been well recognized. Effective strategies to support the conservation of mangroves have yet to be developed. To date, a considerable number of people of Yeesarn Sub-district are involved in *R. apiculata* plantation and charcoal production and marketing for their livelihood and income generation. But unfortunately there is no updated information on *R. apiculata* plantation for charcoal making. Only few literatures are available but the information was not satisfactory for assessment. As a matter of fact we have no recent information on growth and productivity of *R. apiculata* plantation and charcoal out-put, charcoal quality and marketing systems.

## 3. Conceptual Frame Work

There are many environmental factors that affect mangrove structure and composition. These factors are topography, climate, temperature, tide, soil, nutrients and salinity (Chapman, 1975). The study was focused on soil properties of *R. apiculata* plantation, silvicultural management, growth and productivity, harvesting, wood quality, evaluation of charcoal output, charcoal quality, and marketing systems. The cost and benefit of *R. apiculata* plantation were analyzed to determine the economic feasibility of private mangrove plantation. The cost, revenues and profit of charcoal kiln operation was also analyzed. The conceptual framework of this study described the economic return from private mangrove plantation and economic out put from charcoal kiln operation (Figure 1).

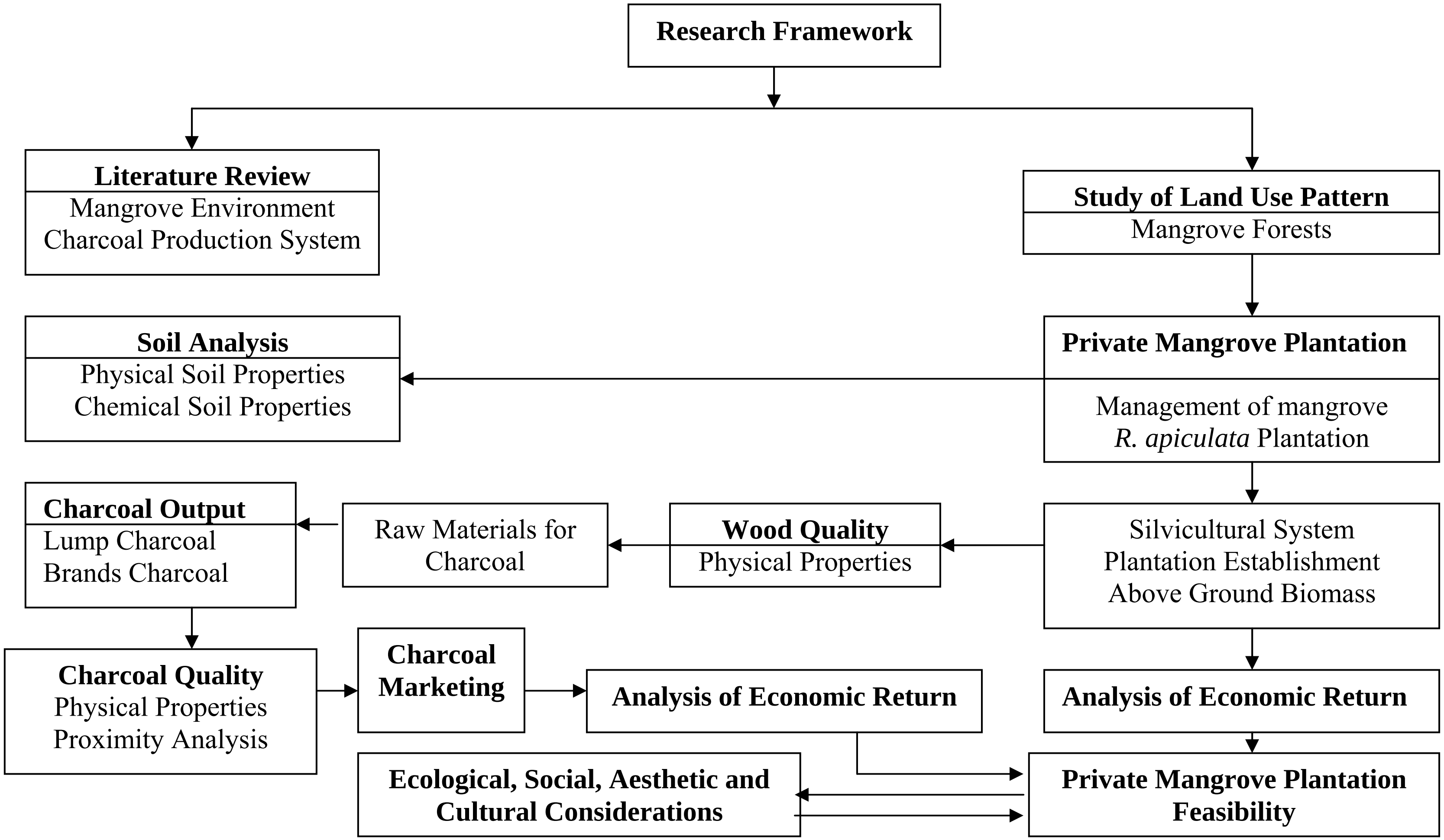


Figure 1 Conceptual framework of the study.

## 4. Research Objectives

The overall objective of the study was to find out the management of private mangrove plantations for charcoal production

The specific objectives of this study were as follows:

1. To study some soil properties of the *R. apiculata* plantation in Yeesarn.
2. To investigate information on plantation establishment and maintenance.
3. To determine growth performance and production of the plantation in terms of above ground biomass and wood volume.
4. To investigate charcoal output and charcoal quality from *R. apiculata* wood.
5. To analyze the financial benefit in terms of B/C, NPV and IRR from the plantation.

# LITERATURE REVIEWS

## 1. Terminology

There are very confused on the meanings of mangrove forest, peat swamp forest and freshwater swamp forest that had waterlogged or flooding, especially always misunderstood about these wetland areas to be wasted areas. Consequently, it was necessary to adjust with the meaning of the definition about mangrove forest, peat swamp forest and freshwater swamp forest.

### 1.1 Mangrove Forest

Mangrove forests are one of the primary natural features of coastlines throughout the tropical and sub-tropical regions of the world. The forests are generally flooded with brackish water during high tides. Because mangroves are sensitive to frost and freezing temperatures, the latitudinal limits are determined by temperature, with north-south extensions of the limits occurring only where warm coastal currents modify the climate. The term "mangrove forest" has been defined by several scientists. Du's (1962) defined the mangrove involves two different concepts. Firstly, the term 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 habitats. Secondly, it implies a complex of plant communities, fringing sheltered tropical shores. Such communities usually comprise of trees, normally species of the family Rhizophoraceae associated with other trees and shrubs growing in a zone of tidal influence - both on the sheltered coast itself and further inland, lining the banks of estuaries. The definition proposed by Saenger *et al.* (1983) described mangroves as characteristically littoral plant formations of tropical and sub-tropical sheltered coastlines while Hamilton and Snedaker (1984) described mangroves are as salt-tolerant forest ecosystems of the intertidal regions along the coastlines. Today many researchers also use the term "tidal forest" and "coastal woodland" as synonyms for mangrove forest.

### 1.2 Peat Swamp

Peat swamp forest is the plant community occurring in the shallow that has flooding all over the year. It has organic matter or vegetation accumulated for long time. Raining is the main source of water in the area. Oxygen deficiency that cause slowly decomposes and makes it to become peat bog is the result of waterlogged for a long time (Hankaew, 2000).

### 1.3 Freshwater Swamp

Freshwater swamp forest is the plant community occurring in a area that is regularly to occasionally inundated with mineral-rich, freshwater of fairly high pH (6 upwards), and water level fluctuates, thus allowing periodic drying of the soil surface. A few centimeters of peat or muck may occur which have deep peat and are more or less entirely depended on rain as the water source. A very shallow peat layer usually has little effect on the species composition of freshwater swamp forest (Hankaew, 2000).

### 1.4 Silviculture

Silviculture has been widely defined as the art of producing and tending a forest; the application of knowledge of silvics in the treatment of a forest; or the theory and practice of controlling forest establishment, composition, structure and growth. The immediate foundation of silviculture in the natural sciences is 'silvics' which deals with the growth and development of single trees and other forest biota as well as of whole forest ecosystems. Silvicultural management consists of the various treatments applied to forests to maintain and enhance their utility for any purpose. Silviculture is designed to create and maintain the kind of forest that will best fulfill the objectives of the owner and the governing society. The production of timber though the most common objective, is neither the only nor necessarily the dominant one (Smith *et al.,* 1997).

## 2. Distribution of mangroves

Mangroves are mainly restricted to the tropics, but some mangrove formations are also found in subtropical areas, particularly in Japan and New Zealand (Aksornkoae, 1993). Walsh (1974) divided the geographical distribution of mangrove vegetation into two main areas: the Indo-Pacific region includes East Africa, the Red Sea, India, Bangladesh, Southeast Asia, Southern Japan, the Philippines, Australia, New Zealand and the South Pacific Archipelago, as far east as Samoa. The West African-American Region includes the Atlantic Coasts of Africa and the Americas, the Pacific Coast of Tropical America and the Galapagos Islands. Most tropical countries were originally covered with mangrove vegetation. Walsh (1974) suggested five basic requirements for extensive mangrove development, namely; tropical temperature, fine-grained alluvium soil, shores free of strong wave and tidal action, salt water and large tidal range. These five important environmental factors can influence the occurrence and size of mangroves, the species composition, species zonation, other structural characteristics and the functions of the ecosystem itself. The most recent estimates of areas covered by mangrove forests gave a total of 18.1 million ha worldwide, with South and Southeast Asia having 41.5%, the Americas 27.1%, West Africa 15.5%, East Africa and the Middle East 5.5% and Australasian 10.4% (Spalding *et al.*, 1997).

## 3. Distribution of Mangroves in Thailand

In Thailand, mangroves occur on the sheltered muddy shores and low-lying bogs of the river and stream estuaries at levels between low and high tides, along the bank of the Gulf of Thailand and on the west and east costs of the peninsula. The best developed natural mangrove forests remain only along the west coast of the peninsula, especially in the Provinces of Ranong, Phang-Nga, Krabi, Trang and Satun. The mangroves along the coasts of the Gulf of Thailand are mainly classified as young growth because most of these mangrove forests have suffered heavy felling for many years, especially along the upper part of the Gulf of Thailand, in the Provinces of Petchaburi, Samut Prakarn, Samut Sakorn and Samut Songkram. During 1961 – 1986 the total mangrove areas of Thailand reduced from 367,900 ha to 196,428 ha. The reduction was more than 45% and more than half of it took place during 1979 – 1986 (Aksornkoae, 1993). Mangroves have been primary targets for development due to rising coastal population and rapid economic expansion in Thailand for the period of 1961-1991 which resulting to the loss of 50% of the mangroves areas (Aksornkoae, 1993). The Remote Sensing Division, National Research Council of Thailand estimated the total existing mangrove forests by visual interpretation of LANDSAT-MSS data recorded in 1986-1987, to be approximately 196,429 ha. Of the estimated total mangrove forest area, approximately 75% was found on the west coast of the peninsula. The Province of Phang-Nga comprised the biggest mangrove forest area of the country which covered 33,510 ha (IDRC/NRCT/RFD, 1991). In 1991, the government of Thailand in the wake of alarming decrease in mangrove forest areas by more than 50%, with a large part of the remaining forests being deteriorated and allocated a 750 million-baht budget for 40,000 ha of mangrove re-afforestation. The five-year mission started in 1992. Mangrove species selected for reforestation those of economic value, *Rhizophora* sp. was most popular and *Bruguiera* sp. and *Ceriops tagal* are runner-up. The most recent estimation of mangrove areas in Thailand are approximately 275,805 ha (RFD, 2004).

Aksornkoae, (1996) reported that the private mangrove plantations in Thailand were approximately 2,800 ha and these were mainly found in the upper part of the Gulf of Thailand, particularly in the Provinces of Samut Sakorn, Samut Prakarn and Samut Songkram. In southern Thailand, private mangrove plantations existed in Chumphorn and Pattani Provinces but the total area is very limited. Most of the plantations consist of *R. apiculata* for charcoal production (90%) and for posts and firewood (10%), except the private mangrove plantation in Chumphorn Province where *Bruguiera* sp. and *C. tagal* were planted for stakes for mussel culture.

## 4. Mangrove Forests Structure

In Southern Florida, mangrove forests had been classified by Lugo and Snedaker (1974) based on their physiognomy. There are six types of mangrove community resulting from different geological and hydrological processes. Each type has its own characteristics set of environmental variables such as soil type and depth, soil salinity and flushing rates. The mangrove communities are as follows:

### 4.1 Overwash Mangrove Forests

These occur on the small islands and fingerlike projections of large land masses in shallow bays and estuaries. Their positions and alignments obstruct tidal flow, and thus they are overwashed frequently by tides and much of the organic matter is washed away. The dominant species is *R. mangle*.

### 4.2 Fringe Mangrove Forests

These from thin fringes along protected shorelines and islands, being best developed along shorelines whose elevations are higher than mean high tide. The low velocities of the incoming and retreating tides and the dense, well-developed stilt root systems entrap all the small organic debris. Because of the relatively open exposure along shorelines, the fringe forest is occasionally affected by strong winds, causing breakage and resulting in the accumulation of relatively large amounts of debris among the stilt root. Again the dominant species is *R. mangle*.

### 4.3 Riverine Mangrove Forests

These include the tall (up to 20 m.) floodplain forests along flowing waters such as tidal rivers and creeks. Although a shallow beam often exists along such creeks, the entire forest is usually flushed by daily tides. This forest type is often fronted by a fringe forests occupying the slope on the creek side of the beam. During the wet season, water levels rise and salinity drops because of upland terrestrial drainage. Low flow velocities over the surface preclude scouring and redistribution of ground litter. The forest is often composed of *Rhizophora, Avicennia* and *Laguncularia*

### 4.4 Basin Mangrove Forests

These occur in inland areas along drainage depressions channel towards the coast. Close to the coast, they are influenced by daily tides. In Florida, this type of forest is dominated by *R. mangle*. Moving inland, the tidal influence lessens and the dominance is increasingly shared with *Avicennia germinans* and *Laguncularia racemosa.*

### 4.5 Hummock Forests

These are similar to the basin type except that they occur on ground that is slightly elevated relative to surrounding often by underlying peat deposits.

### 4.6 Scrub or Dwarf Forests

These are limited to the flat coastal fringe of southern Florida and the Keys. Individual plants rarely exceed 1.5 meters in height, except where they grow over depressions filled with mangrove peat. Nutrients appear to be limiting although highly calcareous substrates also may play a role.

## 5. Species Composition and Zonation

Chapman (1975) reported that the total number of mangrove species were to be around 90, of which 63 species are found in the Asia-Pacific Region while Saenger *et al.* (1981) reported 33 genus and 79 species of mangroves over the world. Most of these species grow in the Asia-Pacific Region. *B. gymnorrhiza, N. fruticans,* *R. apiculata* and *R. mucronata* are among the most common species in the Region. Santisuk (1983) reported that there were about 35 families including 53 genera and 74 species of trees and shrubs in the mangrove forest of Thailand. Most of the dominant and important species are in the family Rhizophoraceae, genera *Rhizophora, Ceriops*, and *Bruguiera*, the family Sonneratiaceae with *Sonneratia* and the family Avicenniaceae with many species of genera *Avicennia*. The distribution of mangrove species zonation varied from place to place depending on various factors, such as geographical conditions, tidal inundation and tidal amplitude, frequency of inundation, water salinity and soil conditions. The adaptations of individual species to environmental stress and of human activities are also important for either distribution of species or species zonation of the mangrove forests (Aksornkoae, 1993).

Zonation characteristics of species result from the differences of root system, seedling development and capable of intra-specific competition that difference between neap-tide and high-tide (Kuenzler, 1968). Watson (1928) classified the distribution factors of mangrove species into five classes; 1) frequency of inundation, 2) drainage, 3) soil age, 4) mangrove age and 5) the accumulation of sediment or soil erosion. Steenis and Van (1958) believed that soil characteristics and sediment accumulation or soil erosion including salinity were the most important factors, while De Hann (1931) reported that salinity and frequency of inundation were important factors. Chapman (1975) described that the important factors of species zonation were tidal inundation, soil type, soil water content and soil salinity. Watson (1928) classified the mangrove community of western Malaysia into five classes based on the number of inundation per month. The communities are:

Class 1 Areas inundated by all high tides: This class is usually devoid of plants other than *R. mucronata.*

Class 2 Areas inundated by all medium high tides: *A. alba, A. marina* and *S. alba,* are found in this area and *R. mucronata* exists along the river bank.

Class 3 Areas inundated by normal high tides: Mangrove flourishes in this area, especially *R. mucronata, R. apiculata, X. granatum, B. parviflora, S. alba* and *C. tagal*. However this area is dominated by *Rhizophora.*

Class 4 Areas inundated only by spring tides: This area is too dry for *Rhizophora* but is suitable for *B. cylindrica, B. parviflora, Lumnitzera* sp., *Xylocarpus* sp. and *Excoecaria* sp.

Class 5 Areas inundated by equinoctial or exceptionally high tides: Most of the plants in this area are *B. gymnorrhiza, Intsia bijuga, Heritiera littoralis, E. agallocha* and *N. fruticans.*

Aksornkoae (1975) described the mangroves in the southeast of Thailand that the community structure varies from edge of the estuary or river to island sites; *R. apiculata* and *R. mucronata* are dominant species to occupy on area along the edge of the forest. *N. fruticans* is also found in the area. *Avicennia* and *Bruguiera* are associated with *Rhizophora* but they formed a more distinct zone of *Rhizophora*. On area adjacent to the *Avicennia* and *Bruguiera* that have drier soil and subject to tidal inundation, *Xylocarpus* and *Excoecaria* become the dominant species. Some areas behind the *Avicennia* and *Bruguiera* zone particularly the areas with a low topographic relief and soil high in clay content *Ceriops* and *Lumnitzera* are usually formed. In transitional area of mangrove forest and island forest *Melaleuca* reaches its highest dominance. The study from the field survey of LANDSAT-MSS data and topographic maps (data recorded on 4 Jan, 1986) found that the mangrove forest areas of Samut Songkram had been exploited for shrimp farming for a long time. The existing land use was mainly shrimp farm which alternated with mangrove tree plantation *(Rhizophora* sp.*)* from the coastline to inland areas. The mangrove forest profile from the seashore to inland was the *Avicennia* sp. mainly found in the margin facing the sea and followed by *Rhizophora* sp. associated with under growth plants of *Indigofera* sp. (IDRC/NRCT/RFD, 1991).

## 6. Mangrove Forest Land Use Zoning

Mangrove forest land use zoning is one of the first steps to be taken towards controlled and sustainable use of mangrove resources. Aksornkoae (1996) stated that mangrove land use zones were scientifically classified based on the association of physical, biological environments and human activities together with LANDSAT image and field survey. The physical environment includes geomorphology, soils, tide and water quality, while the biological environment emphasis on flora and fauna densities and distributions. The human activities include the conversion of mangrove forests to other purposes such as shrimp farms, agriculture, salt pans, resettlement sites, mining area and industrial complex. Regarding to these scientific information, the area was classified into three main zones, these are:

*Preservation Zone* This zone includes rich mangrove forests, relatively unspoiled by human activity, which provide food resources and constitute breeding grounds for marine animals. They also serve to protect coastal areas from wind, storms and soil erosion.

*Economic Zone A (Mangrove Forest Management Zone)* This mangrove zone is allowable only for forest utilization purpose under government supervision on a sustain yield basis. This includes concession forest area and private forest plantations. Management of mangrove forests in this zone is divided into two main areas; manage mangrove forest and manage mangrove plantations.

*Economic Zone B (Development Zone)* This covers remaining mangrove areas that are badly degraded and must either be reforested or developed for some other uses with careful consideration of the impact on the environment.

## 7. The Mangrove Environment

Many environmental factors control the distribution of mangrove. Watson (1928) stated that the distribution of mangrove forests varies and depends on location and tidal regime, such as open sea, wide estuary, and small creek. Moreover Thom, (1967) stated that inundation frequency, salinity, certain characteristics of habitats;

such as water regime and substratum properties, interact with mangrove growth form and species distribution are some of the important factors considered for mangrove distribution.

### 7.1 Physical Environmental Settings for Mangrove Growth

Mangroves do not occur indiscriminately all along the shoreline. They grow only where environmental conditions are favorable. Thom (1982) proposed five general environmental settings, based upon the classification of delta types in which mangrove colonization often occurs. These are as follows:

*Setting I*: River-dominated (allochthonous) is the most extensive mangrove forests that develop in the deltas of large tropical rivers. In such cases, river discharge of freshwater and sediment leads to the rapid deposition of terrigenous sands, silts and clays to form deltas. These deltas are building seawards over flat offshore slopes composed of fine grained pro-delta sediments. The delta consists of multiple branching distributaries forming elongated, finger-like protrusions, resulting in a highly crenulated coastline with shallow bays and lagoons between and adjacent to the distributaries. These mangrove areas predominantly are of high fresh water discharge, so that salt tolerant plants are not common.

*Setting II*: Tide-dominated (allochthonous) occurs on coasts where high tidal ranges and associated strong bidirectional tidal currents predominate. These currents are responsible for the dispersion of sediments brought to the coast by rivers, and in the offshore zone it from elongate sand bodies. Wave power is often low because of frictional damping over broad intertidal shoals. The main river channels are typically funnel-shaped, fed by numerous tidal creeks and are often separated by extensive tidal flats.

*Setting III*: Wave-dominated barrier lagoon (autochthonous) is characterized by much higher wave energy than previous ones, and by relatively low amounts river discharge. Offshore barrier islands, barrier spits or bay barrier are typical of this setting. Small finger-like deltas provide into these water bodies without significant opposition from marine forces. Considerable tidal modification may occur within the barrier system, where the barriers project from the coast or link island to the mainland, sheltered water in their lee provides sites for extensive mangroves if a sediment supply is available. Salt-tolerant plants occur around the margins of the lagoon in a variety of habitats.

*Setting IV*: Composite river and wave dominated represents a combination of high wave energy and high river discharge. Sand carried to the sea by the river is rapidly redistributed by waves along shore to form extensive sand sheets. Much of the sand deposited on the inner continental shelf during lower sea levels is reworked landward during periods of rising or stable sea levels. The result is a coastal plain dominated by sand beach ridges and narrow discontinuous lagoons with an alluvial plain to landward. Salt tolerant plants such as mangroves are concentrated along abandoned distributaries and in areas near river mouths and adjacent lagoons. Where the tidal range is large and the climate dry, there is a spread of saline habitats to interdistributary areas which are periodically inundated by high spring tides.

*Setting V***:** Drowned bedrock valley can be described as a drowned river valley complex. The depth of deposition is confined by a bedrock valley system which has been drowned by a rising sea level. Neither marine nor river deposition has been sufficient to infill an open estuarine system. However, the heads of the valley may contain relatively small river deltas which are little modified by waves, and often maintained by self scouring. At the mouth of the drowned valley bordering the open sea, a tidal delta may occur, composed of marine mud and sand reworked landward during rising sea level.

### 7.2 Climate

Light, temperature, rainfall and wind all have a strong influence on the mangrove ecosystem. Apart from playing a significant role in the development of plants and animals, they also cause changes in other physical factors such as soil and water (Aksornkoae, 1993).

#### 7.2.1 Light

In general, mangrove plants are long-day plants and require high intensity of full sunlight. This makes tropical coastal zones an ideal habitat. The range of light intensity which is optimal for the growth of mangrove species is 3,000-3,800 kcal/m$^2$/da (Aksornkoae, 1993). Clarke and Hannon (1971) observed that long hours of shade harm seedlings while inadequate light exposure impedes plant growth and increases the death rate. Aksornkoae (1993) described that planting some mangrove species in heavy shade and planting some mangrove species in unsheltered areas, revealed that *R. mucronata, R. apiculata* and *Bruguiera* sp. grown in shaded areas showed slower growth rates and a higher death rate. Under shelter, the annual height growth rate for *R. mucronata* was 28 cm. *R. apiculata* was 38 cm. and *Bruguiera* sp. was 39 cm. compared with corresponding figures of 66 cm, 67 cm. and 60 cm. , respectively under full sunlight. In contrast, death rates of these 3 species were very high under shelter: 18%, 81% and 80%, compared with only 4%, 5% and 9%, respectively, for those in the open area. Light also affects the flowering and germination of mangrove species. Those growing in outer fringes of the plantations were found to produce more flowers and seedling than those growing inside.

#### 7.2.2 Temperature

Temperature is of importance to physical processes such as photosynthesis and respiration. However, there is little evidence of the relationship between temperature variation and the growth of plants in mangroves. Glendhill (1963) stated that extensive mangrove development occurs only when the average air temperature of coldest month is higher than 20 °C and where the seasonal range does not exceed 10 °C. Hutchings and Saenger (1987) carried out a study in Australia and found that *Avicennia marina* sprouted fresh leaves at temperatures of 18 to 20 °C and at higher temperatures new leaf production became lower. For *R. stylosa*, *Ceriops* sp., *Excoecaria agallocha* and *Lumnitzera* sp., the highest rate of fresh leaf production occurred at 26 to 28 °C, while most *Xylocarpus* sp. preferred 21 to 26 °C with the exception of *X. granatum* (2 °C). In general, the appropriate temperature for fresh leaf production of mangroves is the average temperature of the tropical zone, which is the best habitat for mangroves (Aksornkoae, 1993).

#### 7.2.3 Rainfall

The annual rainfall appears to be significant in mangrove distribution. The area that receives high annual rainfall tends to be high in mangrove productivity. Macnae (1968) pointed out that in Queensland the most luxuriant forest occurs where rainfall was highest. Rainfall is one of the sources of nutrients and water supply during the neap tide and also dilutes the water salinity to the level suitable for plant growth. Oliver (1982) suggested that the most favorable condition for a well-distributed mangrove was a plentiful of rainfall. Moreover, Aksornkoae (1993) suggested that mangroves can grow well in areas which receive an annual rainfall between 1,500 and 3,000 mm.

#### 7.2.4 Wind

Wind has a number of effects on the mangrove ecosystem (Aksornkoae, 1993). Winds, waves and currents in coastal areas influence the coastal erosion and changes in mangrove structure. Plants often depend on winds as agent of pollination and seed dissemination. Wind can also increase evapotranspiration of plants. Strong winds are capable of impending plant growth and causing abnormal physiological characteristics.

### 7.3 Tide

Tide is not a direct physiological requirement for mangroves but play an important indirect role in the transport of nutrients, export accumulation of organic carbon and reduction of sulphur compounds. On the other hand, tides can help prevent soil salinity from reaching a high concentration and aid in dispersal of mangrove propagules (Odum *et al.*, 1982). In coastal areas, tides determine the zonation of plant and animal communities found within the mangroves. Tidal duration greatly influence the salinity changes in mangroves areas. Salinity of water is high during high tide and decreases during low tides. Moreover, water salinity varies during spring and neap tides. During spring tide, highly saline water intrudes further into the mangrove areas than during neap tides. Changes in water salinity due to tides are one of the factors limit species distribution in mangroves, especially horizontal distribution. Tides also contribute to the exchange of mass between fresh water and salt water and thereby affect the vertical distribution of mangrove organisms.

Aksornkoae (1993) reported that tidal duration has effects on species distribution, vegetative structure and function of mangrove ecosystem. Mangrove forests influenced by diurnal tides differ in structure and fertility from mangroves affected by semi-diurnal tides and those affected by mixed tides. Watson (1928) studied the existence and distribution of plants in mangroves of Malaysia and found that species composition and distribution in inundated areas differed according to duration of tides and frequency of inundation. In areas where inundation occurs all the time, only *R. mucronata* exists. *Bruguiera* sp. and some *Xylocarpus* sp. dominated the occasionally inundated areas. Aksornkoae (1993) also stated that the tidal range between high and low tides is a factor affected the root systems of mangrove species particularly prop roots of *Rhizophora* sp. extend far above the soil surface while those with a narrow tidal range have significantly lower roots.

### 7.4 Soil

Mangrove soils are formed by the accumulation of sediment derived from coastal of river bank erosion, or eroded soils from higher areas transported down along rivers and canals. Some may be originated from the sedimentation of colloidal materials and particulates. Sediments that have accumulated along the coast and in mangroves have different characteristics, depending on their origin. Sediments from rivers and canals are fine muddy soil, while coastal sediment is mainly sand. Aksornkoae *et al.* (1978) stated that both physical and chemical characteristics of soils differed in different vegetative zones. Steenis (1958) reported that *R. mucronata* could grow well in muddy and relatively deep soils. Glendhill (1963) stated that soil characteristics limit the growth and distribution of plants in mangroves. He also found that *A.* marina and *Bruguiera* sp. could grow well in muddy sandy soils. Aksornkoae (1993) described that in the community of *Rhizophora* sp. and *Aegialites* sp. soil pH was 6.6 and 6.2 , respectively and the pH range for *Rhizophora* soils under dry and nearly dry conditions varied 4.60 to 4.90. Giglioli and King (1966) studied soil moisture under several plant communities in mangroves. They found that soil surface moisture in *Rhizophora* forest ranged from 67-245% by weight.

Mangrove swamps in Natal and Pondoland (South Africa) have the typical zonation due to the presence of sand which appears to restrict the growth of certain species, notably *Bruguiera, Rhizophora* and *Ceriops*. Where fresh water influence is strong, *Bruguiera* predominates and grow up to 20 m. Moreover, if the soil is well drained, *Lumnitzera* sp. may reach low intertidal levels (Macnae, 1968). The degradation of organic matter deposited through time is also a part of mangrove soils (Aksornkoae, 1993). The mangrove swamps of Keneba, Lower Gambia showed that the soils under *Rhizophora* contained relatively low concentration of chloride from 16 to 19 mg Cl/g, whereas under *Avicennia* from 42 to 58 mg Cl/g. These values were attributed to the constant leaching by tidal waters of the relatively low chloride content and concentration (Giglioli and King, 1966).

In Southern Thailand, mangrove soils were classified into three groups according to its development: unripe, ripe and organic soils (Khemnark *et al.,* 1987). The unripe soils are new soils and not yet fully developed. Only the A and C profiles can be observed with the top soils darker in color than subsoils. These soils are highly acidic with very low pH, varying between 2.5 to 6.0; high salt concentration, variation of organic matters through soil depth in the range of 2 to 20%; considerable amounts of potassium and phosphorus. The ripening soils are more developed and mostly found in the upper and occasionally flooded areas. These soils are defined as 'Inceptisol' and 'Entisol'. The top soils are dark clay, 10 to 30 cm. deep with relatively high organic matter content; lower soils, with a depth of 40 to 90 cm, lighter in color, high acidity, high salt content and low phosphorus content. Organic soils on the other hand, contain a high percentage of high organic matter and have a deep profile. The organic soil layer comprised of incompletely degraded organic materials. Top soils are dark gray to grayish-brown, low pH, high concentration of salts and potassium but low phosphorus content.

### 7.5 Nutrients

Boto (1982) reported that inorganic nutrients (nitrate, ammonia, phosphate, calcium, magnesium, sodium and other metals) can enter the mangrove ecosystem via rainfall, fresh water runoff from surrounding terrestrial forest, nitrogen fixation, mineralization, tidal-borne dissolved or particulate-bound nutrients, chemical release from fixed states in soils by changes in soil Eh and pH, man-made influences, e.g. agricultural land, drainage, sewage, clearing of mangrove areas. Hutchings and Saenger (1982) stressed that the availability of nutrients depend largely on the type of soil and its microbial characteristics. Nitrogen becomes available through microbial fixation of atmospheric nitrogen and through the biological decomposition of organic matter in the soils. Nitrogen bound up in proteins is converted to ammonia by numerous proteolytic bacteria and fungi (ammonification process). Ammonia can serve directly as a source of nitrogen and provides energy for nitrate bacteria which, in the presence of oxygen, oxidize the ammonia to nitrate; nitrate is further oxidized to nitrate by another group of nitrifying bacteria.

Concentration of dissolved inorganic and organic phosphorus in mangrove water is too low. Dissolved inorganic phosphorus exists mainly as a nutrient salt ($H_2PO_4$) at pH of sea water. While the inorganic phosphorus in mangrove sediments is either bound in the form of calcium, iron and aluminum phosphate or as soluble reactive phosphorus absorbed onto hydrated Fe and Al in the form of oxides (Alongi *et al.,* 1992). Aksornkoae (1993) reported that organic detritus are organic nutrients derived from biogenic materials through several stages in the microbial degradation process. Nutrients can leave mangrove ecosystem via a) tidal transport of dissolved and particulate-bound nutrient and plant litter, b) leaching of nutrients from plants followed by tidal export, c) denitrification and volatilization, d) immobilization of inorganic nitrogen in the soil and e) leaching of soils by fresh water (Boto, 1982).

### 7.6 Salinity

Salinity is one of the major environmental factors that influence the development of mangrove forests (Bunt *et al.,* 1982). It is also a causal factor in the distribution of *Rhizophora* and other species along abandoned tributary channels, even though the main stream relatively little mangroves at the confluences. Moreover, high salinity in the abandoned tributaries and coastal lagoon during the dry months of the year are correlated with well-developed mangrove forests. Under low salinity stress and high light availability, soil fertility is proposed to be dominant factor controlling *R. mangle* seedling development to a sapling stage in South Florida mangrove forests. Furthermore, in areas subjected to frequent flooding by the tides, the salinity of the soil water is a key determinant of the extent and nature of the plant cover and topographic position. Thus the amount of both sea water and rain water reaching or draining away from any given area are the most important factors of soil salinity (Clarke and Hannon, 1967). Mangroves usually thrive in estuaries with salinity ranging between 10 to 30 ppt (Macnae, 1968). However, several mangrove species can grow in very highly saline water. According to Wells (1982) mangrove species in Australia, where *A. marina* and *E. agallocha* can grow in areas with salinity as high as 85 ppt, *A. officinalis* can grow in area with maximum salinity of 63 ppt, *Ceriops* sp. in 72 ppt, *Sonneratia* sp. in 44 ppt, *R. apiculata* in 65 ppt and *R. stylosa* in 74 ppt. *X. granatum* can grow in areas with salinity less than 34 ppt and *Bruguiera* sp. less than 37 ppt. There is no clear evidence indicating the maximum interstitial water salinity that mangrove species can withstand, but the optimal range is 28 to 34 ppt and if the salinity is less than 28 ppt, the growth of mangrove plants will decline (Aksornkoae, 1993).

## 8. <u>Silvicultural Systems for Mangrove Management</u>

### 8.1 Silviculture of Natural Mangrove Forests

Silvicultural systems have been used for years in the management of the Asia and Pacific mangrove forests (Aksornkoae, 1993). In Africa and Latin America, however use of silvicultural system is not common, except in Venezuela where clear-felling in alternate strips is practiced. In Malaysia, mangrove forests have been managed since the beginning of the last century and silvicultural systems are highly advanced. Malaysian mangroves forests are among the best manage in the world. Management practices in the country vary from state to state. In Peninsular Malaysia, the best manage forest is the Matang Forest Reserve, Perak. The main objective is to maximize sustained yield of wood particularly for charcoal production. The rotation or working cycle has ranged from 25 to 40 years in the past, but presently 30 years. The silvicultural system is essentially clear felling with retention of standards. At the final felling, standards are retained (7 trees per ha) for regeneration. In places where natural regeneration is poor, supplementary planting is done with *R. apiculata* and *R. mucronata*. In India, mangrove trees are used for house construction, transmission and telegraph poles, and certain household items. Different management techniques such as selection and clear-felling are used and the felling cycle varying from 20 to 100 years. In Bangladesh, the Sunderbans mangrove forest is manage for timber, pulpwood production firewood, *Nypa* leaves and honey. The selection-cum-improvement system is adopted with a 20 year cycle for all commercial species. A minimum exploitable girth has been fixed for all species and all trees above this diameter are removed during felling, provided such removals do not create any permanent gaps in the canopy. This is followed by an improvement felling where, in addition to the thinning of congested stands, all dead, dying and deformed trees are removed. The entire above operation is carried out over 12-18 months and the forest is thereafter left undisturbed, until it is ready for another harvest in 20 years. The principal species in Sunderbans are *Heritiera fomes* and *E. agallocha* (Hussain, 1991). In Indonesia, large mangrove areas are manage for the production of charcoal, firewood, logs, chips and pulpwood. Logging is performed through concessions. When timber concessions are granted, certain regulations and guidelines on the system of exploitation are formulated, stipulating the time schedule, methods of cutting and regeneration.

In Thailand, the silvicultural system has been revised from time to time in order to suit action licensing, to promote effective regeneration and to prevent illegal cutting. Before 1961, the sole objective was charcoal production. The mangrove management plan at the time was in use only in some Provinces because only a few concessionaries were interested. The management plan did not provided clear prescriptions. The silvicultural system was a Shelterwood System, with the cutting rotation varying from 10 to 20 years. The forest area was divided into 10 to 20 annual coupes of approximately equal area. Each year one annual coupe was granted for wood extraction under a short-term permit. Trees of above 30 cm girth at breast height could be cut, but 170-250 large trees had to be left standing per ha to facilitate regeneration (Aksornkoae, 1993).

In 1961, the Royal Forest Department (RFD) revised the mangrove operating plans throughout the country and introduced Shelterwood System with minimum girth limit. The felling cycle was fixed at 15 years, with 15 annual coupes. During the implementation of the Shelterwood System with minimum girth limit (1961-1969), it was found that it was difficult to supervise and control field operations. To solve this problem, the RFD revised the management plan again in 1969. The silvicultural system applied was Clear-felling in alternate strips. Rotation was set at 30 years with a felling cycle of 15 years. This is practiced by dividing the area into 15 coupes, forming an angle of 45° to the tide, and cutting alternate strips every 15 years, thus giving a rotation of 30 years. This silvicultural system shows promising results and continues to be used today. So far, 189,850 ha of mangrove forest are managing by the RFD. The major use of mangrove wood is for fuel and charcoal production. The 5 Regional Forests Offices, with 36 Mangrove Management units are responsible for the management, control and technical assistance to the concessionaries in logging, replanting maintenance of forests, and for research activities. Direct utilization of forest resources is carried out by the concessionaries under certain terms and conditions of the mangrove forest concession (Aksornkoae, 1993).

### 8.2 Silviculture of Mangrove Plantation

The silvicultural system for mangrove plantations is a clear-felling system. When the trees are completely removed, planting operations are promptly carried out. Rotation periods vary from country to country depending on the end-products required. In some countries, mangroves are planted for protecting the coastal environment and maintaining the equilibrium of coastal ecosystem, while in others they are planted mainly for forest products. There are a number of countries in the

Asia and Pacific Region which are in the process of establishing large-scale plantation. In some countries like Vietnam, plantations are replacing instead of natural stands with the main species of *R. apiculata*. The rotation is 14 years and the silvicultural system is two-stage selective felling system (FAO, 1993). While in Bangladesh, large plantations have been established on barren, newly accreted land mainly for protecting lives and properties from natural calamities such as cyclones, tidal bores and stabilizing of coastal land (FAO, 1985[b]).

Silvicultural systems applied for mangrove plantation in Thailand including mangrove plantation established by the RFD and the private plantation. Mangrove plantation covering an area of 29,518 ha established by the Royal Forest Department has not yet been managed for any economic benefit (Aksornkoae, 1993). The total area of government owned plantations is being maintained for ecological protection and seed production. However in future, the RFD plans to manage the plantation on a sustainable basis on a 15 year rotation. Aksornkoae (1996) reported that, the silvicultural systems applied for mangrove plantation management particularly *Rhizophora* plantation on sustainable basis together with available scientific information can be adopted and made the following recommendations:

1. The silvicultural system is a Clear-felling System.
2. Rotation is set at 15 years.
3. Two thinning will be operated at the ages of 8 and 11 years with application of mechanical thinning system in order to maximize productivity of plantation at 15 years cutting rotation.
4. After harvesting, mangrove trees, *Rhizophora* species particularly *R. apiculata* will be planted immediately with spacing 1 × 1 m.
5. Maintenance of plantation especially enrichment planting, weeding, pest and disease control should be carried out at least 3 years after planting to ensure maximum survival rate.

Regarding private mangrove plantations, the application of silvicultural system is a Clear cutting System and rotation period varies according to the end-use products of planted tree species. Aksornkoae (1996) reported that, presently the silvicultural systems applied for management of private mangrove plantations setting by their own experiences with little technological assistance from foresters. He made the following remarks:

1. Cutting rotation period is set up depending on the planted tree species and end-use products such as 4 years cutting rotation for *Ceriops tagal* and *Bruguiera* sp. Plantations used for stakes of mussel culture and firewood at Chumporn Province and 8 to15 years cutting rotation for *R. apiculata* plantation using for firewood and charcoal at Samut Songkram Province.
2. After harvesting, planting will be made immediately.
3. Maintenance of plantation is made only the first year after planting.
4. No thinning has been operated for private mangrove plantations of any rotations.

Aksornkoae *et al.* (1992) reported that the productivity of mangrove plantations varies considerably due to site qualities, especially the elevation in relation to the sea level, i.e. the frequency of flooding. He stated that there were no systematic long term research had been carried out in growth and yield of *R. apiculata* plantations in Thailand under different management regimes.

## 9. Energy from *R. apiculata* Wood and Charcoal

A significant benefit of mangrove forest is fuelwood, especially for charcoal. Chantarasena (1985) made a study on charcoal making and quality from timber of 9 mangrove species by small brick kiln and found that *R. apiculata and R. mucronata* were the most potential species for production of good quality charcoal. Heat value of most kinds of dry woods in mangrove forest was about 4,500-5,000 calorie/gram. Charcoal from mangrove forest has heat value of 6,400-7,600 calorie/gram, which is sufficient for household cooking.

In addition, branches and roots of *R. apiculata and R. mucronata* could produce charcoal of compatible quality. However, dry stems of *R. apiculata* have the highest average energy value. Other parts such as roots and branches also have considerable heat value. A summary of Chantarasena (1985) findings are presented in Table 1.

Table 1 Energy and wood ash from different parts of *R. apiculata* plants

| Part of plant | Energy (kcal/g)<br>Mean ± std | Wood ash (%)<br>Mean ± std |
|---|---|---|
| Stems | 3.82 ± 177.05 | 0.98 ± 0.12 |
| Branches | 3.72 ± 100.32 | 1.81 ± 0.47 |
| Prop roots | 3.81 ± 84.73 | 1.16 ± 0.46 |

Source: Chantarasena (1985)

## 10. Charcoal Production

The charcoal production system of mangrove trees in Eastern, Upper Gulf and Southern Provinces of Thailand has in the recent past, involved many different kinds of people particularly, urban and rural farmers. At times the income generating potential of this enterprise was such that it made some people rich and enabling them to invest in other business. In addition, landed and landless farmers whose crops have failed, and for people who have no other economic options, charcoal making and marketing provide critical sources of income. Charcoal was the main product from the mangrove forests in the past. In Thailand the average wood harvested from mangrove forests was amounted 783,780 $m^3$ per year and produced about 387,800 $m^3$ charcoals per year (FAO, 1985). Aksornkoae *et al.* (1992) reported that in the northern part of the Gulf of Thailand, the local farmers are producing mangrove trees for charcoal making and this traditional system that has safeguarded mangrove ecosystem for the past 50 years. He also mentioned that it is a sustainable production system, in which about 8 to 15 years old mangroves are felled and converted into charcoal, after which the area is replanted.

Earl (1975) reported that the types of charcoal kilns according to their characteristics can be divided into three categories:

1. Fixed or permanent kilns such as brick beehives, masonry kilns, mud beehives, furnaces and retorts.
2. Nonpermanent kilns such as pits and mounds, and
3. Portable or mobile steel kilns such as Mark V, Tropical Product Institute (TPI) design, Single-drum, Double-drum and Tonga.

These kilns differ in capital investment and charcoal production yields, as well as ease of operation. Chomcharn (1984) reported that the estimated annual capital investments per ton of charcoal production from earth mounds and pits kiln varied from 800 to 1,200 baht and brick kiln 7,000 to 14, 000 bath, portable steel kilns 25,000 to 56,000 baht and small steel retorts 24,000 to 66,000 baht.

Research showed that the charcoal production yield from a fixed kiln was the highest (U.S. Forest Products Laboratory, 1961; Earl, 1975). The average lowest charcoal production yield from fixed kilns could be as high as 35%, whereas the lowest charcoal production yield from an earth mound kiln could be as low as 10% (Chomcharn, 1984). According to the baseline survey and the project report, charcoal in Thailand is mainly produced from both fixed and nonpermanent kilns such as mud beehive, brick beehive, earth mound, rice husk mound and sawdust mound (Chomcharn, 1983). However, the comparison of charcoal yields from these kilns is variable because many factors such as wood quality, kiln operators, kiln size, etc. can influence the charcoal yield. The average charcoal yields from the kiln of brick beehives was 36%, mud beehives 30%, rice husk mounds 22%, sawdust mounds 20%, earth mounds 19%. Aksornkoae *et al.* (1992) stated that the dome-shaped brick beehive the only type of charcoal kilns in Yeesarn of Samut Songkram Province and the charcoal yield from *R. apiculata* wood varied 35.60 to 36.60%.

## 11. <u>Charcoal Quality</u>

### 11.1 The Effects of Carbonization, Temperature and Wood Moisture Content upon Charcoal Quality and Quantity

The main factors that affect charcoal quality and quantity in a kiln were carbonization temperature and wood moisture content (Florestal Acesita S. A., 1982; U.S. Forest Products Laboratory, 1961). The results of the experiment of a 37 $m^3$ brick beehive kiln using *Eucalyptus grandis* is presented in <u>Table 2</u>. The results revealed that with the increasing of the carbonization temperature increased the percentages of fixed carbon but the volatile matter and yield of charcoal decreased.

Table 2 Effects of carbonization temperature of *Eucalyptus grandis* on fixed carbon, volatile matter and charcoal yield

| Carbonization temperature, $^0$C | Fixed carbon (%) | Volatile matter (%) | Charcoal yield ( %) |
|---|---|---|---|
| 300 | 68 | 31 | 42 |
| 500 | 86 | 13 | 33 |
| 700 | 92 | 7 | 30 |
| 900 | 94 | 5 | 29 |

Source: Chomcharn (1984)

Chomcharn (1984) stated that as charcoal yield is reduced, the carbon content will increase as a function of temperature. Wood moisture content plays an important role in charcoal yield and properties. Several studies reported that a slight effect of wood moisture content to charcoal yield, charcoal fine content and compressive strength when the moisture content was below 35%. The wood moisture content influences the charcoal quality and quantity when it is greater than 35%.

## 11.2 Theory of Carbonization Process

### 11.2.1 Anatomical Property of Wood after Carbonization

The chemistry and physics of wood degradation are changed in the carbonization process and the structure of wood cell remains basically intact when the temperature is bellow 277 °C. Chomcharn (1984) described that the anatomical change of Black Cherry, Birch, White Oak and White Ash while those wood specimens were heated at the rate of 3 °C per minute in a nitrogen atmosphere. The specimens were held for two hours at 600 °C and the average fractional weight loss of Black Cherry specimens was 72%. Kollmann and Sach (1967) reported that the atmosphere of heat treatment (either in nitrogen or in air to 277 °C) did not produce any anatomical change. Several microstructures of the cell wall such as helical thickening, simple perforation plates, bordered pit pair and vessel pits were revealed in carbonized wood at temperature below 600 °C. The vessel pits of Black Cherry disappeared after the temperature of 900 °C but the helical thickening, simple perforation plates, intervessel pits and bordered pit pairs still clearly remained in the specimens.

### 11.2.2 Chemical and Physical Properties of Carbonized Specimens

#### a. Wood chemical composition and mass loss in carbonization

Karchey and Koch (1979) stated that the organic chemical composition of wood consists of cellulose, hemicelluloses, lignin and extractives and the composition varies from species to species, for example, hardwood grown on Southern Pine sites consists of 33.8 to 48.7% cellulose, 23.2 to 37.7% hemicelluloses, 19.1 to 30.3% lignin and 1.1 to 9.6% extractives. These organic chemicals could yield various charcoal amounts at carbonization temperatures below 400 °C but there would be slightly different yields above 400 °C (Slocum, McGinnes and Beall, 1978). Shafizadeh and Chin (1977) stated that mass loss of cellulose was found greater than lignin and hemicelluloses. The quality and quantity of wood extractives vary greatly but the amounts add up to only a small percentage of total cell wall components. Kryla (1980) revealed that extracted wood specimens from several angiosperms and gymnosperms provided slightly less charcoal yield than the unextracted one at a carbonization temperature of 600 °C.

**b. Mass-loss, heat content and conversion efficiency in carbonization**

A number of studies have been reported concerning mass loss of wood specimens during carbonization and all studies concluded that the wood greatly deteriorated at temperatures between 200 and 400 °C (Chomcharn, 1984). Baily and Blankenhorn (1981) reported that the relationship between mass loss and heat of combustion of three hardwoods and a softwoods with carbonization temperatures up to 700 °C. They confirmed that the average charcoal residual mass and calculated conversion efficiency were greatly affected at temperature ranges of 200 to 450 °C and the heat of combustion of charcoal greatly increased above 300 °C. They also formulated an equation for gross heat of combustion of each species at a heating rate of 3 °C /minute from carbonization temperatures of 200 to 700 °C as follows:

$$HC = A + BT$$

Where, HC is gross heat of combustion in cal/gm, T is carbonization temperature in degree Celsius, A and B are constants specific to each species.

**c. Heating rates and mass loss**

Beall (1977), and Slocum, McGinnes and Beall (1978) reported that the mass loss of Redwood specimens at the heating rate of 1 °C /minute was greater than 50 °C /minute when the carbonization temperature was below 400 °C. They also stated that the mass losses of both heating rates were slightly different at higher carbonization temperatures and the higher the heating rate the greater the charcoal yield. However, the study of heating rates, heat transfer coefficients of wood and charcoal, and mass loss still need more future investigation in order to confirm Beall’s work (Chomcharn, 1984).

**d. Dimensional shrinkages, density and porosity changes during carbonization**

The dimensional shrinkages of charcoal can be divided into two categories that are dimensional changes by losses of absorbed water and the water from carbonization of cell wall components (mass). Panshin and de Zeeuw (1970) reported that the shrinkage during absorbed water loss normally takes place at wood moisture content below the fibre saturation point or at about 25 to 30% moisture content. They found that the tangential shrinkage for air-dried tropical wood was about twice as larger as the radial at the same moisture content and the longitudinal shrinkage from the green to oven dried condition for normal wood was very small, only 0.1 to 0.5%.

There are three criteria used when dealing with mass loss and volumetric shrinkage in wood carbonization; apparent wood density, real wood density and total wood porosity. The apparent density and total porosity of charcoal was reported to depend on carbonization temperature, but the real density was somewhat ambiguous. Results from the carbonization of Red Oak, Southern Yellow Pine, Black Cherry and Hybrid Poplar specimens that were heated in an electric furnace at 3 °C /min under a nitrogen atmosphere, indicate that apparent density decreased, total porosity increased but the real density remained fairly constant with respect to temperature. The decrease in apparent density of charcoal with the increase in carbonization temperature was confirmed by several studies (Beall, 1977; Kryla, 1980, and Cutter and McGinnes, 1981). Studies of latter group contradicted the results of real density constancy. The carbonization of seven hardwood and softwood specimens at a heating rate of $1^{0}$C/min under a nitrogen atmosphere revealed that the real density of charcoal, combining all species, slightly decreased with temperatures up to 600 °C (Chomcharn 1984).

### 11.3 Charcoal Properties

The properties of charcoal and the proximate analyses normally reported the quality of the charcoal as well as the heat content. These analyses reveal the fixed carbon, volatile matter and ash content, which are accepted in the charcoal market. The quality of the charcoal is of major concern to experienced consumers. Such qualities as the presence of smoke, the fire bursting effect when the charcoal is ignited, the hardness of charcoal bulk, the amount of charcoal fines that are left when the charcoal is crushed or broken during size reduction, and the weight of the charcoal. These should be made known to charcoal users and makers. In addition, that charcoal properties from kiln production are not uniform even within a kiln, due to the temperature gradient inside which varies from the top to the bottom of the kiln (Chomcharn, 1984).

#### 11.3.1 The Relationship of Charcoal Yield and Properties in Commercial Kilns

The charcoal production from 10.4 and 24.2 $m^3$ pilot masonry block kilns could yield 27 to 32% charcoal with the final carbonization temperature between 450 and 520 °C (U.S. Forest Products Laboratory, 1961). The proximate analyses of the charcoal produced moisture 2 to 4%, ash 1 to 4%, volatile matters 18 to 23% and fixed carbon 74 to 81%. The fixed carbon content of Southern Red Oak charcoal produced from the 24.2 $m^3$ kiln vary within kiln zones and the result were top zone 85%, middle zone 80%, floor zone 75-79%. Florestal Acesita S.A. (1982) reported that the charcoal production from a brick kiln is more efficient. He mentioned that a 5 m. diameter of brick beehive Brazilian designed kiln, could yield

33% charcoal produced from five year old *Eucalyptus grandis* at 76% to 81% fixed carbon content. The average carbonization temperature at the final stage varied from 450 to 500 °C. The average fixed carbon content of each kiln zone was recorded as top zone 81%, middle zone 80% and bottom zone 76%. Maslekar (1982) and Majumdar (1982) reported that average charcoal yield and properties from nonpermanent and portable kilns were rather poor. They also mentioned that the average charcoal yields of country (Thailand) kilns (pits and mounds) and 6.64 $m^3$ portable kilns (the TPI designed steel kilns) were only 20%. The proximate analyses of charcoal from both kiln types were different. The average percentages of fixed carbon, volatile matter, ash and moisture content of charcoal from the country kilns was 60%, 29%, 6% and 4% , respectively whereas The average percentages of fixed carbon, volatile matter, ash and moisture content of charcoal from the portable kilns was 70%, 24%, 4% and 2% , respectively.

#### 11.3.2 Relationship between Charcoal Properties and End Use Application

The applications of charcoal can be categorized as industrial and non-industrial. Chomcharn (1984) described that charcoal compositions are 80 to 90% fixed carbon, 7 to 30% volatile matters and 0.5 to 10% ash. The industrial applications of charcoal can be divided into two classes: metallurgical and chemical charcoal (U.S. Forest Products Laboratory, 1961). Both types of charcoal should content high fixed carbon, low volatile matter and low ash content. The properties of industrial charcoal are identically to white charcoal specifications (as in Japan where carbonization temperature ranged from 700 to 1000 °C). Chomcharn (1984) described that the volatile matter content of Oak white charcoal was about 5%, while that of black charcoal was about 30%. Most charcoal production in Thailand is destined for non-industrial applications, particularly for cooking (Chomcharn, 1984).

## 12. <u>Charcoal Marketing</u>

Marketing is very important for charcoal producers and entrepreneurs for sustaining this system. In Yeesarn of Samut Songkram, Aksornkoae *et al.* (1992) found that the middleman buys the charcoal directly from the operator, often on contract basis. With this type of arrangement, the middleman normally unloads the kilns into the boats. A fleet consisting of 6 to 16 small boats tugged by one motor boat is employed for longer distance charcoal transport such as to Bangkok. Another mode of transport, especially for smaller quantities, is by pick-up or bigger trucks. Mostly they supply to the local markets and the neighboring Provinces.

Panya *et al.* (1988) reported that in Nakhon Phanom and Sakon Nakhon Province, rural charcoal entrepreneurs take their charcoal to town, a few big sacks or baskets at a time by using the local bus system. In some places of Northeastern Provinces, the charcoal entrepreneurs are referred to hire local villagers as “charcoal runners” those are specialized in transporting charcoal village to urban areas using modified push carts pulled by bicycles and motorcycles. Some villagers place big sacks of charcoal along roadsides to be bought by passing motorists. This type of marketing strategy usually occurs in villages near well-traveled roads. Panya *et al.* (1988) also found that in some urban areas of Northeast where there were historically large-scale wholesalers who exported charcoal to Bangkok. In addition, there were existed a number of small-scale retailers who rent selling "spots" in city market places and sell charcoal as well as other types of goods.

In Bangkok and most urban areas, charcoal from various sources finds its way to the consumers through various marketing channels; small pick-up trucks distribute charcoal to retail stores and major consumers, pushed cart and boat vendors to small users. Aksornkoae *et al.* 1(992) found that the selling of mangrove charcoal in Bangkok originated from Yeesarn of Samut Songkram gave the price of 70 to 80 bath/10 kg basket. They also noted that compared with the producer price at the source, this consumer price is about 67 to 94% higher and reflects various cost components in transport, handling, distribution and profit margins of the parties involved.

## 13. <u>Concepts of B/C, NPV and IRR</u>

### 13.1 Benefit-Cost Ratio

Gittinger (1982) stated that anyone interested in comparing alternative investments would naturally compare costs and benefits, and recognizing the need to take account of the differing time streams of alternative projects by means of discounting, it may turn to the first of the discounted measures to project worth in common use of benefit-cost ratio. The ratio can be calculated from the following equation:

$$\frac{\text{Pr esent worth of benefits}}{\text{Present worth of costs}} = \text{Benefit - cost ratio}$$

Incidentally, economists are quite inconsistent in their use of "benefit-cost ratio" to emphasize the computation by which the measure is worked out: that is to take the benefits and divide them by the cost. The benefit-cost ratio is used almost exclusively as a measure of social benefit- that is, for economic analysis.

### 13.2 Net Present Value

The most straightforward discounted cash flow measure of project worth is the net present worth which often referred as the net present value or NPV. This is simply the present worth of the cash flow stream. The net present value may also be computed by finding the difference between the present values of the benefit stream less the present value of the cost stream. The problem of choice of discount rate in connection with the benefit-cost ratio arises also in connection with the net present value criteria. Most analysts recommend using the opportunity cost of capital in the society and many underdeveloped countries seem to feel the opportunity cost of capital is in the neighborhood of about 8 to 15 percent. The net present value also may be computed by subtracting the total discounted present value of the costs from that of the benefits, it is easier and normal practice to compute it by discounting the cash flow. To get the cash flow, it may subtract gross costs from gross benefits, the investment costs from the net benefits, or any other computation pattern that suits the analytical needs providing only that avoid of double counting. The formal selection criterion for the net present value measure of project worth is to accept all projects with a positive net present value when discounted at the opportunity cost of capital. An obvious problem of the net present value measure is that the selection criterion cannot be applied unless there is a relatively satisfactory estimate of the opportunity cost of capital.

### 13.3 Internal Rate of Return

Internal Rate of Return is one of the ways of using discounted cash flow for measuring the worth of a project to find that discount rate which just makes the net present value of the cash flow equal zero. This discount rate represents the average earning power of the money used in the project over the project life. When the internal rate of return is used in economic analysis, the result is termed the internal economic return; in financial analysis it is called the internal financial return. The formal selection criterion for the internal rate of return measure of project worth is to accept all projects having an internal rate of return above the opportunity cost of capital. Projects are ranked in order of the value of the internal rate of return. The lowest acceptable internal rate of return is often termed the "cutoff rate" and normally is set slightly above the opportunity cost of capital.

## 14. Project Analysis Theory

Basic economic problems of all countries are the limitation of resources such as labor, land cost and natural resources should be effectively utilized to be products and services for the highest net return on investment. However, social demands are varied, uncertain and endless so it is necessary to effectively utilize and economize existing national resources. In the meantime, it should be mostly consistent with demands or holistic purpose. Hence, prior to make decision of using national resources for any purpose, it is essential to estimate existing resources for the highest benefit. One way to analyze economic effectiveness of natural resource utilization is feasibility study of the project. Financial analysis is to determine the project in term of private investment. The return on investment should be good as well as profit. Project analysis is not only good for investors but also necessary for financial institutes, cooperatives and organization that offer loan. In addition, financial analysis includes proper financial planning for the project and project analysis of return on investment for each investor such as farmers, private sector, government enterprise and relevant ones. It assures the project will yield incentive return for investors (Thammincha *et al.,* 1993).

# STUDY AREA

## 1. Physical Feature

Yeesarn Sub-district is located in Amphawa district of Samut Songkram Province, 80 km south-west of Bangkok and 5 km from inner part of the Gulf of Thailand. It covers an area of 6,090 ha and sustains a population of 3,217 in 716 households. Aquaculture is the main livelihood of the people this area and about 60% people involve in these activities. The other occupations are mangrove plantation (*R. apiculata* locally called Mai Kongkang), charcoal making, government and private employee. About 15% of the people are incorporated with *R. apiculata* plantation and charcoal making system. The area is situated one of the largest canals locally known as Bangtapoon River and various canals and creeks crisscross the area. It receives deposition of some alluvial soil and sediment from bank erosion and from the Maeklong River estuary. There are 5 villages over the Sub-district and 4 villages are brought under mangrove plantation mainly with *R. apiculata*. The main utilization of the plantation is production of charcoal and dyewood. The private mangrove plantation for charcoal production is a unique feature of this area and consequently this system giving more importance by different agencies. On the other hand scarcity of fresh water, polluted water from shrimp ponds and poor management of solid wastes are the major environmental threats of the area.

Aksornkoae *et al.* (1992) stated that the villages were established before 1932 and the villages were declared legally in 1973 after issuing the land ownership certificates. Before 1975 the only means of transport were boats which were very inconvenient due to the fluctuating tides in the canals. The road was constructed in 1975 and connected the area with the southern highway and greatly improved the accessibility and stimulated fisheries production. However, many of these lands of this area have been converted into shrimp ponds during the past couple of decades. Natural aquatic life which was an important source of protein and additional income of the local people has seemed to be greatly diminished.

## 2. Geographical Position and Climate

The study area lies between 13º 16′ and 13º 19′ South latitude and 99º 52′ and 99º 56′ East longitude. The area is a flat coastal zone and the elevation is hardly exceeded 4 m above the mean sea level.

The rainy season starts from mid April and lasts till late October. During the past 20 years most of the precipitation fell between May and October. The mean monthly rainfall received in October was the highest as 295.4 mm and lowest in February as only 1.4 mm. The annual mean rainfall of the period was 1,064.5 mm. The annual mean rain-day was 92.9 and the mean monthly rain-day was highest in October as 16.9 days (Appendix 1).

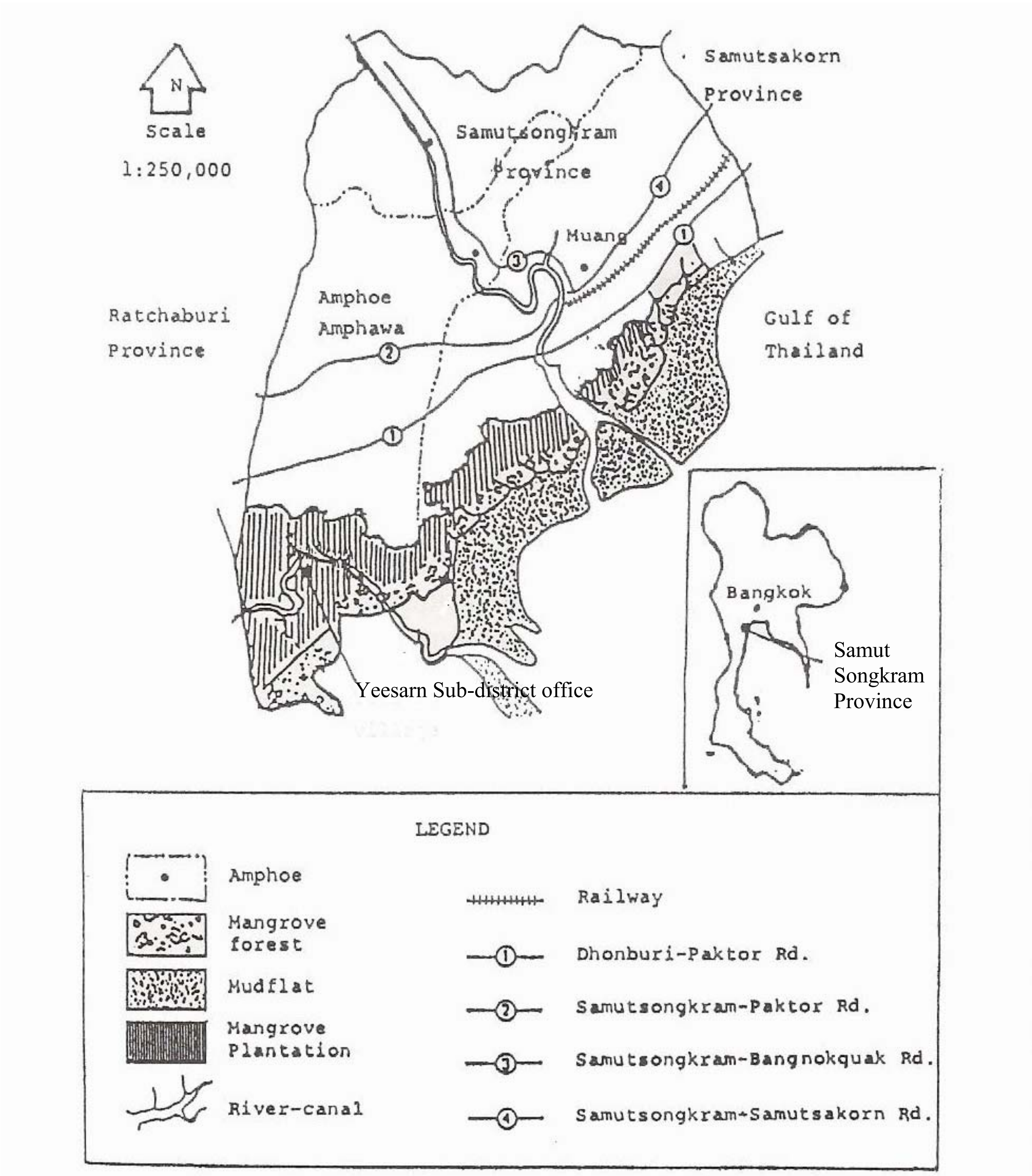


Figure 2 Map of Samut Songkram Province showing the location of Yeesarn Sub-district office.

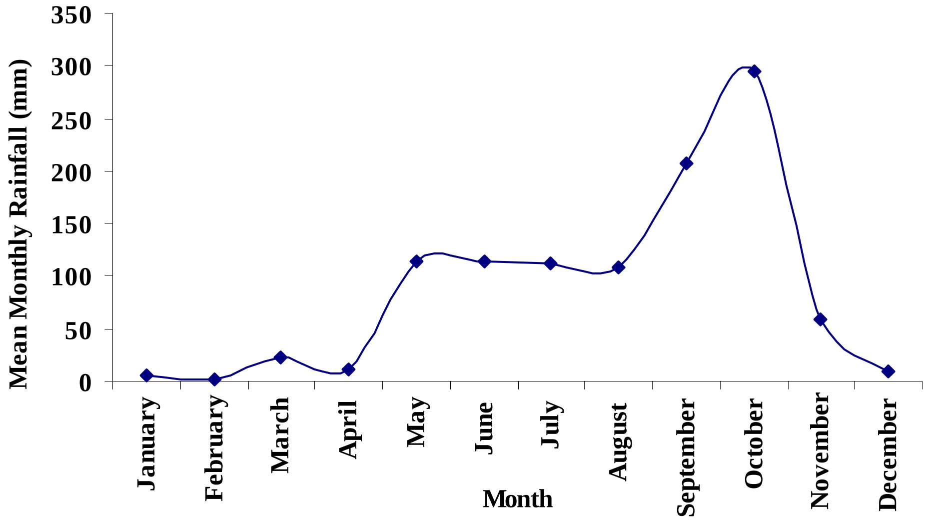


Figure 3 Mean monthly rainfall of Samut Songkram Province between 1986 and 2005 (Data based on Amphawa Meteorological Station).

The climate of the study area which area has been designed as tropical climate is characterized by moderate temperature and hot summer. The cold weather lasted from November to February. Meteorological data of the past 20 years (1986-2005) revealed that the coldest months were December and January recorded with a minimum temperature of 22.0 °C and 22.9 °C, respectively. In March the temperature began to rise and the hottest months were April and May with a mean maximum temperature 35.4 °C and 34.4 °C, respectively (Appendix 1). The monthly mean temperature varied from 31.6 °C to 35.4 °C (mean maximum) and 22.0°C to 26.9 °C (mean minimum). The mean monthly temperature was highest in April as 30.6 °C and the lowest was in December as 26.6 °C. The annual mean temperature was 28.7 °C.

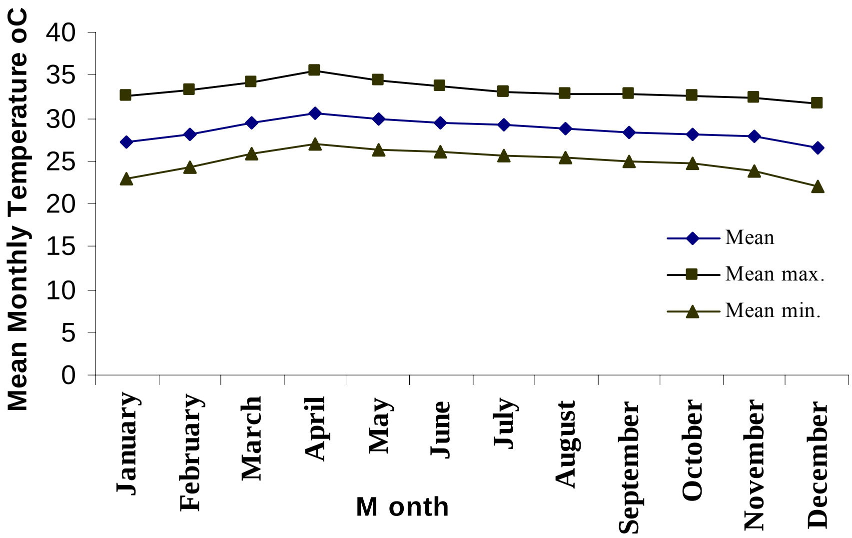


Figure 4 Mean monthly temperature between 1986 and 2005 (Data based on Bangkok Metropolis Meteorological Station).

The monthly mean maximum humidity of the air varied from 80% to 91% which was in December and September, respectively and the mean minimum humidity were varied from 49% to 62% which was in January and September, respectively. The monthly mean humidity was highest in September as 79% and the lowest was in December as 66%. The annual mean humidity was 73% (Appendix 1).

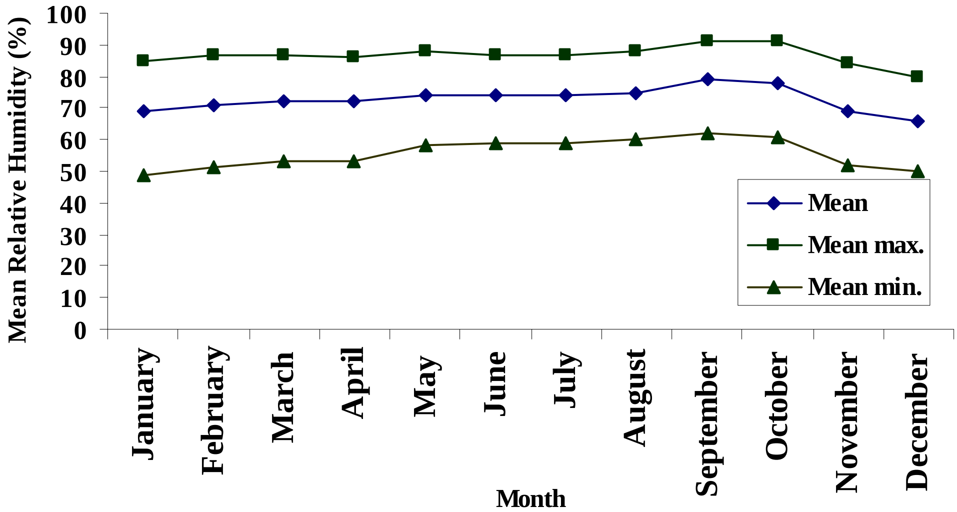


Figure 5 Mean monthly relative humidity between 1986 and 2005 (Data based on Bangkok Metropolis Meteorological Station).

## 3. Land Tenure and Use

During 1943-1944, the Royal Forest Department (RFD) carried out a survey in this area and noticed that the plantations of *R. apiculata* were established by villagers. As this type of land use was classified as agricultural land and the government decided to offer certificates of land ownership in 1955 and again in 1961 and 1973. Presently almost land is privately owned and there is no obligation for the land owner to use the land. The land use patterns of Yeesarn Sub-district are presented in Table 3**.**

To date, land tenure and land use pattern was drastically changed in this area. A major cause was the rise of commercial shrimp farming began in early eighties. During that period, the high demands of shrimps and prawns both in local and international markets together with high price attracted the land owners for intensive shrimp farming. This was the permanent conversion of mangrove land into shrimp ponds and latter to be changed into intensively manage ponds. Chaichavalit (1989) found that there were 40% of the intensive shrimp farms in Samut Songkram were developed from such native methods. About 21% was derived from mangrove plantations, 11% from *Nypa* plantations and the rest from other types of land use.

Table 3 Land use pattern in Yeesarn Sub-district of Samut Songkram Province

| Category of land use | Area | |
|---|---|---|
| | (ha) | (% of the total) |
| Residential | 192.00 | 3.15 |
| Construction for school, office, temple, market | 103.52 | 1.70 |
| Agriculture (mainly for coconut) | 272.00 | 4.47 |
| Aquaculture | 4,082.40 | 67.03 |
| Mangrove forests and plantation | 1,352.00 | 22.20 |
| Others | 88.08 | 1.45 |
| Total | 6090.00 | 100.00 |

Source: Tambol Yeesarn Administrative Office, (personal communication, 2006).

**4. Mangrove Area**

Based on information from Tambol Yeesarn Administrative Office, there were 1,315 ha land brought under *R. apiculata* plantations which constituted 21.60% of the whole area. In addition, there were another 37 ha natural mangrove areas. Thus the mangrove area at Yeesarn was estimated about 1,352 ha which covered 22.20% of the whole area (Table 3). An inventory in 1987 estimated that the private mangrove (*R. apiculata*) plantation in Yeesarn was about 2560 ha and due to conversion of this plantation area into shrimp ponds the plantation area decreased to 1694 ha in 1990 (Aksornkoae *et al.*, 1992). A considerable number of plantation farmers of this area do not like to wish to convert or sell their mangrove land for other uses. However, the natural stands of Yeesarn consisted of *R. apiculata, R. mucronata, A. marina, A. alba, S. caseolaris, B. gymnorrhiza, L. racemosa, C. tagal, X. granatum* and *E. agallocha*. Private mangrove plantation was done in mudflat the areas mostly with *R. apiculata*. *Nypa fruticans* was found along the bank of river, canals and creeks as man made plantation. A list of mangrove plant in the study area is given in Appendix 2**.**

Figure 6 Natural mangrove forests (mixed stands) in Yeesarn Sub-district, Samut Songkram Province.

Figure 7 Thirteen years old mangrove (*R. apiculata*) plantation in Yeesarn Sub-district, Samut Songkram Province.

# MATERIALS AND METHODS

## 1. Materials

Local area map was used for find out of the plantation area. Measuring tapes and ropes were used for plantation plot measurement. Digital caliper was used for tree DBH measurement. Haga altimeter and measuring poles were used for tree height measurement. Weight balance, electric oven, desiccator and volumeter were used for determination of density, moisture content and specific gravity of *R. apiculata* wood and charcoal. Crucible, thermometer, and electric furnace were used for proximate analysis of charcoal and adiabatic oxygen bomb calorimeter was used for determination of heat value of charcoal. Camera and laptop computer was used for documentation. Various equipments and chemical reagents were used for soil analysis in the laboratory.

## 2. Methodology

### 2.1 Soil Properties

The transect line method for the study of mangrove forests (English S., C. Wilkinson and V. Baker (eds.), 1997) was applied. The transect line was laid on both sites of Bangtapoon River. Each transect was covered 1600 m from the river bank. The reason was that it covered the bulk of the plantation area. The first transect was laid to the seaward site and the second transect was laid to the landward site. In seaward site, the first sample was collected from 2 years old plantation which was located 1600 m far from the river bank and the second one was collected from 6 years old plantation which was located 100 m far from the river bank. In landward site, the first sample was collected from 9 years old plantation which was located 100 m far from the river bank and the second one was collected from 14 years old plantation which was located 1600 m far from the river bank. The soil samples were collected at the surface approximately from the surface to 15 cm depth at *R. apiculata* plantation area. This technique was also used in several studies (Aksornkoae *et al.,* 1982; Meepol, 2002). Soil samples were air-dried and they were analyzed at the laboratory for soil texture, pH, organic matter, electrical conductivity, phosphorus, potassium, calcium, magnesium, sodium and cation exchange capacity (CEC). The method for analyzing the soil particle sizes was followed by Hydrometer Method. The pH values were measured by a pH meter using soil-water ratio 1:1. The determination of organic matter was carried out by using Walkley and Black's rapid titration method. Cation exchange capacity was obtained by using the I N Ammonium Acetate (pH 7) Method. Electrical conductivity (EC) was determined followed by bridge using soil and water ratio of 1:5. Exchangeable calcium (Ca), Magnesium (Mg) and Sodium (Na) were extracted by 1 N $NH_4OAC$ (pH 7) and determined by Atomic Absorption Spectrophotometer (AAS). Exchangeable potassium (K) content was determined by using $NH_4OAC$ as described in Jackson (1967). Available phosphorus (P) was extracted by Bray II Method and was determined by Spectrophotometer at 882 nm wavelength. Analysis of soil samples were performed at Department of Silviculture, Faculty of Forestry, Kasetsart University, Bangkok.

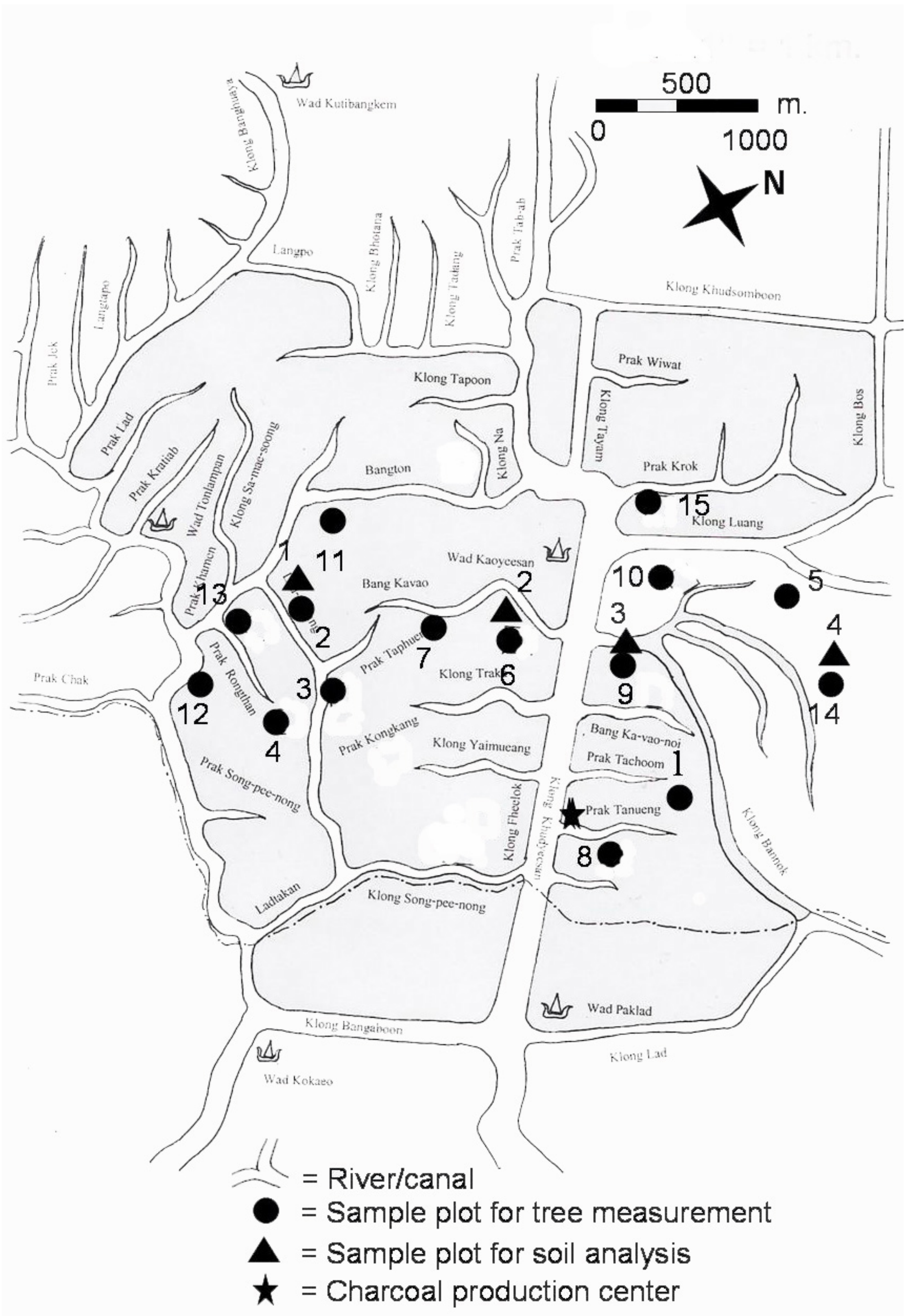


Figure 8  Map of Yeesarn showing the location of sampling plots.

### 2.2 Plantation Management

Data on silvicultural practices such as site preparation, seedling, planting, maintaining and harvesting techniques was collected by personal observation and interviewing the plantation owners who took over the responsibility for the whole program.

### 2.3 Growth Performance and Production

15 selective temporary sampling plots were established for growth study of *R. apiculata* plantation in Yeesarn. The size of the sample plots were 10 ×10 m. The selection of plot for each year was based on personal judgment that represented the average stands condition. This method also used in several studies on mangrove forests (Aksornkoae *et al.,* 1982; Wechakit, 1987; Meepol, 2002; Chanprapai, 2005). Within each plot the following parameters were recorded:

1. Number of individuals of *R. apiculata* by actual count.
2. DBH (Diameter at Breast Height) at 1.30 m above ground for 3 to 15 years old plantation and ground level diameter (Do) for 1 and 2 years old *R. apiculata* plantation.
3. Diameter of trees was measured by using Digital-Caliper with 0.01 mm accuracy and total height was taken by measuring pole and a Haga altimeter.
4. The age of the plantation was confirmed by the plantation owner.

### 2.4 Stands Density

The stand density was calculated from the numbers of individual divided by per unit of area. The following equation was used:

$$D = n / a$$

When, D = Density
n = Numbers of individual species
a = Per unit area (ha)

Survival percentage was calculated from the actual counting of living trees of the individual species per unit of area base on the number of planting trees.

### 2.5 Biomass and Volume

This study used non-destructive method of biomass and volume estimation, such as the relationship equation of allometric term $y = a \times x^h$. The allometric equation relationship between diameter square ($cm^2$) and height (m) for estimation of biomass and volume for 3 to 15 years old *R. apiculata* plantation was referred to the study conducted by Wechakit (1987) at Yeesarn of Samut Songkram Province. Trees having more than 2 cm DBH were considered for the estimation of commercial volume. The annual growth rate was estimated from the total production divided by the age of the stands. However, the equations and formulas for the calculations were as follows:

Biomass of the dry stems ($W_S$):

$$\log W_S = 2.0576 + 0.8124 \log D^2 H$$
$$r = 0.9954$$

Biomass of the dry branches ($W_B$):

$$\log W_B = 1.9928 + 0.4866 \log D^2 H$$
$$r = 0.8596$$

Biomass of the dry leaves ($W_L$):

$$\log W_L = 1.9655 + 0.3865 \log D^2 H$$
$$r = 0.7562$$

Biomass of the prop roots ($W_R$):

$$\log W_R = 1.6630 + 0.5806 \log D^2 H$$
$$r = 0.9385$$

Commercial volume of wood ($V_M$):

$$\log V_M = 1.8198 + 0.9195 \log D^2 H$$
$$r = 0.9977$$

Total volume of wood ($V_T$):

$$\log V_T = 1.8515 + 0.9100 D^2 H$$
$$r = 0.9990$$

The estimation of above ground biomass and volume for 1 and 2 years plantation were estimated by harvest technique method followed by Wechakit (1987). This method was detail described by Whittaker and Woodwell (1971). The ground level diameter (Do) and height of all stands of a plot were measured and the average of Do and height was used as tools for the indirect estimation of above ground biomass and volume of 1 and 2 years plantation. The average Do and height of 1 year plantation was 1.73 cm and 0.51 m , respectively and the average stem, branch, leaf biomass production and volume was 12.71, 8.05, 11.86 gm/tree and 30.51 $cm^3$/tree , respectively. On the other hand, the average Do and height of 2 year plantation was 2.91 cm and 1.27 m , respectively and the average stem, branch, leaf, root biomass production and volume was 41.23, 21.33, 44.08, 14.69 gm/tree and 86.26 $cm^3$/tree , respectively. The current annual increment (CAI) of diameter, height, above-ground biomass, commercial volume and total volume of each age year were calculated from the values of each component divided by the age.

### 2.6 Wood Materials for Charcoal Production

The measurement of *R. apiculata* fresh green wood, air dried wood input to the kilns, firewood and charcoal out put were recorded based on observation and interviewing the kilns operator. Measurements were taken from the charcoal kilns of Mr. Sai Saksareechai of Yeesarn of Samut Songkram Province. During the determination of wood weight, 10 pieces of fresh billets from stacks were collected randomly and measured the volume and weighted. The billets were air-dried for 130 days and again measured the volume and weighted. From these measurements it was calculated that the average moisture content of the wood was 33.13% and within this moisture content level the average weight of 1 $m^3$ *R. apiculata* air dried wood was approximately 690 kg. This value was used for estimation of wood input in the kilns.

### 2.7 Wood and Charcoal Quality

Physical properties of *R. apiculata* wood and charcoal were determined in terms of density, moisture content and gravity. Sampling methods for specimens was used in these experiments. The sample was made into blocks in size of 1.5 × 1.5 × 1.5 cm. The samples were weighted and measured the volume. These were considered for fresh weight and fresh volume of the samples. The samples then kept in an electronic oven with a fixed temperature of 105 °C for 24 hours and then put the samples in a desiccator. After cooled down the samples again weighted and measured of the volume. These were considered the oven dried weight and oven dried volume of the samples. Then the samples placed into the volumeter for measuring the volume. The following formulas were applied for determination:

$$D = \frac{M}{V}$$

$$MC = \frac{Fw - Dw}{Dw} \times 100$$

$$SG = \frac{Dw}{Vs - Vm} \times Ct$$

When, D = Density of wood or charcoal ($gm/cm^3$)
M = Oven dried weight of sample of wood or charcoal (gm)
V = Oven dried volume of sample of wood or charcoal ($cm^3$)
MC = Moisture content of wood or charcoal (%)
Fw = Fresh weight of sample of wood or charcoal (gm)
Dw = Oven dried weight of sample of wood or charcoal (gm)
G = Specific gravity of wood or charcoal
Vs = Volume of wood/charcoal sample in mercury ($cm^3$)
Vm = Volume of mercury ($cm^3$)
Ct = Content tool of volumeter (0.3)

### 2.8 Charcoal Output Evaluation

The charcoal output was evaluated in terms of yield and production rate. The gross yield of charcoal was evaluated by the weight of charcoal output/wood input. The lump charcoal output was calculated from the following relation:

$$\%\ \text{Yield} = \frac{\text{Weight of lump charcoal output (freshly recovered)}}{\text{Oven dried weight of wood input - Weight of brands}} \times 100$$

Output from charcoal kilns was considered lump charcoal and brands since these products have commercial value. The brands may be resulted from the incomplete conversion of wood to charcoal. Most of the brands were at the bottom end of wood standing on the kilns floor. It is assumed that the lump charcoal immediately taken from the charcoal kiln has no moisture content. Weight of lump charcoal, brands and kiln operation time was collected by personal observation and interviewing of the kiln owner who took responsibility of the production system.

### 2.9 Production Rate

The charcoal output production rate was calculated from the following relation:

$$\text{Production rate, kg/hr} = \frac{\text{Lump charcoal weight, kg}}{\text{Total operation hour}}$$

(Note: total operating time counted from start firing until kiln cool down)

### 2.10 Proximate Analysis and Heat of Combustion

The lump charcoal was ground into powder for the determination of moisture, volatile matter, and ash content according to the method described in ASTM D 1762-64. The fixed carbon content was the amount of carbon that was not volatized in the furnace at a temperature of 950 °C for 15 minutes, less the amount of ash remaining after the charcoal was completely combusted in the furnace at a temperature of 750 °C for 6 hours. The amount of fixed carbon was calculated from the following relation:

$$\% \text{ Fixed Carbon} = 100 - \% \text{ volatile matter} - \% \text{ ash}$$

The heat value of charcoal from the combustion of charcoal powder in the presence of excess oxygen was determined by using an adiabatic oxygen bomb calorimeter following ASTM D 2015-72 procedures. The heat of combustion of the charcoal was the total heat that the charcoal could produce when it was combusted in an oxygen atmosphere. The charcoal quality was used to calculate amount of energy from charcoal weight. The heat of combustion of charcoal was reported based on oven dried weight of the charcoal. For this study the raw materials and the charcoal kilns were same, so one sample of charcoal from *R. apiculata* wood was tested for the proximate analysis and heat content experiment. This analysis was done in the laboratory of Thailand Institute of Scientific and Technological Research, Bangkok.

### 2.11 Financial Analysis

The cost of plantation per hectare and price of the plantation per hectare were obtained by personal observation and interviewing the respective plantation owner. The total cost of *R. apiculata* plantation for charcoal production was considered the fixed costs plus variables costs. The fixed costs included the depreciation of the asset and the variable costs included the costs of all activities for establishment of the stands. The benefit of *R. apiculata* plantation was derived from the stumpage values (minimum and maximum prices). The achievement of invest in

*R. apiculata* plantation for charcoal production can be evaluated by employing the three methods, namely; B/C, NPV and IRR. These methods also used in several studies (Chanprapai, 2005; Hoamuangkaew, 2002).

The rational decision for the investment was made, when the obtained B/C was equal to or greater than 1. The calculating formula was as follows:

$$B/C = \frac{\sum_{t=0}^{n} B_t/(1+i)^t}{\sum_{t=0}^{n} C_t/(1+i)^t}$$

The rational decision for the investment was made when NPV was greater than zero. The calculating formula was as follows:

$$NPV = \left[\sum_{t=0}^{n} B_t/(1+i)^t\right] - \left[\sum_{t=0}^{n} C_t/(1+i)^t\right]$$

The IRR was that rate of interest which was given a NPV of zero. The calculating formula was as follows:

$$NPV = LI + (HI - LI) \times \left[\frac{NPV_{LI}}{NPV_{LI} - NPV_{HI}}\right]$$

When, $B_t$ = Revenue in year t
$C_t$ = Cost in year t
i = Interest rate (%)
t = 8…….. 15 (year)
LI = Low interest rate (%)
HI = High interest rate (%)
$NPV_{LI}$ = Summation of NPV from year 8 to 15 for low interest rate
$NPV_{HI}$ = Summation of NPV from year 8 to 15 for high interest rate

Discount rates were given as 6%, 8%, 10%, 12%, 14% and 16% based on below and above of the bank interest rate.

The cost for charging the kiln and total benefit from the kiln were obtained by personal observation and interviewing the respective kiln operator. The total cost of charcoal kiln operation was included the depreciation of the assets plus the opportunity coasts and the variable costs. The variable costs comprised expenses of raw materials, labor costs, charcoal packaging and marketing costs. The profit of charcoal kiln operation per kiln charge was calculated from the total costs minus the total revenues.

### 2.12 Statistical Analysis

Correlation analysis was used for determination of the relationship between the height and DBH of different age year *R. apiculata* plantations. Production of above ground biomass and volume of different age years were evaluated by using Logistic Growth Model. Compare mean statistics One-way ANOVA was used to compare physical properties of *R. apiculata* wood of different ages, charcoal yield of different kilns, physical properties of charcoal of different kilns.

# RESULTS AND DISCUSSION

The study on management of mangrove plantation for charcoal production was carried out in a private mangrove (*R apiculata*) plantation in Yeesarn Sub-district of Samut Songkhram Province. The results of the study were as follows:

## 1. Soil Properties

The results of physical and chemical properties of the soils in the *R. apiculata* plantation area in Yeesarn are given in Table 4.

### 1.1 Physical Properties

The physical properties of soils of the study area were included sand, silt, clay and soil texture.

#### 1.1.1 Sand

The amount of sand in soils of the 4 locations of the study area varied between 9 and 19% and the average was 13%. The average amount of sand was high in the southwestern part of Bangtapoon River (seaward side) particularly in 6 years old plantation and low in the northeastern part of the River (landward side). The variation of sand in different locations would be due to the differences of sea water fluctuation and sedimentation process. Juindanuch (2003) found that the amount of sand in mangrove soils of Thung Kha estuary in Chumphon Province varied from 32 to 67%. Aksornkoae *et al.* (1982) found the variation of the amount of sand in soils in mangrove forest near the mining area at Muang, Ranong was 9 to 26%. Wechakit (1987) found that the amount of sand in mangrove soils of Yeesarn varied from 8 to 24% and the average was 13%. The present study showed quite similar amount of sand in soils with the previous study.

#### 1.1.2 Silt

The amount of silt in soils in the study area varied from 26 to 30% and the average was 28%. The amount of silt was high at the southwestern part than the northeastern part of the Bangtapoon River particularly in 2 years old plantation and it would be due to the area received regular inundation in all medium tide. Juindanuch (2003) found that the amount of silt in mangrove soils of Thung Kha estuary in Chumphon Province varied from 10 to 19%. Aksornkoae *et al.* (1982) found the variation of silt in soils in the mangrove forest near the mining area at Muang, Ranong was 31 to 40%. Wechakit (1987) found that the amount of silt in mangrove soils in Yeesarn varied from 27 to 40% and the average was 32.87%. The present study showed somewhat less amount of silt in soils than the previous study and it would be due to some sorts of hydrological changed in the area particularly for the construction shrimp pond and a number of small culverts which put negative impact on the hydrology of the area.

### 1.1.3 Clay

The amount of clay in soils in the study varied between 53 and 62% and the average was 59%. The amount of clay in soils observed higher in the areas that far from the main river channel particularly in 2 and 14 years old plantation and lower in the river bank particularly in 6 and 9 years old plantation. The variation of clay in different locations of the study area would be due to differences in water drainage and the magnitudes of the tidal current of the areas. Juindanuch (2003) found that the amount of clay in mangrove soils of Thung Kha estuary in Chumphon Province varied from 23 to 49%. Aksornkoae *et al.* (1982) found the variation of clay in soils in the mangrove forest near the mining area at Muang, Ranong was 43 to 57%. Wechakit (1987) found that the amount of clay in mangrove soils in Yeesarn varied from 40 to 65% and the average was 55%. The present study showed slight higher percentage of clay in soils than the previous study and it would be due to the changes in water drainage systems of the area.

### 1.1.4 Texture

The relative size of the soil particles was expressed by the term texture which referred to the fineness or coarseness of the soil. More specifically, soil texture is the relative proportions of the different size groups or separates; sand, silt and clay particle. But soils type depends upon group of dominant particle in soils (Foth, 1978). The results of soils texture of the study area revealed that the soil texture of the area was clay. Juindanuch (2003) found that the texture of mangrove soils of Thung Kha estuary of Chumphon Province varied from clay to sandy clay loam. Aksornkoae *et al.* (1982) studied extensively on soils in the mangrove forest near the mining area at Muang, Ranong and found that the soil texture was clay. Wechakit (19870 studied soils in 15 locations in the *R. apiculata* plantation areas in Yeesarn and found that the soil texture of all locations was clay.

## 1.2 Chemical Properties

The chemical properties of soils were included soil reaction pH, percentage of organic matter, electrical conductivity (EC), phosphorus, potassium, calcium, magnesium, sodium and cation exchange capacity (CEC).

### 1.2.1 Soil pH

Soil pH or acid-base condition of the soil was essential for plant growth in a certain way owing to either a depressed solubility of some elements or to increased solubility of others and activity of micro-organism in soil. The soil pH of the study area varied from 5.94 to 7.51 with an average of 6.68. Soil pH was found higher in the areas that were far from the river particularly in 2 and 14 years old plantation and lower in the river bank. Juindanuch (2003) found that the mangrove soil pH varied from season to season and also varied within soil horizons. Aksornkoae *et al.* (1982) found that the soil pH of top soil in the mangrove forest near the mining area at Muang, Ranong varied 3.70 to 5.70. Chunkao *et al.* (1982) found the soil pH in mangrove forest of Khlong Kapoe and Khlong Ngao watersheds in Ranong Province was 5.40. Wechakit (1987) found that the soil pH in the *R. apiculata* plantation areas in Yeesarn varied from 3.60 to 6.20 and the average was 5.11. The present study revealed somewhat higher soils pH than the previous study and it would be due to some sorts of physical and biological changed of the area. However, the present study showed the soils of the study area were moderate acidic.

### 1.2.2 Percentage of Soil Organic Matter (%OM)

Generally there are two major sources of the soil organic matter in mangrove areas. The first one is autochthonous sources such as phytoplankton, diatoms, bacteria, algae on tree or roots and other plants in mangroves. This category also includes dead organisms and their excreta. The second source of organic detritus is allochthonous sources such as particulates from river runoff, soil particles from coastal and upland erosion, dead plants and animals in coastal zone or the sea (Aksornkoae, 1993). The percentage of organic matter in the study area varied from 4.04 to 19.53% and the average was 6.59%. The percentage of organic matter was found higher in the soils of the areas that were near to river particularly in 6 and 9 years old plantation and lower in areas that were far from the river. Juindanuch (2003) found that the percentage of organic matter in mangrove soils varied from season to season and also varied within soil horizons. Aksornkoae *et al.* (1982) found that the percentage of organic matter of top soil in the mangrove forest near the mining area at Muang, Ranong varied 7.50 to 11.70%. Chunkao *et al.* (1982) found that the percentage of organic matter in soil of the mangrove forest of Khlong Kapoe and Khlong Ngao watersheds in Ranong Province of Gulf of Thailand was 9.00 and 5.00% , respectively. Wechakit (1987) found that the percentage of organic matter in the soils of *the R. apiculata* plantation areas in Yeesarn varied from 4.22 to 19.95% and the average was 10.10%. The present study showed somewhat less amount of organic matter in soils than the previous records and it would be some changes of the hydrology of the area. The other cause might be due to construction of a number of shrimp pond and culvert that trapped the upward floating organic matter.

### 1.2.3 Electrical Conductivity (EC)

The measurement of electrical conductivity has been referred to estimate salt content in soils. Electrical conductivity has a great influence on tidal change, type and constant of soils, distribution of rain, the level of underground water, wind power, plants and soils cover from river runoff and relative with type and percentage of clay, minerals and percentage of organic matter (Jindanuch, 2003). The electrical conductivity in the study area varied from 0.43 to 0.68 S/m and the average was 0.56 S/m. Electrical conductivity was found high in the landward site particularly in 14 and 9 years old plantation and low in the seaward site. It would be due to the differences of sea water drainage systems. The results of electrical conductivity indicated that the salinity level of the study area was medium as EC 0.40 S/m to 0.80 S/m refers medium salinity level. Juindanuch (2003) found that the average electrical conductivity of mangrove soils of Thung Kha estuary in Chumphon Province was higher in dry season than that of rainy season and electrical conductivity varied within soil horizons. He found that the electrical conductivity was higher in C horizon than that of A horizon.

Table 4 Physical and chemical properties of soil in *R. apiculata* plantation areas in Yeesarn of Samut Songkram Province

| Age of plantation (year) | Soil texture | | | | pH | OM (%) | EC (S/m) | P (mg/kg) | K (mg/kg) | Ca (mg/kg) | Mg (mg/kg) | Na (mg/kg) | CEC (cmol/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | %Sand | %Silt | %Clay | Texture | | | | | | | | | |
| 2 | 9 | 30 | 62 | Clay | 6.88 | 4.04 | 0.43 | 34 | 1,100 | 1,233 | 1,509 | 1,585 | 62 |
| 6 | 19 | 28 | 53 | Clay | 5.94 | 10.53 | 0.55 | 43 | 643 | 870 | 1,948 | 3,868 | 59 |
| 9 | 11 | 29 | 60 | Clay | 6.38 | 6.60 | 0.60 | 61 | 717 | 925 | 1,276 | 2,009 | 30 |
| 14 | 13 | 26 | 61 | Clay | 7.51 | 5.19 | 0.68 | 61 | 605 | 1,005 | 1,244 | 2,123 | 42 |
| Mean ± std | 13 ± 4 | 28 ± 2 | 59 ± 4 | Clay | 6.68 ±0.67 | 6.59 ±2.83 | 0.56 ±0.10 | 50 ± 14 | 766 ± 227 | 1,008 ± 160 | 1,494 ± 325 | 2,396 ±1008 | 48 ± 15 |

### 1.2.4 Phosphorus

The amount of available phosphorus of the study area varied from 34 to 61 mg/kg and the average was 50 mg/kg. High content of phosphorus was observed in landward site particularly in 9 and 14 years old plantation while low amount of phosphorus was observed in seaward site. Aksornkoae *et al.* (1982) found the amount of available phosphorus varied from 7 ppm to 27 ppm in the soils of mangrove forest at Had Sai Khao, Ranong Province. Chunkao *et al.* (1982) found the amount of phosphorus in the mangrove soils of Khlong Kapoe and Khlong Ngao watersheds in Ranong Province was 21 ppm and 23 ppm, respectively. Wechakit (1987) found that the amount of available phosphorus in the soils of the *R. apiculata* plantation areas in Yeesarn varied from 36 to 140 ppm and the average was 71.73 ppm. However, the amount of phosphorus in soils of the study area was seen still higher than other mangrove areas.

### 1.2.5 Potassium

The exchangeable potassium in the soils of the study area varied from 643 to 1,100 mg/kg and the average was 766 mg/kg. High content potassium were observed in the soils of 2 and 9 years old plantation and low content potassium found in soils of 6 and 14 years old plantation. Aksornkoae *et al.* (1982) found that the amount of potassium varied from 324 to 495 ppm in the mangrove soils forest near the mining area at Muang, Ranong and 320 to 533 ppm in the natural mangrove soils at Kapur, of the Province. Chunkao *et al.* (1982) found the amount of exchangeable potassium in the mangrove soils of Khlong Kapoe and Khlong Ngao watersheds in Ranong Province was 193 ppm and 400 ppm, respectively. Wechakit (1987) found that the amount of potassium in the soils of *R. apiculata* plantation areas in Yeesarn varied from 750 to 1,285 ppm and the average was 1,013.33 ppm. The present study showed somewhat less amount of potassium in soils than the previous study but rather high amount of potassium content in soils than other mangrove areas.

### 1.2.6 Calcium

The amount of exchangeable calcium in the study area varied from 870 to 1,233 mg/kg and the average was 1,008 mg/kg. The amount of calcium was high in soils of the areas that were far from the river particularly in 2 and 14 years old plantation and low in soils of the area that were closed to the river particularly in 6 and 9 years old plantation. Aksornkoae *et al.* (1982) found that the amount of calcium varied from 84 to 187 ppm in the mangrove soils of mangrove near the mining areas at Muang and 930 to 2,800 ppm in the soils of natural mangrove forest at Kapur of Ranong Province. Chunkao *et al.* (1982) found that the amount of phosphorus in the soils of mangrove forest of Khlong Kapoe and Khlong Ngao watersheds in Ranong Province was 143 ppm and 290 ppm, respectively. Wechakit (1987) found that the amount of calcium in the soils of the *R. apiculata* plantation areas in Yeesarn varied from 580 to 1,730 ppm and the average was 924 ppm. The present result showed that the soils of the study had somewhat less amount of calcium content than natural mangrove forest of Ranong Province.

### 1.2.7 Magnesium

The amounts of exchangeable magnesium in soils of the study area varied from 1,244 to 1,948 mg/kg and the average was 1,494 mg/kg. The exchangeable magnesium was high in the soils of seaward site particularly in 2 and 6 years old plantation and low in the landward site. Aksornkoae *et al.* (1982) found that the amount of exchangeable magnesium varied from 1,250 to 2,900 ppm in the soils of mangrove forest near the mining area at Muang and 1,612 to 1,950 ppm in the natural mangrove soils at Kapur, Ranong. Meepol (2002) found the amounts of magnesium in the soils of downstream and upstream mangrove forests of Khlong Ngao of Ranong Province varied from 972 to 2,728 ppm and 1,174 to 1,919 ppm, respectively. Wechakit (1987) found that the amount of magnesium in the soils of *R. apiculata* plantation areas in Yeesarn varied from 470 to 2,340 ppm and the average was 1,176 ppm. The result showed that the soils of the study area content compatible amount of magnesium than other mangrove areas.

### 1.2.8 Sodium

The amount of exchangeable sodium in the soils of the study area varied from 1,585 to 3,868 mg/kg and the average was 2,390 mg/kg. High amount of Na observed in 6 and 14 years old plantation. The amount of sodium in soils varies from location to location, season to season and also within in the soil horizons (Foth, 1978). Aksornkoae *et al.* (1982) found that the amounts of sodium varied from 1,320 to 3,020 ppm in the soils of mangrove forest near the mining area at Muang and 275 to 533 ppm in the natural mangrove soils at Kapur, Ranong. Chunkao *et al.* (1982) found that the amount of sodium in the mangrove soils of Khlong Kapoe and Khlong Ngao watersheds in Ranong Province was 3,148 ppm and 2075 ppm, respectively. Meepol (2002) found the amount of sodium in the soils of downstream and upstream mangrove forests of Khlong Ngao of Ranong Province varied from 0.5 to1.64% and 0.63 to 1.21%, respectively. Wechakit (1987) found that the amount of sodium in the soils of *R. apiculata* plantation areas in Yeesarn varied from 0.21 to 1.00% and the average was 0.51%. However, the result showed that the amount of sodium content in soils of the study was somewhat higher than the natural mangrove forests of Ranong Province.

### 1.2.9 Cation Exchange Capacity (CEC)

Clay and humus are of utmost importance in soils because they are in a colloidal state and they expose a relatively large amount of surface area for adsorption of water and ions. The adsorption of a cation by a colloidal nucleus or micelle and the accompanying release of one or more ions are held by the micelle in termed cation exchange (Foth, 1978). The values of CEC varied from 30 to 62 cmol/kg and the average was 48 cmol/kg. CEC was observed high in seaward site particularly in 2 and 6 years old plantation and low in landward site particularly in 9 and 14 years old plantation. Juindanuch (2003) stated that the CEC in soils varied from season to season and also varied within soil horizons. He also found that the CEC was highest in soils of the reforestation mangrove areas of Thung Kha estuaries of Chumphon Province which was about 23.69 to 29.78 me/100gm soils while in natural mangrove and *Rhizophora* mangrove plantation CEC varied about 8.85 to 12.16 me/100gm soils and 2.72 to 10.29 me/100gm soils, respectively. Aksornkoae *et al.* (1982) found CEC varied from 7.50 to 11.70 me/100gm soils in mangrove forest soils near the mining area at Muang and 11.80 to 30.30 me/100gm soils in the natural mangrove soils at Kapur, Ranong. Meepol (2002) found that CEC in the soils of downstream and upstream mangrove forests of Khlong Ngao of Ranong Province varied from 6.80 to 29.60 cmol/kg and 14.10 to 20.80 cmol/kg , respectively. However, the result showed that the soils of the study area having more cation exchange capacity than other mangrove area.

Mangrove soils are subject to the flooding of sea water and are always saturated with sea water. Therefore, the physical and chemical properties of soils depend upon the chemistry of sea water, oxygen supply and duration of soil aeration. There is a great reduction in oxygen diffusion when soil is flooded. Hence, oxygen supply to the soil is affected by the depth of flooding and amount of time the soils remain flooded. When soils become increasingly anaerobic, very drastic and significant chemical changes are expected such as the reduction of sulphate to sulphide and the production of methane utilizing carbon and ‘excess’ hydrogen (Boto, 1982). Under normal environment, the soils are saline and alkaline but contain high amounts of sulphur derived from sea water and decomposition of organic materials. When soils are dry, sulphuric acid develops and causes strong soil acidity. Soils become hard and not suitable for mangrove growth. The results of the present study showed that almost all the physical and chemical properties of soils in Yeesarn had degraded based on the previous study conducted by Wechakit (1987). Hence, mangrove soils must be maintained under natural environment.

## 2. Plantation Management

### 2.1 Silvicultural system

Silvicultural system applied for *R. apiculata* plantation in Yeesarn was a Clear-felling System. It was observed that the cutting rotation varied from 8 to 15 years depended on accordance with the end-use products of planted trees and the financial return needed by the plantation owner. Local plantation farmers reported that the main objectives of *R. apiculata* plantation in Yeesarn were for the production of charcoal (98%) and poles (2%).

Aksornkoae (1996) sated that the cutting rotation was set at 15 years for *Rhizophora* sp. (*R. apiculata* and *R. mucronata*) plantation used for charcoal making in Pattani Province. Kongsangchai *et al.* (1990) recorded that the cutting rotation of *Rhizophora* sp. in Trang, Nakorn Si Thammarat, Pattani and Krabi Provinces varied from 6 to 20 years. Aksornkoae (1993) found that the cutting rotation was fixed as 4 years in mixed mangrove forest mainly *C. tagal* and *Bruguiera* sp. plantations used for stakes of mussel culture and firewood at Chumporn Province. Thinning practice for *Rhizophora* plantation was not reported in Thailand (Aksornkoae, 1993).

In the Matang mangrove forest of Malaysia, the main objective of the forest was to maximize sustained yield of wood, particularly for charcoal production with a felling cycle of 30 years. The silviculture system was clear felling with retention of 7 stands per ha for regeneration. In place where natural regeneration was poor, supplementary plantation was done with *R. apiculata* and *R. mucronata* and three stick thinning was undertaken (Siddiqi, 2001). Silvicultural system of *R. apiculata* plantation in Can Gio District of Southern Vietnam was two-stage selective felling system with two thinning and the rotation was set at 14 years (Nam *et al.,* 1993).

## 2.2 Establishment of Plantation

It was observed that the silvicultural practices applied for management of *R. apiculata* private mangrove plantation were developed by themselves with their own experiences. The activities were as follows:

### 2.2.1 Site preparation

In Yeesarn, very little efforts were needed for site preparation before planting. The residues and intensive removal leave of the previous felling were left in the area. In some cases, if felling had left excessive slash, this was sometimes chopped and heaped in rows at right angles to the waterway or burned. Exploitable slash were observed to collect from the felling areas and gathered near the waterway and carried by boat. Most of the cases, if the plantation was more than 12 year old the plantation owner allowed some interest groups to collect the slash and uproot the remaining part of the stands after feeling. During site preparation it was observed that slashes were not clearly removed from the planting area. It is assumed that such small slash might be provided partial shade in primary stage of the new planted propagules for development and subsequently it might be provided nutrients by decomposed. In areas where *Acanthus ilicifolius, Acrostichum aureum, A. speciosum* and *Pluchea indica* were abundant, weeding and cleaning were necessary before planting. In areas above the normal tide level, small canals (2-3 m wide, 50 to 500 m long and 0.75 to 1.50 m depth) were dug to facilitate sea water flooding over the plantation area.

Aksornkoae (1975) stated that muddy areas with frequent tides along the coastline or river banks were the most suitable sites for *Rhizophora* planting and under this condition, the planting of *Rhizophora* were quite successful. Chan (1990) stated that in Can Gio District of Southern Vietnam, areas in open swampy wastelands site preparation prior to planting was not necessary whereas in areas with scattered shrubs and bushes, site preparation prior to planting was carried out by cleaning and heaping in rows. But in degraded interior and elevated forests of predominantly *A. aureum* and mixed stands of species of less economic value occurred, heavy cleaning was necessary and required 24 man days per ha (Nam *et al.,* 1993).

### 2.2.2 Source of planting material

The fruiting season of *R. apiculata* in Yeesarn was from July to September. Mature propagules were pale green in color with distinctive reddish abscission collar between the fruit and hypocotyls. The length of propagules (hypocotyls together with cotyledon) was about 25 to 35 cm. In Yeesarn, the farmers never established nursery for *R. apiculata* seedlings. Local people collect the propagules directly from the trees, the plantation floor and those floating in the river. Generally, propagules were collected one month before planting. The propagules were stored under a shed and kept in a horizontal position, covered with *Nypa* leaves to prevent excessive loss of moisture. They were watered daily in the morning or afternoon by sea water. The storage sites were constructed both at the plantation sites and in areas adjacent to their houses. The propagules were usually sold to the plantation owners at low price only 0.10 baht per propagules. In many cases, it was observed that the plantation owners had kept some mother trees in suitable locations particularly near their houses, or near water ways for the source of propagules. The plantation owners reported that the source of good quality propagules for planting became scarce due to destruction of natural habitat and mother trees. Propagules were transported to the planting sites by boat. Planting local propagules at the planting site is the right way at least it cans presence local genetic materials that can survive well under changeable environment.

Aksornkoae (1996) suggested that propagules of *R. apiculata* to be used for planting were mainly collected locally in order to ensure survival and adaptation of young plants to the planting sites and also to reduce the seed damage due to transport. Phapavasit *et al.* (1997) stated that *R. apiculata* seedlings raise through poly-bag containers in nursery were practiced in Klong Khone village of Muang district located about 20 km northeast of Yeesarn Sub-district. In nursery, propagules were directly sown in black plastic bags in a vertical position to about one quarter to one-third of the total length of the propagules. Seedlings were watered daily with sea water. The seedlings were usually used in enrichment plantation for conservation purposes. Hong (1994) stated that in Can Gio mangrove forests of Southern Vietnam where two hundred ha of matured mangrove plantation mainly *R. apiculata* plantation were selected as a specialized source of propagules and the experience showed that it gave the best performance with healthy and straight stem trees. However, there is too little improvement program in the mangrove forest in Yeesarn.

### 2.2.3 Spacing and Planting Techniques

Planting was carried out after site preparation. Usually farmers planted approximately 25,000 propagules per ha with a spacing of about 0.6 × 0.6 m. Mono-species with direct showing of *R. apiculata* propagules was only the planting technique in Yeesarn. Planting was carried out from July to September while August was observed the peak month for planting. The farmers preferred to plant of *R. apiculata* propagules in a dazzling and cloudy day. No pit was needed to be excavated before planting. While planting, each labor was carried a small bundle of propagules and at every step they stick one propagule about one-third of the total length of propagule in a vertical position into the soft mud. Due to mortality of a considerable numbers of propagules, replanting was done within 6 months after establishment planting.

Wechakit (1987) found the average distance between new planted seedlings in Yeesarn was about 0.63 × 0.63 m. The present study showed the similar pattern of new planted seedlings density and the reason seemed to behind that the plantation farmers would like to make ensure sufficient number of stands per unit of area. Aksornkoae (1975) conducted a comparative study on productivity and mortality of *Rhizophora* seedlings planted with different spacing and found that *Rhizophora* planted at 1 × 1 m and 1.5 × 1.5 m show the highest productivity and lowest rate of mortality. He also stated that in Tung-ka village of Chumporn Province, where *C. tagal* plant with a spacing of only 0.5 × 0.5 m. Hong (1994) found that there were three types of planting techniques (i.e. direct showing, transplanting nursery-raised seedlings and transplanting wildings) applied for *R. apiculata* in Can Gio District of Vietnam. The planting operation was usually carried out between August and November with approximately spacing of 1 × 1 m or 10,000 seedlings per ha. and 1.5 × 1.5 m spacing had been recommended for fuel-wood and charcoal production.

### 2.2.4 Maintenance

It was observed that weeding was necessary for *R. apiculata* plantations in Yeesarn. Normally, in the second year weeding and 2$^{nd}$ beating-up (vacancy filling) was done simultaneously. Areas in comparatively higher elevation and inundated only all medium to medium high tide, in these areas the plantation needed two weeding, the first one in the second year and the second one in the third year. After planting, *A. ilicifolius, Acrostichum aureum, A. speciosum* and *Derris trifoliata* may grow. Thinning was never carried out in *R. apiculata* plantation in Yeesarn. It would be involved high labor costs due to the difficulties of moving in the deep muddy soil, thickly interwoven with prop roots of the *R. apiculata* stands. However, many dead trees were observed in the plantations area and exploitable dead trees were collected from the plantations for using either as firewood for charcoal kiln or as raw materials for charcoal making. No pruning was observed in the plantation because natural pruning and thinning occurred in the plantations due to planting of high numbers of propagules per unit of area.

Aksornkoae *et al.* (1992) stated that weeding was rarely carried out, not even in the first year but in some plantations in the second year. He also quoted the example from Yeesarn where 18 man days were required for weeding in the second year. Wechakit (1987) stated that thinning was not applied in the *R. apiculata* plantation in Yeesarn. Aksornkoae *et al.* (1989) recommended that the first thinning should be applied for 1 × 1 m planting space of *R. apiculata* plantation after approximately 5 to 6 years where the rotation was set at 15 years. In Can Gio District of Southern Vietnam, two thinning and pruning operations were carried out in 14 years rotation of *R. apiculata* plantations where the first and second thinning were practiced between the year 6 to 7 and 9 to 10 , respectively. A third thinning was recommended between the year 14 and 15 in case of 20 years rotation (Nam *et al.,* 1993).

### 2.2.5 Pests and Diseases

Pests and diseases were not to be a serious problem for *R. apiculata* plantations in Yeesarn. Some crab like *Sesarma taeniolata* destroyed young seedlings by eating the bark above the collar. Barnacles attacked the seedlings in places where the sea water drainage was not quite well. The plantation owner reported that monkeys sometime damage the new plantation by uprooting the seedlings and by eating the new leaves.

Aksornkoae (1993) observed that pest and diseases in mangrove plantation were not as serious as compared to inland forest plantations. Chaiglom (1982) reported that foliage eating larvae (*Cleora injectaria*) and the seed borer (*Poecilips fallax*) were found in mangrove plantations in Samut Songkhram Province where large areas of *R. apiculata* plantations of 2 to 3 years age were attacked by *Cleora injectaria* and *Poecilips fallax* in larvae and adult stages, tunneled into and fed on the hypocotyls. Aksornkoae (1993) stated that the seed borer infested large numbers of planted seedlings of *R. apiculata* and *R. mucronata* in some mangrove plantation in Thailand. He found that various types of marine organisms such as barnacles, oyster, *Uca* and *Sesarma* crabs were damage the *Rhizophora* seedlings. He pointed that infestation was generally occurred in the muddy substrate of the plantation. Mangrove planted on elevated areas which were not frequently flooded by sea water was affected by *Thalassina anomala* which made a large number of mounds and caused changed in soil. The mangrove seedlings were therefore killed or their growth was retarded (Aksornkoae, 1993). Such type of phenomenon was observed in some plantations in Yeesarn mostly near the roadside where areas were filled by soil resulted from road construction activities.

## 2.3 Stands Density and Survival Rate

The stands densities of 1 to 15 years old *R. apiculata* plantation varied between 23,600 and 8,700/ha , respectively (Table 5). During the age of 1 to 5 year the stands density was high. Though the initial numbers of planted seedlings was high but after planting considerable number of seedlings of *R. apiculata* died. At the age of 2$^{nd}$ year the stands density decreased to 21,100/ha due to high mortality of the new planted propagules. In the 3$^{rd}$ and 4$^{th}$ year the stand density increased than the previous year due to vacancy filling and coppice of the stands. During the age of 6 to 10 years, the stands density varied between 20,700 and 15,300/ha. At the age of 11 to 15 the stands density again decreased from 13,600 to 8,700/ha. The study showed that during the age of 1 to 5 years the stands density was high. At the age 6 to 15 years, the stand density of the plantations gradually decreased because increased mortality of the stands (Figure 9).

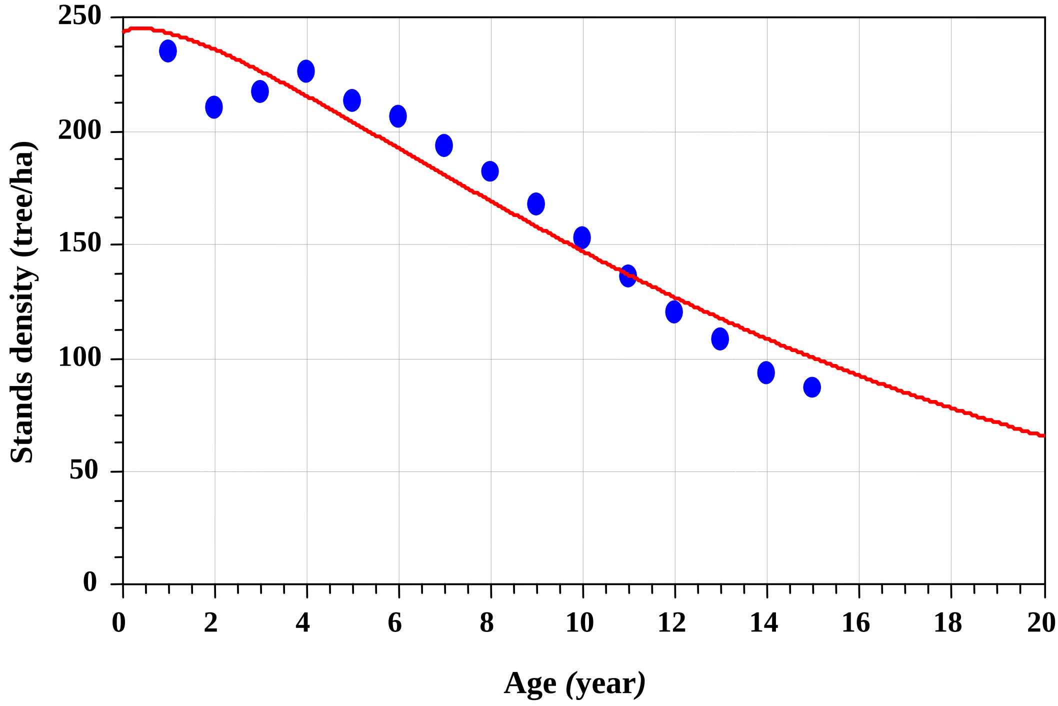


Figure 9  Stands density of different age of *R. apiculata* plantation.

Based on the initial planting of 25,000 propagules/ha the survival rate of 1 years old *R. apiculata* plantation was 94.4% (Table 5). During the age of 1 to 5 year the survival rate was high and the average survival rate was 88.48%. At the age of 2$^{nd}$ year the survival rate decreased at 84.4% due to high mortality of the new planted propagules. In the 3$^{rd}$ and 4$^{th}$ year the survival rates increased than the previous year due to vacancy filling and coppice of the stands. During the age of 6 to 10 years, the survival rate varied between 82.8% and 62.2% and the average was 72.52%. At the age of 11 to 15 the survival rate again decreased from 54.4% to 34.8% and reached almost about one-third in stand number considering the number of the 1$^{st}$ planting. The survival rate decreased with increasing age of the plantation because of high density of stands generated competition among them for light and nutrients (Macnae, 1968; Du, 1972). The other causes of death of the stands were imperfect seeds or propagules and the effects of crabs and barnacles.

Wechakit (1987) observed that the survival rate of 1 to 15 years of *R. apiculata* plantations in Yeesarn varied between 95.2 and 41.2% , respectively. He stated that at the age of 4$^{th}$ year the density somewhat increased than the previous year due to coppice of the stands. The present study showed similar coppice phenomenon in the early age of the plantation with the previous study but lower stand density in the plantations than the previous study. It would be due to high mortality of the stands in different age of the plantations.

## 3. Growth and Productivity

This investigation examined the above-ground biomass and volume of wood as one step in assessing the net primary productivity of *R. apiculata* plantations in Yeesarn. A summary of average values of 15 different age groups of *R. apiculata* plantation is shown in Table 5.The CAI (Current Annual Increment) of Do (ground level diameter), DBH, height, above-ground biomass, commercial volume and total volume of the different ages of *R. apiculata* plantation are given in Table 6.

### 3.1 Diameter

The average ground level diameter of *R. apiculata* plantations of 1 and 2 years old was 1.73 cm and 2.91 cm , respectively. The CAI of ground level diameter of 2 years old plantation was about 1.45 cm/yr. The average DBH was of 3 to 15 years *R. apiculata* plantations varied between 1.16 and 6.54 cm , respectively and the CAI of diameter of the plantations varied from 0.38 to 0.46 cm/yr. During the age of 3 to 5 years the diameter increased 1.16 to 2.23 cm and the average growth was about 0.43 cm/yr. At the age of 6 to 10 the diameter increased 2.46 to 4.36 cm and the average growth was 0.41 cm/yr while in the year 11 to 15 the height increased 4.87 to 6.54 cm with an average growth of about 0.45 cm/yr. The CAI of diameter was highest in 12 and 14 years old plantations as 0.46 cm/yr while the lowest was in 3 years old plantation (0.39 cm/yr). The trend of increase of diameter showed that during the year 3 to 5 it was gradually increased and from year 6 to 10 the growth rate fluctuated where in 6 years the growth rate fall down and then again in year 7 to 9 the growth rate gradually increased and finally 11 to 15 years the growth rate remained more or less same with exception of the year 12 and 14 which had somewhat higher rate of diameter increment in compared to other age year plantations (Figure 10).

Tanapermpool (1989) found that the average diameter of 5 to 20 years old *R. apiculata* plantations in Pattani Province varied from 2.64 to 9.70 cm and diameter of the 15 years old plantation was 6.48 cm. The CAI of diameter was greatest in a 17 year old stand (1.30 cm/yr) and the lowest in a 13 year old stand (0.01 cm/yr). The average diameter increment was approximately 0.47 cm/yr. Kongsangchai *et al.* (1990) found that the average diameter of 6 to 11 years old *Rhizophora* plantations in Nakorn Sri Thammarat Province were about 4.28 to 6.49 cm and the average diameter increment of the plantations was about 0.44 cm/yr while in Trang Province, the average diameter of 9 to 14 years old *Rhizophora* plantation was about 5.7 to 10.6 cm and the average height increment was approximately 0.98 cm/yr. In Krabi Province, they found that, the diameter of 9 to 11 years old *Rhizophora* plantations was about 7.25 to 8.67 cm and the average diameter increment was approximately 0.71 cm/yr. Chanprapai (2005) found that annual diameter increment of 2 to 30 years old *R. apiculata* plantations in Yaring District of Pattani Province varied from 0.21 to 50 cm/yr and the highest increment rate were in 14 and 15 year old plantation (50 cm/yr). Wechakit (1987) found that the diameter of 3 to 15 years old *R. apiculata* plantations in Yeesarn were 0.94 and 6.26 cm , respectively. The present study showed more or less similar diameter increment pattern to the previous studies on *Rhizophora* plantations at Pattani, Nakorn Sri Thammarat and Samut Songkram Province.

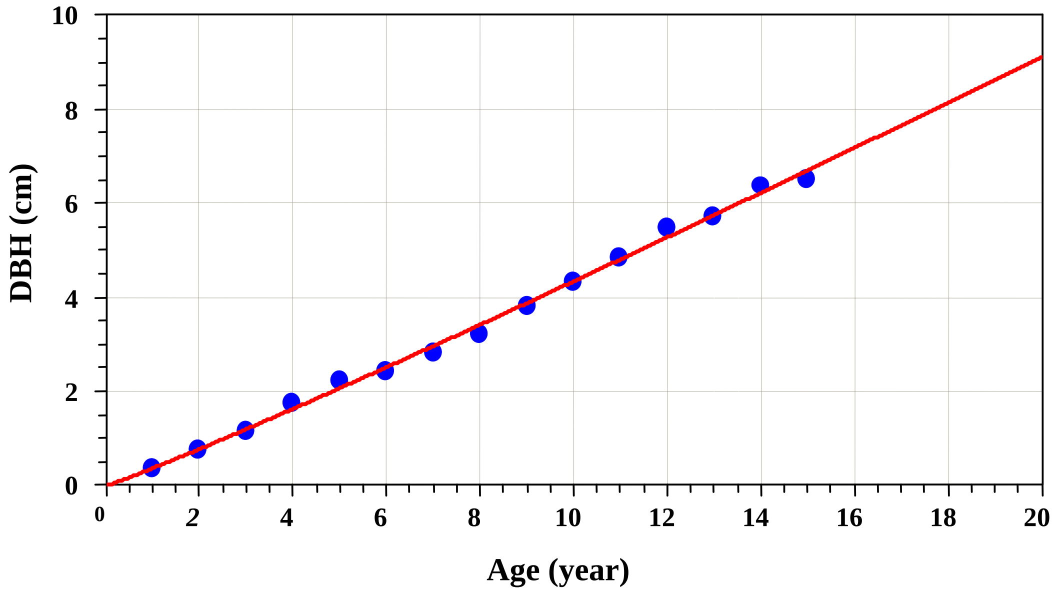


Figure 10 Trend of diameter increment of 1 to 15 years old *R. apiculata* stand.

**3.2 Height**

The average height of 1 to 15 years *R. apiculata* plantations varied between 0.51 and 11.49 m , respectively and the CAI of height of 2 to15 years varied between 0.64 to 0.82 m/yr. During the age of 1 to 5 years the height increased 0.51 to 3.78 m and the average growth was about 0.64 m/yr. At the age of 6 to 10 the height increased 4.51 to 7.93 m and the average growth was 0.75 m/yr while in the year 11 to 15 the height increased 8.74 to 11.49 m with an average growth of about 0.8 m/yr. The CAI of height was higher in the plantations of 10 to 14 years and the peak was in the 12 years old plantation as 0.82 m/yr. The trend of increase of height showed that during the age of 1 to 5 years the growth rate was slow. At the age of 6 to 10 years the rate somewhat increased and during 11 to 15 years the growth rate fluctuated with little variation (Figure 11).

Tanapermpoo1 (1989) found that the average height of 5 to 20 years old plantations of *R. apiculata* in Pattani Province varied from 3.56 to 14.23 m and the average height increment of the plantations was approximately 0.71 m/yr. He found that the height of 15 years old plantation was 10.82m. Kongsangchai *et al.* (1990) found that the average height of 6 to 11 years old *Rhizophora* plantations in Nakorn Sri Thammarat Province were about 7.73 to 9.76 m and the average height increment of the plantations was 0.41 m/yr while in Trang Province, the average height of 9 to 14 years old *Rhizophora* plantation were about 9.2 to 13.8 m and the average height increment was approximately 0.92 m/yr. In Krabi Province, they found that, the height of 9 to 11 years old *Rhizophora* plantations were about 11.76 to 13.20 m and the average height increment was approximately 1.25 m/yr. Chanprapai (2005) found that the height of 1 to 30 years old *R. apiculata* plantations in Yaring District of

Pattani Province varied from 0.96 to 12.82 m and the annual height increase of the plantations varied from 0.01 to 0.99 m/yr. He found that the height of 15 years old plantation was 11.03 m. Wechakit (1987) found that the height of 1 to 15 years old *R. apiculata* plantations in Yeesarn varied 0.45 to 12.36 m. The present study showed similar height increment pattern to the previous studies.

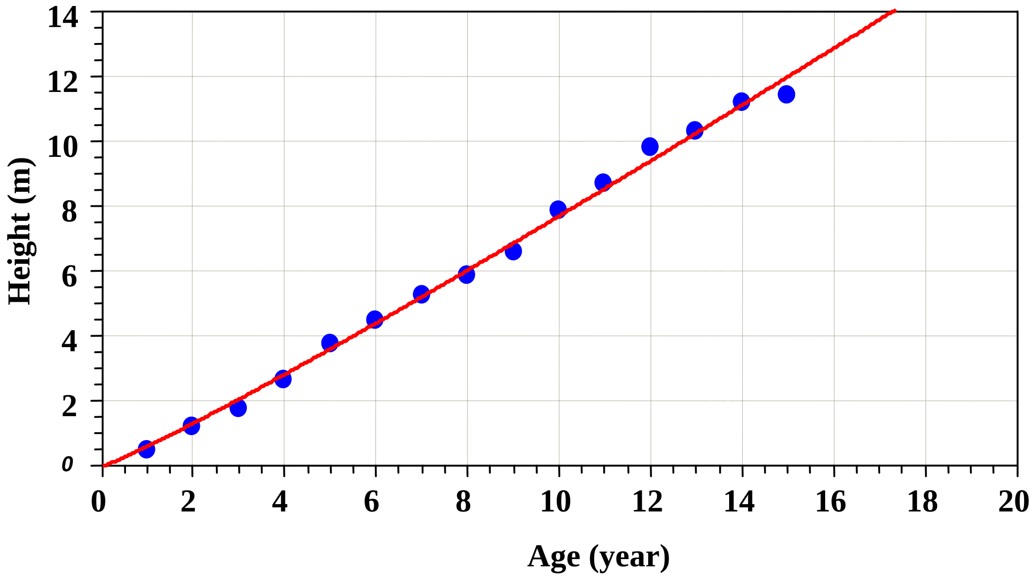


Figure 11  Trend of height increment of 1 to 15 years old *R. apiculata* stand.

### 3.3 Stem Biomass

Stem biomass production of 1 to 15 years old *R. apiculata* plantations varied between 0.30 and 159.11 tons/ha and the highest production observed in a14 year old plantation. The CAI of stem biomass production of 2 to 15 years old plantations varied from 0.44 to 12.08 tons/ha/yr. Highest stem biomass production increment observed in 12 years old plantation and lowest was in 2 years plantation. During the age of 1 to 5 years the production of stem biomass increased 0.30 to 27.92 tons/ha and the average increment was about 2.42 tons/ha/yr. At the age of 6 to 10 the stem biomass production increased 35.57 to 106.57 tons/ha and the average increment was 8.09 tons/ha/yr.

Table 5 Growth and yield at different ages of *R. apiculata* plantations in Yeesarn of Samut Songkram Province

| Age / Year | Stand density (tree/ha) | **Survival rate (%) | Diameter (cm) | Height (m) | Above-ground biomass (ton/ha) | | | | | Commercial volume ($m^3$) | Total volume ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Stem | Branch | Leaf | Prop root | Total | | |
| 1 | 23,600 | 94.4 | 1.73* | 0.51 | 0.30 | 0.19 | 0.28 | - | 0.77 | - | 0.72 |
| 2 | 21,100 | 84.4 | 2.91* | 1.27 | 0.87 | 0.45 | 0.93 | 0.31 | 2.56 | - | 1.82 |
| 3 | 21,800 | 87.2 | 1.16 | 1.83 | 5.76 | 3.39 | 2.86 | 1.76 | 13.77 | - | 4.06 |
| 4 | 22.700 | 90.8 | 1.78 | 2.69 | 15.35 | 6.38 | 4.80 | 3.67 | 30.20 | 4.73 | 11.92 |
| 5 | 21,400 | 85.6 | 2.23 | 3.78 | 27.92 | 8.84 | 6.14 | 5.50 | 48.40 | 17.69 | 23.57 |
| 6 | 20,700 | 82.8 | 2.46 | 4.51 | 35.57 | 10.11 | 6.78 | 6.50 | 58.96 | 27.85 | 30.98 |
| 7 | 19,400 | 77.6 | 2.84 | 5.28 | 48.52 | 11.77 | 7.53 | 7.91 | 75.73 | 41.59 | 44.36 |
| 8 | 18,200 | 72.8 | 3.25 | 5.94 | 62.70 | 13.52 | 8.33 | 9.41 | 93.96 | 57.44 | 59.32 |
| 9 | 16,800 | 67.2 | 3.83 | 6.65 | 82.00 | 15.45 | 9.13 | 11.19 | 117.77 | 78.50 | 80.74 |
| 10 | 15,300 | 62.2 | 4.36 | 7.93 | 106.57 | 17.38 | 9.83 | 13.12 | 146.90 | 107.04 | 109.63 |
| 11 | 13,600 | 54.4 | 4.87 | 8.74 | 121.17 | 18.00 | 9.88 | 13.96 | 163.01 | 125.29 | 128.00 |
| 12 | 12,100 | 48.4 | 5.48 | 9.87 | 144.91 | 19.07 | 10.09 | 15.32 | 189.39 | 156.00 | 158.80 |
| 13 | 10,900 | 43.6 | 5.72 | 10.38 | 147.40 | 18.37 | 9.58 | 14.98 | 190.33 | 161.81 | 164.43 |
| 14 | 9,400 | 37.6 | 6.38 | 11.27 | 159.11 | 18.29 | 9.27 | 15.28 | 201.95 | 178.98 | 181.49 |
| 15 | 8,700 | 34.8 | 6.54 | 11.49 | 155.36 | 17.50 | 8.81 | 14.71 | 196.38 | 175.84 | 178.20 |

Note: * Measurement was taken at ground level (Do) of the stands instead of diameter at breast height (DBH).
**Survival rate was estimated based on initial planting of 25,000 seedlings/ha.

Table 6  Current annual increment of diameter, height, above-ground biomass production and volume of wood of *R. apiculata* plantations of different ages in Yeesarn of Samut Songkram Province

| Age (year) | CAI of diameter (cm/yr) | CAI of height (m/yr) | CAI of above ground biomass (ton/ha/yr) | | | | | CAI of commercial volume ($m^3$/ha/yr) | CAI of total volume ($m^3$/ha/yr) |
|---|---|---|---|---|---|---|---|---|---|
| | | | Stem | Branch | Leaf | Prop root | Total | | |
| 1 | 1.73* | 0.51 | 0.30 | 0.19 | 0.28 | - | 0.77 | - | 0.72 |
| 2 | 1.45* | 0.64 | 0.44 | 0.23 | 0.47 | 0.16 | 1.28 | - | 0.91 |
| 3 | 0.39 | 0.61 | 1.92 | 1.13 | 0.95 | 0.59 | 4.59 | - | 1.35 |
| 4 | 0.44 | 0.67 | 3.84 | 1.60 | 1.20 | 0.92 | 7.55 | 1.18 | 2.98 |
| 5 | 0.45 | 0.76 | 5.58 | 1.77 | 1.23 | 1.10 | 9.68 | 3.54 | 4.71 |
| 6 | 0.38 | 0.75 | 5.93 | 1.69 | 1.13 | 1.08 | 9.83 | 4.64 | 5.16 |
| 7 | 0.40 | 0.75 | 6.93 | 1.68 | 1.13 | 1.13 | 10.82 | 5.94 | 6.33 |
| 8 | 0.41 | 0.74 | 7.83 | 1.69 | 1.04 | 1.18 | 11.75 | 7.18 | 7.41 |
| 9 | 0.43 | 0.74 | 9.11 | 1.72 | 1.01 | 1.24 | 13.08 | 8.72 | 8.97 |
| 10 | 0.44 | 0.79 | 10.65 | 1.73 | 0.98 | 1.31 | 14.69 | 10.70 | 10.96 |
| 11 | 0.44 | 0.79 | 11.02 | 1.64 | 0.90 | 1.27 | 14.82 | 11.39 | 11.64 |
| 12 | 0.46 | 0.82 | 12.08 | 1.59 | 0.84 | 1.28 | 15.78 | 13.00 | 13.23 |
| 13 | 0.44 | 0.80 | 11.34 | 1.41 | 0.74 | 1.15 | 14.64 | 12.45 | 12.65 |
| 14 | 0.46 | 0.80 | 11.37 | 1.30 | 0.66 | 1.09 | 14.43 | 12.78 | 12.96 |
| 15 | 0.44 | 0.77 | 10.36 | 1.17 | 0.59 | 0.98 | 13.09 | 11.72 | 11.88 |

Note: * Ground level diameter increment of 1 and 2 year old stands.

During the year 11 to 15 the stem biomass production increased from 121.17 to 159.11 tons/ha with an average increment was about 11.23 tons/ha/yr. The trend of stem biomass production showed that initially the production rate was very slow and from 6 to 10 years the production rate gradually increased and the years 11 to 12 the production rate was slowly increased and but in the year 13 to 15 the production rate slowly decreased in comparison to previous year (Figure 12).

Tanapermpool (1989) found that stem biomass production of 5 to 20 years old *R. apiculata* plantations in Pattani Province varied from 22.81 to 234.30 tons/ha and the increment was greatest in a 14 years old plantation (20.92 tons/ha/yr). Kongsangchai *et al.* (1990) estimated that the stem biomass production of 6 to 11 years *Rhizophora* plantations in Nakorn Sri Thammarat Province varied from 50.54 to 119.06 tons/ha and the average stem biomass increment was approximately 13.70 tons/ha/yr while the stem biomass production of 9 to 14 years *Rhizophora* plantations in Trang Province varied from 93.59 to 174.71 tons/ha and the average stem biomass increment was approximately 16.22 tons/ha/yr. In Krabi Province, they found that, the stem biomass production of 9 to 11 years old *Rhizophora* plantations were about 148.76 to 168.33 tons/ha and the average increment was approximately 9.78 tons/ha/yr. Wechakit (1987) found that the stem biomass production of 1 to 15 years old *R. apiculata* plantations in Yeesarn of Samut Songkram Province varied 0.25 to 199.58 tons/ha and the highest amount was found in 14 years old plantation. The present study showed somewhat less stem biomass production than the previous study in Yeesarn due to degradation of site quality but the production rate was quite similar to the studies on *Rhizophora* plantations at Krabi Province.

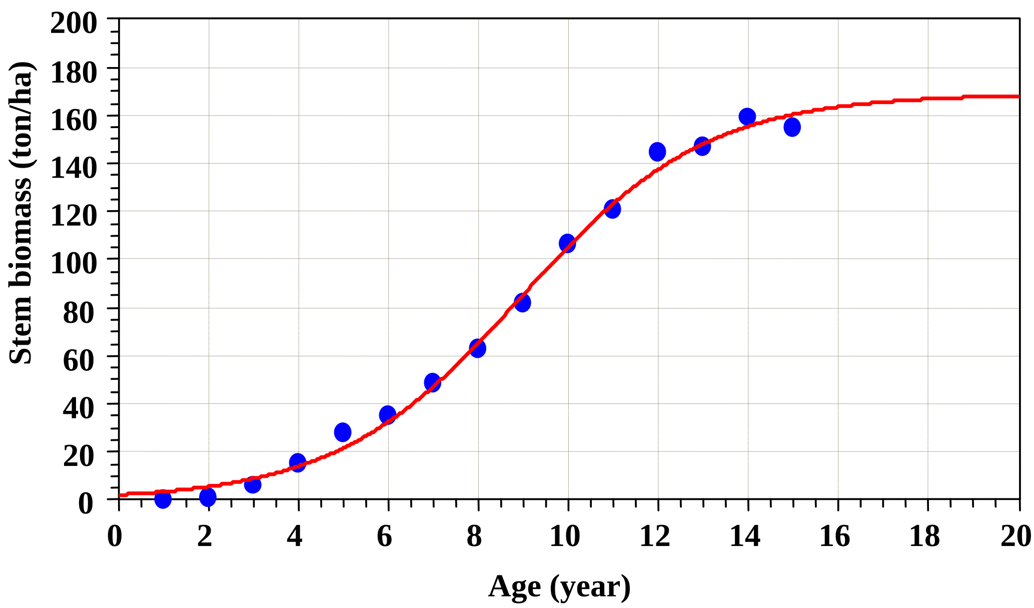


Figure 12 Trend of stem biomass increment of 1 to 15 years old *R. apiculata* stand.

### 3.4 Branch Biomass

Branch biomass production of 1 to 15 years old *R. apiculata* plantations varied from 0.19 to 19.07 tons/ha. Highest branch biomass production observed in the 12 years old plantation. The CAI of branch biomass of 2 to 15 years old *R. apiculata* plantations varied from 1.13 to1.77 tons/ha/yr and the highest increment rate was found in a 5 years old plantation. During the age of 1 to 5 years the production of branch biomass increased 0.19 to 8.84 tons/ha and the average increment was 0.98 tons/ha//yr. At the age of 6 to 10 the branch biomass production increased 10.11 to 17.38 tons/ha and the average increment was 1.70 tons/ha/yr while in the year 11 to 15 the branch biomass production fluctuated 19.07 to 17.50 tons/ha with an average increment was about 1.42 tons/ha/yr. The trend of branch biomass production showed that initially the growth rate was high particularly in 3 to 5 years. But during the age of 6 to 10 years the production rate was too closed among the ages and production rate gradually increased while at the age of 11 to 15 years the production rate gradually decreased (Figure 13).

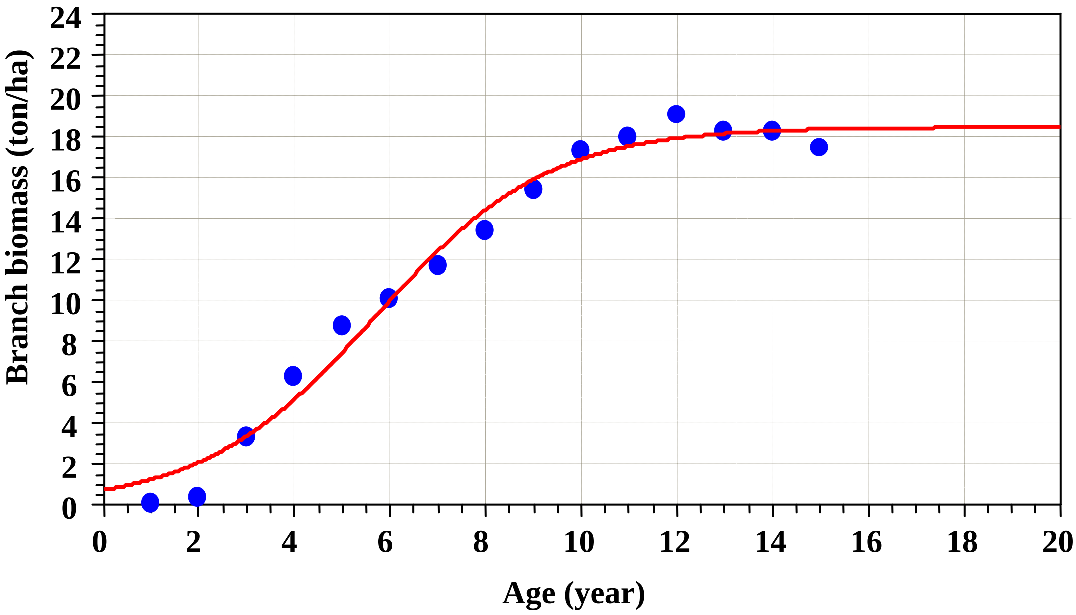


Figure 13 Trend of branch biomass increment of 1 to 15 years old *R. apiculata* stand.

Tanapermpool (1989) found that branch biomass production of 5 to 20 years old *R. apiculata* plantations in Pattani Province varied from 3.02 to 21.79 tons/ha. Kongsangchai *et al.* (1990) estimated that the branch biomass production of 6 to 11 years *Rhizophora* plantations in Nakorn Sri Thammarat Province varied from 13.31 to 27.84 tons/ha and the average increment was 2.91 tons/ha/yr while in Trang Province, the branch biomass production of 9 to 14 years old *Rhizophora* plantations varied from 27.92 to 54.74 tons/ha and the average branch biomass production increment was approximately 5.36 tons/ha/yr. In Krabi Province, they found that, the branch biomass production of 9 to 11 years old *Rhizophora* plantations were about 34.21 to 37.47 tons/ha and the average increment was approximately 1.53 tons/ha/yr. Wechakit (1987) found that the branch biomass production of 1 to 15 years old *R. apiculata* plantations in Yeesarn varied between 0.16 and 20.74 tons/ha and the highest amount estimated as 21.99 tons/ha in a 14 year old plantation. The present study showed more or less same branch biomass production pattern with the previous study at Yeesarn and also the other studies on *Rhizophora* plantations at Pattani, Nakorn Sri Thammarat, and Krabi Province.

### 3.5 Leaf Biomass

Leaf biomass production of 1 to 15 years plantation varied between 0.28 and 10.09 tons/ha and the highest production observed in 12 years old plantation. The CAI of leaf biomass of 2 to 15 years old plantation varied from 0.47 to 1.23 tons/ha/yr and the highest CAI of leaf biomass production observed in a 5 years old plantation and the lowest was in a 2 year old plantation. During the age of 1 to 5 years the production of leaf biomass gradually increased from 0.28 to 6.14 tons/ha and the average increment was about 0.83 tons/ha//yr. At the age of 6 to 10 the leaf biomass production also gradually increased from 6.78 to 9.83 tons/ha and the average increment was about 1.06 tons/ha/yr while in the year 11 to 15 the leaf biomass production fluctuated 8.81 to 10.09 tons/ha with an average increment was about 0.75 tons/ha/yr. The trend of leaf biomass production showed that from 1 to 5 years the growth rate gradually increased and during the age of 6 to 10 the growth rate was somewhat less than the previous year but remained more or less same while at the age of 11 to 15 years the growth rate was gradually decreased. (Figure14).

Tanapermpool (1989) found that leaf biomass production of 5 to 20 years old *R. apiculata* plantations in Pattani Province varied from 1.82 to 11.89 tons/ha. Kongsangchai *et al.* (1990) estimated that the leaf biomass production of 6 to 11 years *Rhizophora* plantations in Nakorn Sri Thammarat Province varied from 6.29 to 10.56 tons/ha and the average leaf biomass increment was approximately 0.85 tons/ha/yr while in Trang Province, the leaf biomass production of 9 to 14 years old *Rhizophora* plantations varied from 2.98 to 5.16 tons/ha and the average leaf biomass increment was about 0.44 tons/ha/yr. In Krabi Province, they found that, the leaf biomass production of 9 to 11 years old plantation varied from 12.80 to 14.06 tons/ha and the and the average leaf biomass increment was approximately 0.75 tons/ha/yr where the production was highest in 11 years old plantation and the increment was highest in 9 years old plantation (1.48 tons/ha/yr). Wechakit (1987) found that the leaf biomass production of 1 to 15 years old *R. apiculata* plantations in Yeesarn varied from 0.23 to 11.12 tons/ha and the highest amount was observed in 14 years old plantation. The present study showed more or less same leaf biomass production pattern with the previous study at Yeesarn and also the other studies on *Rhizophora* plantations at Pattani, Nakorn Sri Thammarat, and Krabi Province.

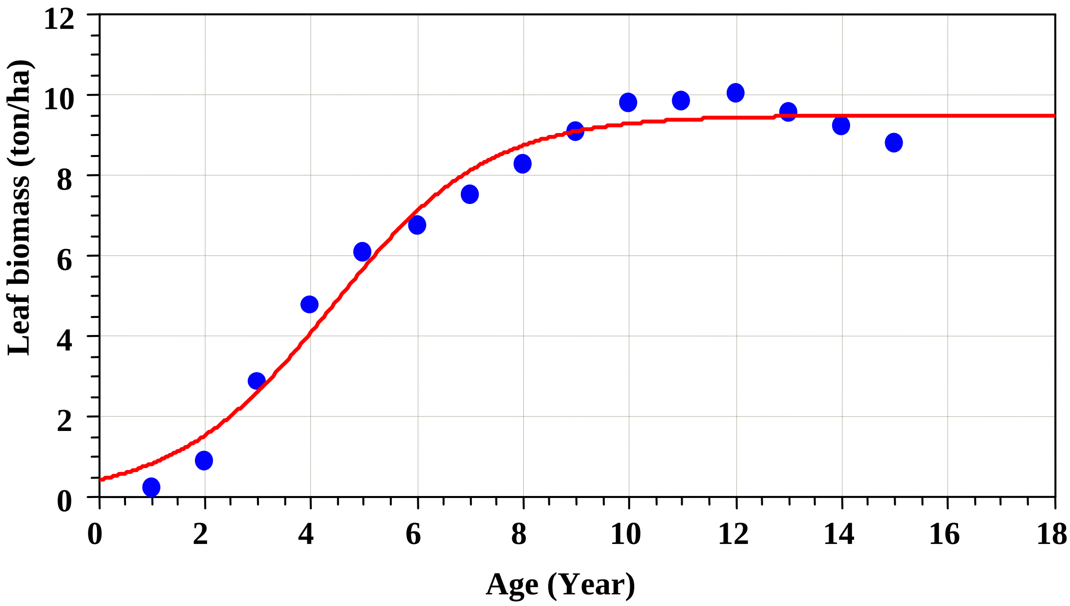


Figure 14  Trend of leaf biomass increment of 1 to 15 years old *R. apiculata* stand.

### 3.6 Prop Root Biomass

Prop root was not found in 1 year old of *R. apiculata* plantation. Prop root biomass of 2 to 15 years old plantations varied from 0.31 to 15.32 tons/ha and the highest prop root biomass production observed in a 12 years old plantation. The CAI of prop root biomass of 2 to 15 years old plantations varied from 0.16 to1.31 tons/ha/yr and the highest prop root biomass production rate observed in a 10 year old plantation. At the age of 2 to 5 the prop root biomass production increased 0.31 to 5.50 tons/ha and the average increment was 0.69 tons/ha/yr. During 6 to 10 years of the plantations the prop root biomass gradually increased from 6.50 to 13.12 tons/ha and the average increment was 1.19 tons/ha/yr while the age of 11 to 15 years, the prop root biomass production fluctuated between 15.32 to 13.12 tons/ha and the average increment was 1.15 tons/ha/yr.  The trend of prop root biomass production of 2 to 5 years plantations showed that the growth rate increased rapidly and during 6 to 10 years the growth rate gradually increased with little variation among the age years while at the age of 11 to15 years the prop root production rate gradually decreased with the exception of 12 year plantation and it would be due to higher growth performance of diameter and height than the other age years plantations (Figure 15).

Tanapermpool (1989) found that prop root biomass production of 5 to 20 years old *R. apiculata* plantations in Pattani Province varied from 4.45 to 34.68 tons/ha and the highest was in the 18 years old plantation. Kongsangchai *et al.* (1990) found that the prop root biomass production of 6 to 11 years *Rhizophora* plantations in Nakorn Sri Thammarat Province varied from 9.98 to 19.05 tons/ha and the average increment was approximately 1.81 tons/ha/yr while in Trang Province, the prop root biomass production of 9 to 14 years old *Rhizophora* plantations varied from 17.51 to 33.93 tons/ha and the average prop root biomass increment was 3.28 tons/ha/yr. In Krabi Province, they found that the prop root biomass production of 9 to 11 years

*Rhizophora* plantations varied from 38.74 to 43.23 tons/ha and the average increment was 2.24 tons/ha/yr. The highest prop root biomass production of the plantations was in 11 years old plantation while the increment was highest in 9 years plantation as 4.30 tons/ha/yr. Wechakit (1987) observed that the prop root was not developed in the 1 year old *R. apiculata* stands in Yeesarn. He found that the prop root biomass production of 2 to 15 years old *R. apiculata* plantations in Yeesarn varied between 0.26 and 18.49 tons/ha and the highest amount of prop root biomass production was found in the 14 years old plantation. The present study showed quite similar prop root biomass production pattern with the previous study at Yeesarn and comparatively less prop root biomass production than the other studies on *Rhizophora* plantations at Pattani, Nakorn Sri Thammarat, Trang and Krabi Province. It would be due variation on locations and tidal amplitudes of the area.

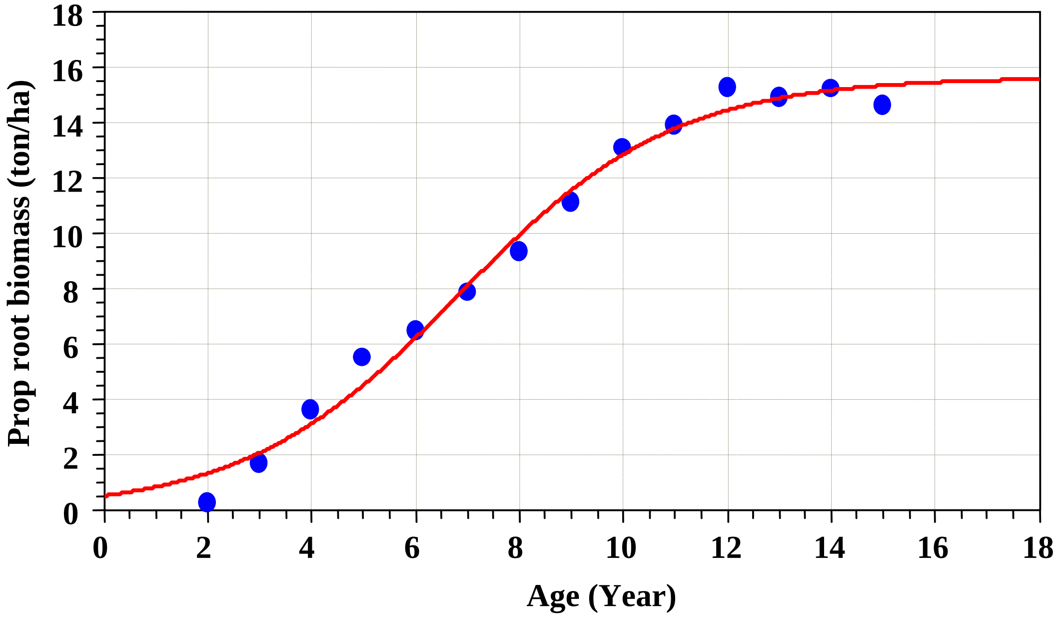


Figure 15 Trend of prop root biomass increment of 1 to 15 years old *R. apiculata* stand.

### 3.7 Total Above-Ground Biomass

Total above ground biomass was included stem biomass, branch biomass, leaf biomass and prop root biomass. The above ground biomass production in 1 to 15 years old plantations varied between 0.77 and 201.95 tons/ha and the highest was in 14 years old plantation. The CAI of above-ground biomass of 2 to 15 years old plantation varied between 1.28 to15.78 tons/ha/yr and the highest growth rate was found in 12 years old plantation. The trend of increase of biomass production showed that at the age of 1 to 5 years, the production rate was slow and from 6 to 10 the rate gradually increased. During the year 10 to 15 the production rate fluctuated and remained quite stable in 13 and 14 years and fall down in 15 year (Figure 16).

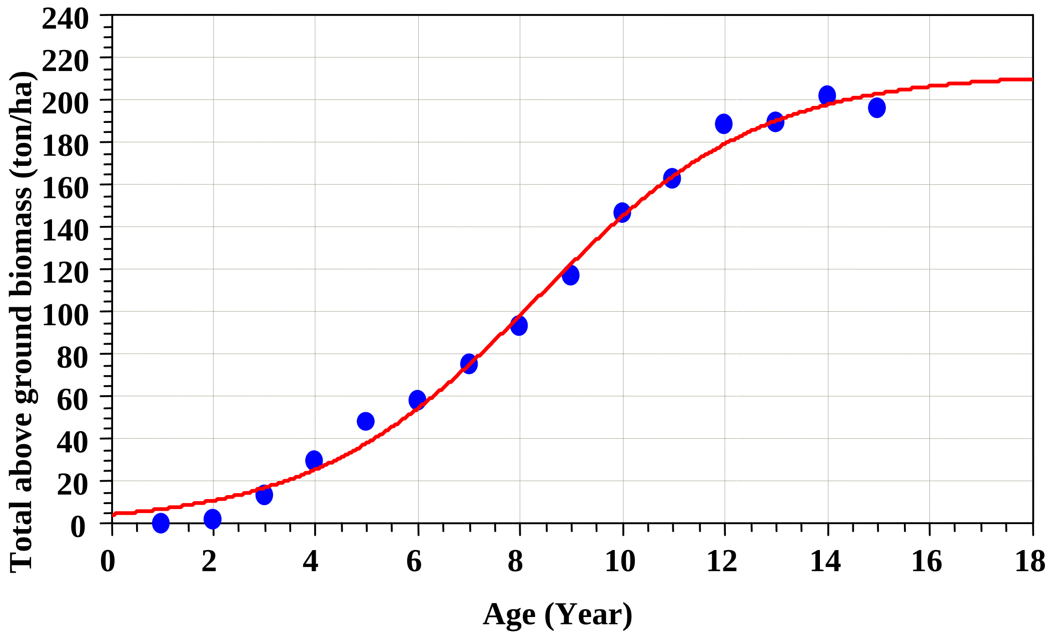


Figure 16 Trend of total above ground biomass increment of 1 to 15 years old *R. apiculata* stand.

Tanapermpool (1989) found that the average above-ground biomass production of 5 to 20 years old *R. apiculata* plantations in Pattani Province was between 22.81 and 234.30 tons/ha. He found that the highest amount of above ground biomass production was in the 18 years old plantation and the production of 15 years old plantation was 194.86 tons/ha. Chanprapai (2005) found the biomass production of 1 to 20 years *R. apiculata* plantation in Pattani Province was between 1.20 and 209.56 tons/ha. Kongsangchai *et al.(*1990) found that the above-ground biomass production of 6 to 11 years *Rhizophora* plantations in Nakorn Sri Thammarat Province was between 80.12 and 176.51 tons/ha while 9 to 14 years old *Rhizophora* plantations in Trang Province was between142.00 to 268.54 tons/ha. In Krabi they found that the biomass production of 9 to14 years old *Rhizophora* plantations were about 235.22 to 263.09 tons/ha. Wechakit (1987) found that the above-ground biomass production of 1 to 15 years old *R. apiculata* plantations in Yeesarn varied between 0.64 and 239.25 tons/ha, respectively and the highest biomass production estimated as 251.09 tons/ha in a 14 year old plantation. The present study showed somewhat less above ground biomass production than the previous study in Yeesarn but the growth rate was quite similar to the other studies on *Rhizophora* plantations at Pattani and Nakorn Sri Thammarat Province.

### 3.8 Commercial Volume

The commercial volume considered of a stand having more than 2 cm DBH. The result revealed that from 1 to 3 years plantations had no commercial volume because the trees of the ages were small. From year 4 to 7 considerable number of trees attained >2 cm DBH while from year 8 to 15 years all *R. apiculata* stands were attained more than 2 cm DBH. It was found that only 28.19% stands were attained > 2 cm DBH in the 4 year and formed only 39.68% of the total volume. During the age of 5, 6 and 7 year attainable trees were 59.81%, 87.92% and 91.24%, respectively which formed 75.05%, 89.9% and 93.76% of the total volume of the plantation , respectively. In year 8, 9, 10, 11, 12, 13, 14 and 15 the commercial volume of wood were formed 96.83%, 97.22%, 97.63%, 97.88%, 98.23%, 98.40%, 98.61% and 98.67% , respectively (from Table 5).

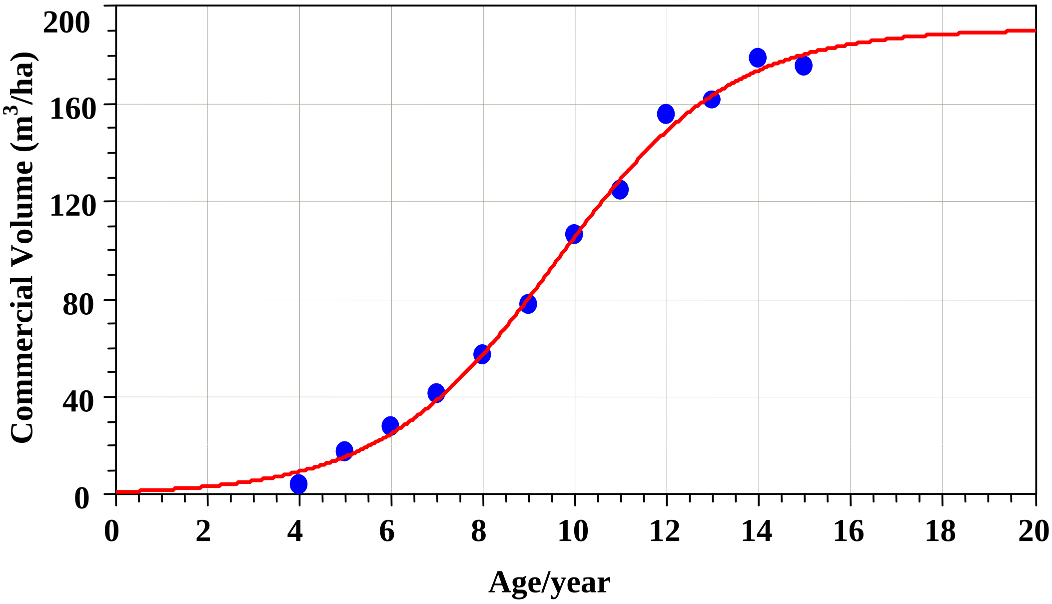


Figure 17 Trend of commercial volume increment of 1 to 15 years old *R. apiculata* stand.

Production of commercial wood of 4 to 15 years *R. apiculata* plantations in Yeesarn varied from 4.73 to 178.98 $m^3$/ha. The CAI of commercial volume of 4 to 15 years plantation varied from 1.18 to13.00 $m^3$/ha/yr. At the age of 4 to 5 years the commercial wood production increased from 4.73 to 17.69 $m^3$/ha and the average increment was 2.36 $m^3$/ha/yr. During the ages of 6 to 10 years, the commercial wood production gradually increased from 27.85 to 107.04 $m^3$/ha and the average increment was about 7.44 $m^3$/ha/yr. During the age of 11 to 15 years plantations the commercial volume of wood production fluctuated between 125.29 to 178.98 $m^3$/ha and the average increment was 12.27$m^3$/ha/yr. The highest commercial volume production observed in 14 year old plantation and the highest increment of commercial wood production observed in 12 year old plantation. The trend of increment of commercial wood showed that the initial growth was very low due to its age and size. But during the age of 6 to 10 years the growth rate of the plantations rapidly increased while from the age 11 to 15 years the growth rate fluctuated among the age of the plantation with little variations (Figure 17).

Tanapermpool (1989) found that commercial volume of 5 to 20 years old *R. apiculata* plantations in Pattani Province varied from 12.56 to 184.87 $m^3$/ha and the productions was highest in a 18 year plantation with average increment of 10.27 $m^3$/ha/yr. He found that the initial average increment was low and in a 5 year plantation it was 2.51 $m^3$/ha/yr. Kongsangchai *et al.* (1990) found that commercial volume of wood of 6 to 11 years *Rhizophora* plantations in Nakorn Sri Thammarat Province varied from 50.90 to 126.15 $m^3$/ha and the highest increment was in 11 years old plantation which was 11.47 $m^3$/ha/yr while in Trang Province, the commercial volume of wood of 9 to 14 years old *Rhizophora* plantations varied from 91.72 to 170.21 $m^3$/ha and the highest was in a 14 year old plantation with an increment of 12.16 $m^3$/ha/yr. In Krabi Province, they found that, the commercial volume of 9 to 11 years old *Rhizophora* plantations varied from 135.26 to 151.66 $m^3$/ha and the average increment of the plantations was14.26 $m^3$/ha/yr. Wechakit (1987) found that the commercial volume of 4 to 15 years old *R. apiculata* plantations in Yeesarn varied from 2.15 to 231.00 $m^3$/ha and the highest commercial volume observed in a 14 year old plantation with increment of 16.5 $m^3$/ha/yr. The present study showed somewhat less commercial wood production than the previous study at Yeesarn and it would be due to degradation of site quality. But the production pattern was quite similar to the other studies on *Rhizophora* plantations at Pattani, Nakorn Sri Thammarat and Trang Province.

### 3.9 Total Volume

The Total volume of wood of 1 to 15 years old plantation varied between 0.72 to 181.49 $m^3$/ha and the CAI of total wood volume of the plantations varied from 0.91 to 13.23 $m^3$/ha/yr. During the year 1 to 5 the production of volume gradually increased from 0.72 to 23.57 $m^3$/ha and the average increment was 2.13 $cm^3$/ha/yr. At the age of 6 to 10 years the total volume rapidly increased from 30.98 to 109.63 $m^3$/ha and the average increment of the plantations was about 7.77 $m^3$/ha/yr. During the year 11 to 15 the production of volume fluctuated between 128.00 and 181.49 $m^3$/ha and the average increment of the plantations was12.47 $m^3$/ha/yr. The highest volume production observed in a 14 years old plantation while the highest increment of volume observed in a 12 year old plantation. The trend of increment of wood volume showed that during 4 to 5 years the production rate was slow and from 6 to 10 years the production of volume gradually increased with the increase of age of the stands while during the age of 11 to 15 the growth rate fluctuated with little variations among the age of the plantations (Figure18). During the age of 1 to 5 years the production of total volume was low due to age and size of the stands. During the year 6 to 10 the rate was gradually increased and it would be considered the growing period of the stands. From 11 to 15 years the growing rate remained quite stable due to maturation stage of the plantations.

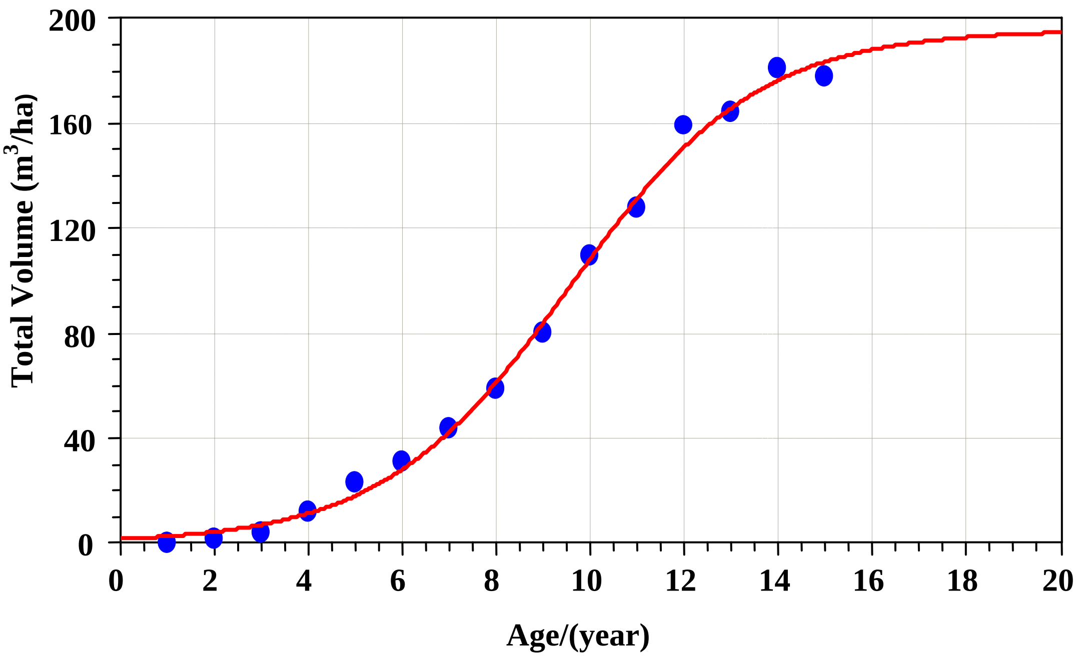


Figure 18 Trend of total volume increment of 1 to 15 years old *R. apiculata* stand.

Tanapermpool (1989) found that the total volume of wood of 5 to 20 years old *R. apiculata* plantations stands in Pattani Province varied from 14.33 to 197.16 $m^3$/ha and the volume increment was greatest in a 18 year age plantation with annual increment of 10.95 $m^3$/ha/yr. Kongsangchai *et al.* (1990) found that the volume of 6 to 11 years *Rhizophora* plantations in Nakorn Sri Thammarat Province varied from 57.36 to 129.85 $m^3$/ha and the average volume increment was approximately 14.70 $m^3$/ha/yr while in Trang Province, the total volume of wood of 9 to 14 years old *Rhizophora* plantations were about 97.18 to 170.63 $m^3$/ha and the average volume increment was approximately 14.69 $m^3$/ha/yr. In Krabi Province, they found that, the wood volume of 9 to 11 years old plantation were about 138.51 to 153.66 $m^3$/ha and the average volume increment was approximately 7.58 $m^3$/ha/yr. Wechakit (1987) found that the total wood volume of 4 to 15 years old *R. apiculata* plantations in Yeesarn varied from 0.60 to 233.56 $m^3$/ha and the highest amount was estimated in a 14 year old plantation with annual increment of 16.68 $m^3$/ha/yr. The present study showed somewhat high wood volume production rate in compared to the wood volume production rate of the *Rhizophora* stands of Pattani, Nakorn Sri Thammarat, Trang and Krabi Province. But less wood volume production rate in compared to the previous study at Yeesarn and it would be due to degradation of the site quality.

## 4. Harvesting

From 8 to 15 years old *R. apiculata* plantation, the planted trees usually harvested for charcoal making. Country made hand-axe used for felling the trees. Generally, plantations owner sold the plantation to charcoal kiln operators if he had no kilns. Sometime middleman bought the plantation from the land/plantation owner and made the stem into billets and sold to the kiln operators. Harvesting was done all year round. Plantations were harvested on contract labor basis and on an average 1.50 baht per billet (1.30 to 1.42 cm long piece of wood) was paid for felling, debarking, carrying and piling up the billet to the kiln site. Sometimes contracts were arranged separately for the clear fellers and de-barkers, and transporters and pile-makers. In both cases the amount was paid which depended on the diameter, height of stands and location of the plantation.

Harvesting carried out by teams consisting of 2 to 4 members. Sometimes one or more couples observed to do this operation. One an average each couple produced 300 to 400 billets per day depending on the age of the plantation and size of the billets. Generally debarking took place in the plantation site and billets were pilled up near the water ways for transportation. Small boats were the only convenient means for transportation of the billets to the kiln site. To facilitate transportation of the billets small canal was observed to dig. The excavated canal was up to 100 m long, 2 m wide and about 1 m depth. It is assumed that these canals also to be provided easy access for regular sea water's flooding to the area and to facilitate replanting.

Figure 19  Two years old (foreground) and 14 years old (background) *R. apiculata* plantation in Yeesarn Sub-district, Samut Songkram Province.

Figure 20  Logging and debarking of *R. apiculata* trees at harvesting site in Yeesarn Sub-district, Samut Songkram Province.

Figure 21  Small canal was dug to facilitate the transportation of billets and for replanting.

Figure 22  Billets of *R. apiculata* were transported by boat from plantation site to the charcoal kiln site.

## 5. Determination of Wood Properties

Attempts were made to determine the physical properties of air-dried *R. apiculata* wood. 24 wood samples were collected from 8 to 15 years old plantation and 3 samples from each year. The results of the experiment were as follows:

### 5.1 Density of Wood

The results of density of wood from 8 to 15 years *R. apiculata* plantation are given in Appendix 3.The observations showed that the density of wood varied within the age classed and also with the other age groups. The density of wood of 8 to 15 years varied between 0.78 and 0.95 gm/cm$^3$ and the average density was 0.86 gm/cm$^3$ (Appendix 3). The average density of wood of 8, 9, 10, 11, 13, 14 and 15years old plantations were 0.80, 0.82, 0.87, 0.85, 0.85 0.87, 0.89 and 0.92 gm/cm$^3$, respectively (Table 7). It was observed that the density of 8 and 9 years were low and the average was 81 gm/cm$^3$ and it would be due to early age of the wood. Very little variation on densities were observed in the year of 10, 11, 12 and 13, and the average density was 86 gm/cm$^3$, whereas the average density of wood of 14 to 15 years were somewhat higher than the other age years and the average density of the years was 90.5 gm/cm$^3$. The results showed that there was highly statistical significant difference in densities of wood between different ages (P = 0.000).

Table 7 Density, moisture content and specific gravity of wood from different ages of *R. apiculata* plantation in Yeesarn of Samut Songkram Province

| Age (year) | Density (g/cm$^3$) | Moisture content (%) | Specific gravity |
|---|---|---|---|
| 8 | 0.80±0.02 | 13.66±0.80 | 0.84±0.05 |
| 9 | 0.82±0.02 | 13.03±1.84 | 0.88±0.01 |
| 10 | 0.87±0.01 | 13.76±0.81 | 0.89 ±0.01 |
| 11 | 0.85±0.01 | 14.35±0.14 | 0.91±0.01 |
| 12 | 0.85±0.04 | 14.21±0.23 | 0.93±0.01 |
| 13 | 0.87±0.01 | 14.17±0.40 | 0.94±0.01 |
| 14 | 0.89±0.03 | 13.77±1.07 | 0.98±0.06 |
| 15 | 0.92±0.03 | 14.18±0.43 | 0.99±0.08 |

### 5.2 Moisture Content of Wood

The moisture content of wood of 8 to 15 years varied between 11.23 and 14.91% and the average moisture content was 13.89% (Appendix 3). The average moisture content of wood of 8, 9, 10, 11, 13, 14 and 15 years old plantations were 13.66, 13.03, 13.76, 14.35, 14.21, 14.17, 13.77 and 14.18%, respectively (Table 7). It was found that year 8 to 10 the moisture content were low in comparison to others year of wood and the average was about 13.48% it would be due early age of the wood and for higher evaporation rate. From year 11 to 15 the moisture content rates were quite same with little variation and it would be due to higher age and the qualities of wood that prevent rapid evaporation. The result showed that there was no significant difference in moisture content of the wood between different ages (P = 0.649).

### 5.3 Specific Gravity of Wood

The specific gravity of wood of 8 to 15 years varied between 0.78 and 1.08 and the average specific gravity of wood of 8 to 15 years was 0.92 (Appendix 3). The average specific gravity of wood of 8, 9, 10, 11, 13, 14 and 15 years old plantations were 0.84, 0.88, 0.89, 0.91, 0.93, 0.94, 0.98 and 0.99, respectively (Table 7). It was found that the specific gravity of 8 and 9 were low in comparison to other years and the average was 0.86 and it would be due to early age of the wood. At the year 10 to 11 and 12 to 13 the specific gravity of gradually increased while during 14 to 15 years the specific gravity was much higher than the other years. It would be due to higher age and qualities of the wood of the years. The result showed that there was highly statistical significant difference in specific gravities of wood between different ages (P = 0.005). However, the results showed that the specific gravity of wood was increased with the increased of age of the stands.

Higaki (1982) found that the specific gravity of air-dried mangrove wood varied between 0.79 and 0.95 and the specific gravity of *A. marina*, *B. gymnorrhiza, R. mucronata* and *R. apiculata* were 0.79, 0.90, 0.93 and 0.95, respectively. Chunwarin (1982) found that the specific gravity in mangrove wood of *B. cylindrical, B. gymnorrhiza*, *B. parviflora*, *and C. decandra* and *L. littorea* were 0.89, 0.83, 0.96, 0.76 and 0.74 , respectively while in *R. apiculata* and *R. mucronata* were 0.98 and 0.83 , respectively. The present study showed very close result of specific gravity of *R. apiculata* wood with Higaki and Chunwarin studies.

## 6. Charcoal Production

### 6.1 Overview of Charcoal Kiln and Charcoal Production in Yeesarn

It was observed that brick beehive was only type of kiln used for charcoal making in Yeesarn Sub-district. The diameter of the kilns varied from 5 to 6 m and the height about 2.5 to 3.5 m (Table 8). The kiln constructed with a single door measuring of 1 m wide and 1.25 m height to facilitate loading and unloading and a basal portion which used for firing port. 4 small chimneys were placed equidistantly around circumference. The kilns were constructed as a battery inside the shed, built with mostly mangrove pole structures and nipa-thatched. There were 8 charcoal production centers identified in Yeesarn Sub-district consisted of 3 to 6 kilns with a total of 40 in number. Aksornkoae *et al.* (1992) found that there were 13 production centers with total of 62 charcoal kilns in Yeesarn. The present study showed less number in terms of production center and kiln than the previous findings. It would be due to many former kilns operator had changed their occupation and simultaneously many farmers converted their plantation land into aquaculture particularly for shrimp farming. The amount of charcoal production from 8 charcoal centers of Yeesarn was estimated as 2,003.23 ton per year. The production of charcoal of the centers varied from 153.09 to 383.40 ton per year. It would be due to size and number of the kilns and operational efficiency of the production center. Highest production was observed in the center no. 4 and it was informed that the owner of the center had a good network for both raw materials collection and charcoal marketing channel.

Figure 23 Dome-shaped brick beehive charcoal kiln under Nipa roof in Yeesarn Sub-district, Samut Songkram Province.

Figure 24 Charcoal packed in plastic sacs and placed in a temporary store for transportation and marketing.

Table 8 Annual charcoal production from mangrove wood in Yeesarn of Samut Songkram Province

| No. of charcoal production center | Name of charcoal kiln operator | Number of charcoal kiln | Size of charcoal kiln (height & diameter) | Average production of charcoal (ton/kiln/cycle) | | | Frequency of operation (time/year) | Annual production (ton/year) |
|---|---|---|---|---|---|---|---|---|
| | | | | Lump charcoal | Brand charcoal | Total | | |
| 1 | Mr. Sai | 3 | 6 ×3.5 m | 6.52 | 0.77 | 7.29 | 7 | 153.09 |
| 2 | Mr. Eurb | 5 | 6 ×3.5 m | 6.45 | 0.75 | 7.2 | 7 | 252.00 |
| 3 | Mr.Bonliam | 4 | 5 ×2.5 m | 3.12 | 0.28 | 3.4 | 8 | 108.80 |
| 4 | Mr.Chalem | 6 | 6 ×3 m | 5.98 | 0.41 | 6.39 | 10 | 383.40 |
| 5 | Mr.Sawai | 6 | 6 ×3 m | 5.76 | 0.42 | 6.18 | 9 | 333.72 |
| 6 | Mr.Wichian | 4 | 6 ×3 m | 5.83 | 0.34 | 6.17 | 10 | 246.80 |
| 7 | Mr. Anan | 6 | 6 ×3 m | 5.95 | 0.48 | 6.43 | 9 | 347.22 |
| 8 | Mr.Chaoon | 6 | 5 ×2.5 m | 3.11 | 0.44 | 5.78 | 9 | 178.20 |
| Total | | 40 | - | - | - | - | - | 2,003.23 |

Table 9  Yield of charcoal from 6 × 3.5 m charcoal kilns in Yeesarn of Samut Songkram Province

| Kiln No. | Weight of Fresh Green Wood (kg) | Weight of Air Dried Wood Input (kg) | Oven Dried Firewood (kg) | Moisture Content of Wood (%) | Operation Time (hour) | Weight of Lump Charcoal (kg) | Weight of Brands Charcoal (kg) | Total Gross Yield (kg) | Brands Charcoal (%) | Lump Charcoal Yield (%) | Net Production Rate (kg/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 27,912.33 | 20,647.33 | 1,985.33 | 33.09 | 592.00 | 6,511.00 | 749.33 | 7,360.33 | 3.63 | 33.23 | 11.16 |
| | ±292.43 | ±224.89 | ±93.04 | ±0.20 | ±3.46 | ±36.76 | ±51.60 | ±84.39 | ±0.27 | ±0.60 | ±0.12 |
| 2 | 28,092.00 | 20,745.33 | 2,015.67 | 33.30 | 598.00 | 6,624.33 | 778.33 | 7,402.67 | 3.76 | 32.84 | 11.08 |
| | ±196.55 | ±202.37 | ±120.70 | ±0.35 | ±1.00 | ±58.05 | ±39.80 | ±30.11 | ±0.23 | ±0.34 | ±0.10 |
| 3 | 27,871.33 | 20,711.33 | 2,021.67 | 33.01 | 595.67 | 6,637.67 | 788.67 | 7,426.33 | 3.81 | 33.32 | 11.14 |
| | ±461.12 | ±357.09 | ±140.61 | ±0.42 | ±4.51 | ±36.36 | ±27.15 | ±45.76 | ±0.07 | ±0.61 | ±0.14 |

## 6.2 Determination of Charcoal Output

Attempts were made to determine the charcoal output from the kilns. 9 experiments were made in 3 charcoal kilns with 3 replications and the average results were showed in Table 9.

### 6.2.1 Raw Materials Preparation

Approximately 11,000 billets and 2,007.56 kg dried firewood were required to run a 6 × 3.5 m kiln. The average fresh green weight of 11,000 billets was estimated as 27,959 kg. The average fresh wood required for the kiln of 1, 2 and 3 were estimated as 27,912, 28,092 and 27,871 kg, respectively (Table 9). There was no significant difference in weight of fresh wood for using in the kilns for charcoal making (P= 0.707). The billets were placed in an open area near the kiln for 120 to 135 days for reducing the maximum moisture.

### 6.2.2 Loading Kiln

The average weight of air dried wood required for charging a 6 ×3.5 m kiln was estimated as 20,701 kg (Appendix 4). The average air-dried wood required for the kiln of 1, 2 and 3 were estimated as 20,647, 20,745 and 20,711 kg, respectively. There was no significant difference in weight of air dried raw wood for charcoal making in the kilns (P = 0.905). The average moisture content of air dried wood of the kiln 1, 2 and 3 were 33.09, 33.30 and 33.01%, respectively (Table 9). There was no significant difference in moisture content of air dried wood for charcoal making (P = 0.585). Aksornkoae *et al.* (1992) found that the moisture content of air dried *R. apiculata* wood for charcoal making varied between 33.08 and 35.20%. Chomcharn (1984) found that the moisture content of semidry wood for charcoal making was between 25 to 35 %.

It was observed that the kiln load required skilled labor and carried out by a team of 6 persons, both men and women. 4 ordinary workers carried the billets to the kiln while the two specialized ones pack the billets into the kiln. The billets were first vertically packed on the kiln floor starting from the opposite side of the door. The billets of wood were pile compactly together. Over the top of the pile, and near the door, the space of about one-third of the kiln volume left to serve as drafts.

### 6.2.3 Firewood

The average weight of air-dried firewood required for a 6 × 3.5 m kiln estimated as 2,008 kg (Appendix 4). The average firewood required for the kiln of 1, 2 and 3 estimated as 1,985, 2,016 and 2,022 kg, respectively (Table 9). There was no significant difference in weight of firewood using in the kilns for charcoal making (P= 0.925).

### 6.2.4 Kiln Operation

The average time required for kiln operation (kiln firing and cooling) was approximately 595 hours (Appendix 4) of which half of the time required for firing and the rest half for cooled down. The average operation time of the kiln 1, 2 and 3 estimated as 592, 598 and 596 hours (Table 9). There was no significant difference in time of operation of the kilns (P = 0.165). Aksornkoae *et al.* (1992) found that a 6 × 3.5 m s kiln took 20 to 24 days (480 to 576 hours) for charcoal process. The results showed somewhat more time required for kiln operation than Aksornkoae's studies and the reason might be the kilns of the present study site were larger in size.

The ignition operated continuously day and night. The time required for firing depended upon the quality of wood, its size, dryness, the method of piling, temperature and weather conditions, and the character of the ground (Chunwarin, 1982). Experienced worker control the rate of burning by opening on closing the draft holes around the circumference of the kiln. When the wood was completely carbonized, the door was sealed off with bricks and clay.

### 6.2.5 Unloading Kiln

After cooled down the kiln, the door of the kiln was opened to carry the charcoal out from the kiln. Unloading of the kin was a group work where 6-7 workers needed to unload the kiln in a day. Generally 30 kg stick charcoal packed in a plastic sac and placed in a temporary store for transportation. Canvas used to cover the pilling sacs in order to prevent atmospheric moisture that may affect the quality of charcoal before marketing.

### 6.2.6 Frequency of Operation

The frequency of charcoal kiln operation in Yeesarn varied between 7 and 10 cycle per year (Table 8). It was observed that the operation number was high in small size charcoal kiln than the large ones and the frequency of operation of the kiln depended on available of raw materials, moisture level of wood input, labor availability, charcoal marketing channels and transportations. Aksornkoae *et al.* (1992) quoted that availability of wood and transportation was major constraint for firing operation of the kilns in Yeesarn. Generally, all the kilns of a battery started to charge in a same time. It would be due to convenient of handling the wood raw materials processing, kiln operation, packaging and marketing of the product.

### 6.2.7 Charcoal Yield

Based on average air-dried wood input the average gross yield was estimated approximately 7,396 kg of which 6,624 kg lump charcoal and 772 kg brands charcoal (Appendix 4). The average gross yield was 36.86% of which lump charcoal and brands charcoal were constituted as 33.13 and 3.73%, respectively. The average yield of lump charcoal in the kilns of 1, 2 and 3 were estimated as 6,511, 6,624 and 6,637 kg , respectively which represented 33.23, 32.84 and 33.32% yield , respectively (Table 9). At the same time the production of brands charcoal of the kilns were 749, 778 and 789 kg, respectively of which constituted 3.63, 3.76 and 3.80% , respectively. There were no significant differences in yield of lump charcoal (P = 0.776) and brands charcoal (P = 0.512) of the kilns. It would be due to the kilns were the same size and the raw materials were from the same species.

Aksornkoae *et al.* (1992) found that the yield of lump charcoal and brands charcoal from a 6 × 3 m kiln was 4,915 and 810 kg, respectively and the total yield was 36.6%. Chomcharn (1982) stated that the average charcoal yield of lump charcoal from brick beehive in Thailand was about 36%. The present study showed quite similar yield rate to the previous observation. of Aksornkoae but somewhat less yield of lump charcoal than Chomcharn findings. It would be due to the kilns were very old and lack of appropriate management for the production systems.

#### 6.2.8 Production Rate

Based on kiln operation time the production rate of the kilns varied between 10.83 and 11.13 kg/hr and the average was 10.96 kg/hr (Appendix 4). The average production rate of the kiln 1, 2 and 3 were 11.00, 10.90 and 10.97 kg/hr, respectively (Table 9). There was no significant difference of production rate of the kilns (P = 0.628). This was due to the kilns were same size and started operation at the same time with same quality raw materials. Chomcharn (1982) found that the production rate of brick beehives was approximately 11.1 kg/hr and varied between 8.2 and 13.3 kg/hr. The present study showed the somewhat less production rate with the highest result of Chomcharn observation. It would be due to the kilns were very old and possibly it lost its highest production efficiency.

## 7. Determination of Charcoal Quality

In this study the determination of charcoal quality included the physical properties of charcoal, proximate analysis and heat value. The physical properties of charcoal included density, moisture content, and specific gravity. For the physical properties experiment 18 charcoal samples from 3 kilns were collected and the results were as follows:

### 7.1 Density of Charcoal

The density of charcoal of the kilns varied between 0.49 and 0.97 $gm/cm^3$ and the average was 0.70 $gm/cm^3$ (Appendix 5). The average density of charcoal from kiln 1, 2 and 3 were 0.67, 0.67 and 0.76 $gm/cm^3$, respectively (Table 10). There was no significant difference in density of charcoal of the kilns (P = 0.443). It would be the charcoal was produced from same type of kilns and wood.

Table 10 Density, moisture content and specific gravity of the sample *R. apiculata* charcoal from 3 different kilns

| Kiln No. | Density (gm/cm$^3$) | Moisture Content (%) | Specific Gravity |
|---|---|---|---|
| 1 | 0.67±0.15 | 4.34±0.34 | 0.79±0.11 |
| 2 | 0.67±0.11 | 4.45±0.43 | 0.74±0.09 |
| 3 | 0.76±0.15 | 4.47±0.16 | 0.81±0.08 |

### 7.2 Moisture Content of Charcoal

The moisture content of charcoal of the kilns varied between 3.60 and 4.94% and the average was 4.42% (Appendix 5). The average moisture content of charcoal of the kilns 1, 2 and 3 were 4.34, 4.45 and 4.47%, respectively (Table 10). There was no significant difference in moisture content of charcoal of the kilns (P= 0.759). Chomcharn (1984) stated that the moisture content of the lump charcoal which was between 3-5% were acceptable for industrial uses. The present study showed somewhat higher moisture content in charcoal of *R. apiculata* wood. It would be due to lack of proper packaging of charcoal after unloading from the kiln. Aksornkoae *et al.* (1992) stated that after unloading from the kiln, the fresh lump charcoal absorb moisture from atmosphere.

### 7.3 Specific Gravity of Charcoal

The specific gravity of charcoal of the kilns varied between 0.60 and 0.93 and the average was 0.78 (Appendix 5). The average specific gravity of charcoal of kilns 1, 2 and 3 were 0.79, 0.74 and 0.81, respectively (Table 10). There was no significant difference in specific gravity of charcoal of the kilns (P= 0.465). The observation showed that the specific gravity of charcoal somewhat varied. It would be due to different ages of wood which used in the kiln for charcoal making those were different in qualities. Another reason might be due to the differences of carbonization temperature in the kiln during wood combustion period. Chomcharn (1984) found that the quality and quantity of charcoal greatly influence by the effect of carbonization temperature.

### 7.4 Proximate Analysis and Heat Value

The result of proximate analysis and heat value of charcoal from *R. apiculata* showed two types of values for each component. The first value was considered for fresh sample basis and the second value was considered for moisture free basis. However, the volatile matter varied from 30.5 to 31.60% which were fresh sample basis and moisture free basis, respectively. The amount of volatile matter was rather high in compare to other studies. Chomcharn (1984) found that the average volatile mater in charcoal from *R. apiculata* was 17.2%. The fixed carbon varied from 63.80 to 66.20% which were fresh sample basis and moisture free basis, respectively. The amount of fixed carbon was rather low in compare to other studies. Chomcharn (1984) found that the average fixed carbon in charcoal from *R. apiculata* was 79.90%. The amount of ash content varied from 2.1 to 2.2% which were fresh sample basis and moisture free basis, respectively. Chomcharn found that the average ash content in charcoal from *R. apiculata* was 2.9%. The heat values of charcoal from *R. apiculata* wood varied between 6,550 and 6,800 kcal/kg which were fresh sample basis and moisture free basis, respectively. Chomcharn (1984) found that the average heat value of charcoal from *R. apiculata* was 7,190 kcal/kg. Chantarasena (1985) found that heat values of charcoal from various mangrove species ranged between 6,400 and 7,600 kcal/kg.

## 8. Charcoal Marketing

Charcoal kiln operator directly sold charcoal to the charcoal distributors of Bangkok, Petchaburi and nearest Provinces. Three charcoal operators of Yeesarn were reported to export charcoal to the overseas countries such as Hong Kong, Taiwan and Japan. However, often the middleman bought charcoal directly from the kiln operator on contract basis. The middleman bought mostly the premium quality charcoal (brands charcoal) from the charcoal operators. The means of transportation of charcoal depended on the location of the marketing site. Place near the sea or river the charcoal kiln operators preferred to transport charcoal to the marketing site by boat. Sometimes a fleet consisting of 4-10 small boats tugged by one motor boat and transported charcoal for longer distance such as to Bangkok. Another mode of transport was by pick-up or bigger trucks. Most of the charcoal kiln operator possessed boat and pick-up for transportation of charcoal for marketing.

## 9. Financial Analysis

The financial analysis of private *R. apiculata* plantation included the cost, benefit and financial return in term of NPV, B/C and IRR while for charcoal operation financial analysis was considered in term of cost and revenue from charcoal making and marketing. The results of this study were as follows:

### 9.1 Financial Analysis of *R. apiculata* Plantation

#### 9.1.1 Cost

The cost of *R. apiculata* plantation considered as fixed cost and variable cost. The fixed cost included a tug boat, a water pump, and various tools and equipments which the plantation owner used for 32 ha of his own plantation. The life span of the fix items considered 15 years. Therefore the fixed cost consideration of the whole plantation area and added only the depreciation cost for per hectare basis. The opportunity cost for land was not included as mangrove land was owned by those who plant the trees and mangrove land in Yeesarn was not reported to rent out to the third parties. The wages of the variable costs varied due to mode of the work. Planting was considered as special work and the wage was somewhat higher than other works. Land clearing was the task of clearing of residues of the previous feeling and undesirable plants. Site preparation included digging of canal and land development for planting. Along with variable costs the depreciation costs of the investment added in the 1$^{st}$ year and there was no fixed cost after 1$^{st}$ year because 1$^{st}$ year was considered the beginning of plantation project for the whole rotation period. The initial costs in the 1st year were 12,136.26 baht/ha which constituted 66% of the total cost (Table 11). In the 2nd year the variable costs were 4,393.75 baht/ha while in 3rd year the variable costs were 1,856.25 baht/ha because in the 3rd year maintenance of the plantation was somewhat less than the previous years. From 4th year to the felling year (rotation was not fixed) there was no cost for plantation maintenance. The total costs for *R. apiculata* plantation for the period of 1 to 15 years were estimated as 18,386.26 baht/ha. Various fixed costs and variable costs for *R. apiculata* plantation are given in Appendix 6. Chanprapai (2005) found that the cost of *R. apiculata* plantation for commercial purpose in Pattani Province was about 19,277.38 baht/ha.

Table 11 Costs and revenues of *R. apiculata* plantation in Yeesarn of Samut Songkram Province

| Age (year) | Cost (baht/ha) | Minimum Benefit (baht/ha) | Maximum Benefit (baht/ha) | Average Benefit (baht/ha) |
|---|---|---|---|---|
| 1 | 12,136.26 | - | - | - |
| 2 | 4,393.75 | - | - | - |
| 3 | 1,856.25 | - | - | - |
| 4 | - | - | - | - |
| 5 | - | - | - | - |
| 6 | - | - | - | - |
| 7 | - | - | - | - |
| 8-15 | - | 56,250.00 | 93,750.00 | 75,000.00 |
| Total | 18,386.26 | 56,250.00 | 93,750.00 | 75,000.00 |

Table 12 Financial analysis of 8-15 years rotation of *R. apiculata* plantation in Yeesarn of Samut Songkram Province

| Interest rate (%) | Cost (baht/ha) | | | NPC (baht/ha) | NPB (baht/ha) | | B/C | | NPV (baht/ha) | | IRR (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1st Year | 2nd Year | 3rd Year | | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. |
| 6 | 11449.30 | 4145.05 | 1751.18 | 17345.53 | 23471.16 | 39118.60 | 1.35 | 2.26 | 6125.63 | 21773.07 | 8.36 | 12.38 |
| 8 | 11237.28 | 4068.29 | 1718.75 | 17024.31 | 17732.35 | 29553.91 | 1.04 | 1.74 | 708.03 | 12529.60 | 8.36 | 12.38 |
| 10 | 11032.96 | 3994.32 | 1687.50 | 16714.78 | 13465.80 | 22443.00 | 0.81 | 1.34 | -3248.98 | 5728.22 | 8.36 | 12.38 |
| 12 | 10835.95 | 3922.99 | 1657.37 | 16416.3 | 10276.66 | 17127.77 | 0.63 | 1.04 | -6139.64 | 711.47 | 8.36 | 12.38 |
| 14 | 10645.84 | 3854.17 | 1628.29 | 16128.3 | 7880.43 | 13134.05 | 0.49 | 0.81 | -8247.87 | -2994.25 | 8.36 | 12.38 |
| 16 | 10462.29 | 3787.72 | 1600.22 | 15850.22 | 6070.90 | 10118.16 | 0.38 | 0.64 | -9779.33 | -5732.07 | 8.36 | 12.38 |

Table 13  Projection of financial analysis of 8-15 years rotation of *R. apiculata* plantation in Yeesarn  in minimum benefit level

| Interest rate (%) | Cost increased 10% and benefit fixed | | | Cost fixed and benefit decreased 10% | | | Cost increased 10% and benefit decreased 10% | | |
|---|---|---|---|---|---|---|---|---|---|
| | NPV (baht/ha) | B / C | IRR (%) | NPV (baht/ha) | B / C | IRR (%) | NPV (baht/ha) | B / C | IRR (%) |
| 6 | 4391.08 | 1.23 | 7.63 | 3778.52 | 1.22 | 7.56 | 2043.96 | 1.11 | 6.85 |
| 8 | -994.40 | 0.95 | 7.63 | -1065.20 | 0.94 | 7.56 | -2767.64 | 0.85 | 6.85 |
| 10 | -4920.46 | 0.73 | 7.63 | -4595.56 | 0.73 | 7.56 | -6267.04 | 0.66 | 6.85 |
| 12 | -7781.27 | 0.57 | 7.63 | -7167.31 | 0.56 | 7.56 | -8808.94 | 0.51 | 6.85 |
| 14 | -9860.70 | 0.44 | 7.63 | -9035.91 | 0.44 | 7.56 | -10648.70 | 0.40 | 6.85 |
| 16 | -11364.40 | 0.35 | 7.63 | -10386.40 | 0.34 | 7.56 | -11971.40 | 0.31 | 6.85 |

Table 14  Projection of financial analysis of 8-15 years rotation of *R, apiculata* plantation in Yeesarn in  maximum benefit level

| Interest rate (%) | Cost increased 10% and benefit fixed | | | Cost fixed and benefit decreased 10% | | | Cost increased 10% and benefit decreased 10% | | |
|---|---|---|---|---|---|---|---|---|---|
| | NPV (baht/ha) | B / C | IRR (%) | NPV (baht/ha) | B / C | IRR (%) | NPV (baht/ha) | B / C | IRR (%) |
| 6 | 20038.51 | 2.05 | 11.63 | 17861.21 | 2.03 | 11.55 | 16126.65 | 1.85 | 10.81 |
| 8 | 10827.16 | 1.58 | 11.63 | 9574.20 | 1.56 | 11.55 | 7871.77 | 1.42 | 10.81 |
| 10 | 4056.74 | 1.22 | 11.63 | 3483.92 | 1.21 | 11.55 | 1812.44 | 1.10 | 10.81 |
| 12 | -930.16 | 0.95 | 11.63 | -1001.31 | 0.94 | 11.55 | -2642.94 | 0.85 | 10.81 |
| 14 | -4607.09 | 0.74 | 11.63 | -4307.66 | 0.73 | 11.55 | -5920.49 | 0.67 | 10.81 |
| 16 | -7317.09 | 0.58 | 11.63 | -6743.88 | 0.57 | 11.55 | -8328.91 | 0.52 | 10.81 |

### 9.1.2 Revenue

It was observed that 1 to 7 years old *R. apiculata* plantation was not exploitable for charcoal making. Because these plantation was too young and wood from such age year plantations could not produce good quality charcoal. The local experienced kiln operator reported that wood from 8 to 15 years old *R. apiculata* plantation were exploitable for making charcoal. In Yeesarn the cutting rotation of *R. apiculata* was not fixed and usually the cutting rotation varied 8 to 15 years which depended on economic return needed by the plantation owner.

The price of the plantation (stumpage value) of 8 and 15 years varied between 56,250 baht/ha and 93,750 baht/ha, respectively (Table 11) and the average was 75,000 baht/ha (average represented the stumpage values of 11 to 12 years old plantation). The stumpage values of the plantation depended on the age and quality of the stands of the respective plantation.

### 9.1.3 Financial Return

Normally the price of plantation and the interest rate always changed, hence in order to avoid from such uncertainties the 6 interest rates (6%, 8%, 10%, 12%, 14% and 16%) with minimum and maximum level of revenues were given to determine the NPV, B/C and IRR from private *R. apiculata* plantation. The results of financial return from the investment for 8 to 15 year rotation of *R. apiculata* plantation are illustrated in Table 12**.**

At the minimum revenue level the NPV would be 6,125.63, 708.03, -3,248.98, -6,139.64, -8,247.87 and -9,779.33 baht/ha , respectively and at the maximum revenue level the *R. apiculata* plantation would provide the NPV at 21,773.07, 12,529.60, 5,728.22, 711.47, -2,994.25 and -5,732.07 baht/ha , respectively when the given interest rate 6%, 8%, 10%, 12%, 14% and 16% in both cases. The higher the discount rate indicates the less the return. At the minimum revenue level, the *R. apiculata* plantation could be started to provide NPV > 0 only when the discount rate 8%. Hence, under such conditions the *R. apiculata* could be provided the NPV, B/C and IRR at 708.03 baht/ha, 1.04 and 8.36%, respectively. In maximum revenue level the *R. apiculata* plantation could be started to provide NPV > 0 only when the discount rate 12%. Hence, under such conditions the *R. apiculata* could be provided the NPV, B/C and IRR at 711.47 baht/ha, 1.04 and 12.38% , respectively (Table 12).

The financial return was basically based on many factors which could be changed. Hence, under such conditions the projections of the financial return from *R. apiculata* private plantation in minimum and maximum revenue level are illustrated in Table 13 and Table 14 , respectively. At the minimum revenue level the projection showed that *R. apiculata* private plantation could be provided NPV, B/C and IRR at 4,391.08 baht/ha, 1.23 and 7.63%, respectively if the cost increased 10% and the benefit fixed. In other way, *R. apiculata* private plantation could be provided NPV, B/C and IRR at 3,778.51 baht / ha, 1.21 and 7.56%, respectively if the cost fixed and the benefit decreased 10%. If the cost increased 10% and benefit decreased 10% in such condition *R. apiculata* could be provided NPV, B/C and IRR at 2,043.96 baht/ha, 1.11 and 6.85% , respectively.

At the maximum revenue level the projection showed that *R. apiculata* private plantation could be provided NPV, B/C and IRR at 4,056.74 baht/ha, 1.22 and 11.63%, respectively if the cost increased 10% and the benefit fixed. In other way, *R. apiculata* private plantation could be provided NPV, B/C and IRR at 3,483.92 baht/ha, 1.20 and 11.55%, respectively if the cost fixed and the benefit decreased 10%. If the cost increased 10% and benefit decreased 10% in such condition *R. apiculata* could be provided NPV, B/C and IRR at 1,812.44 baht / ha, 1.09 and 10.81%, respectively. On the above results, the present study showed that only in maximum revenue level *R. apiculata* plantation through private venture was economically feasible.

### 9.2 Cost and Revenue of Charcoal Kiln Operation

#### 9.2.1 Cost

The costs for charcoal making considered the fixed costs and the variable costs. The reported amount of wood, number of man days for charcoal production, marketing and transportation activities varied widely and therefore the average costs were considered. Based on the information from kiln operator the lifespan of kiln, factory shed and motor boat estimated as 30 years while the tools and equipments for 15 years. So the depreciation costs of factory shed, kilns and motor boat were considered as 30 years and for equipments were 15 years. Aksornkoae *et al.* (1992) stated that the life span of both kiln and shed was about 30 years. In charcoal kiln operation the opportunity cost for land rent included because the land was in non mangrove area with an easy access to the road and canal and the land had the other options for use. The factory occupied an area of 0.16 ha including a battery of 3 kilns, storage and wood processing area. The price of such land about 1250,000 baht/ha and with an annual rental fee was about 125,000 baht/year. So the opportunity cost of land for the kilns battery was about 20,000 baht/year.

On an average 0.24 ha *R. apiculata* plantation produced 11,000 billets which required to run a 6 × 3.5 m sized kiln and the average price of the plantation was 75,000 baht/ha. Felling of plantation, debarking and transportation was done mostly on contract basis. Kiln loading, kiln firing and charcoal unloading considered as special work and the wage of these works somewhat higher than the normal works. Various fixed costs and variable costs are illustrated in Table 15. The study showed that approximately 47,513.46 baht was required to charge a 6 × 3.5 m kiln for making charcoal.

#### 9.2.2 Revenue

The revenue form a 6 × 3.5 m kiln per charge is given in Table 15. The average production of lump charcoal and brands charcoal from the kiln per charge estimated as 6,624.33 and 772.11 kg, respectively (Appendix 4). The price of lump charcoal and brands charcoal was 8.00 and 6.00 baht/kg , respectively. Therefore the total revenues from 6 × 3.5 m kiln per charge estimated as 57,627.30 baht. Considering the production costs of 46,913.46 bath, the net profit was (57,627.30 -47,513.46) 10,113.84 baht/kiln/cycle. This profit was laid after 6 months of the first investment (wood processing for four and half months, kiln operation for one month and marketing for half month). In an average the kiln owner charged the battery of 3 kilns for 7 cycles in a year, therefore the profit would be 212,390.64 baht/year.

Based on the above economic analysis, the profit was not obviously too much if the total investment, opportunities and some uncertainties could be considered. The reason that charcoal was still produced by small number of kiln operators at Yeesarn Sub-district was due to the fact that the large plantation owners were not willing to sell their land or not to invest their land for other options. So they continued the traditional way of earning and could be generated annually from harvesting their own plantation and could be processed into charcoal.

Table 15 Cost of charging of 6 × 3.5 m sized single kiln for making charcoal in Yeesarn of Samut Songkram Province

| Items | Unit cost/rent or wage (baht ) | Depreciation cost (baht ) | Variable cost (baht ) | Total (baht ) |
|---|---|---|---|---|
| 1. Fixed cost | (3kilns) | | - | |
| Kiln construction | 450,000 | 714.29 | - | 714.29 |
| Factory shed | 80,000 | 126.98 | - | 126.98 |
| A motor boat | 160,000 | 253.97 | - | 253.97 |
| Tools and equipments | 15,000 | 47.62 | - | 47.62 |
| Land rent (0.16 ha) | 20,000 | 952.38 | - | 952.38 |
| 2. Variable cost | (11,000 Billets) | - | - | - |
| Wood buying (0.24 ha) | 18,000.00 | - | 18,000.00 | 18,000.00 |
| Felling and debarking | 1.00 | - | 11,000.00 | 11,000.00 |
| Transport of wood | 0.50 | - | 5,500.00 | 5,500.00 |
| Collection of firewood | 150.00 | | 600.00 | 600.00 |
| Kiln loading | 180.00 | - | 1,080.00 | 1,080.00 |
| Kiln firing | 180.00 | - | 2,340.00 | 2,340.00 |
| Charcoal unloading | 180.00 | - | 1,080.00 | 1,080.00 |
| Kiln repairing | 160.00 | - | 160.00 | 160.00 |
| Plastic sacs | 2.00 | - | 500.00 | 500.00 |
| Packaging | 160.00 | - | 320.00 | 320.00 |
| Loading & unloading | 160.00 | - | 640.00 | 640.00 |
| Charcoal transportation | 0.50/kg | - | 3,698.22 | 3,698.22 |
| Miscellaneous | - | - | 500.00 | 500.00 |
| Total | - | 2,095.24 | 45,418.22 | 47,513.46 |

# CONCLUSIONS

## 1. Site condition

The physical characteristics of soils in the *R. apiculata* plantation in Yeesarn was clay in texture and the average physical properties were 13% sand, 28% silt and 59% clay. Soil pH was 6.68 which was moderate acidic and the percentage of organic matter was 6.59% which was high in comparison to other mangrove areas. The results of electrical conductivity indicated that the salinity level of the study area was medium. The exchangeable phosphorus, potassium, calcium, magnesium and cation exchange capacity were varied considerably. This findings could be explained that though the soils of the plantation area at Yeesarn were still fertile than other mangrove areas of Chumphon and Ranong Province but the present study indicated that almost all the physical and chemical soil properties of the plantation areas had degraded in comparison to the previous study.

## 2. Plantation management

The silvicultural system applied for *R. apiculata* plantation in Yeesarn was a Clear-felling System with cutting rotation varied from 8 to 15 years. The main objectives of the plantation were for charcoal making (98%) and poles (2%). The farmers collected the seedlings from the existing plantation. They planted 25,000 propagules/ha with spacing of approximately 0.6 × 0.6 m. Replanting and weeding was needed to maintain the plantation. Thinning was not practiced till to harvest but natural thinning and pruning were occurred.

## 3. Productivity

The highest diameter recruitment and height was observed as 6.54 cm and 11.49 m, respectively in 15 years old plantation. The highest current annual increment of diameter, height, above ground biomass, and wood volume were observed as 0.46 cm/yr, 0.82 m/yr, 15.78 tons/ha/yr and 13.23 $m^3$/ha/yr, respectively in a 12 year old plantation. The highest yield of above ground biomass and commercial volume were estimated as 201.95 tons/ha and 178.98 $m^3$/ha, respectively in a 14 year old plantation. The results revealed that the growth performance of the *R. apiculata* plantation of Yeesarn was similar to the productivity of *Rhizophora* plantation at Pattani, Nakorn Sri Thammarat and Trang Province but showed somewhat less productivity than the previous study.

## 4. Wood Properties

The results showed that the density of wood of 8 to 15 years varied between 0.78 and 0.95 gm/$cm^3$ and the average was 0.86 gm/$cm^3$. There was highly statistical significant difference in density of wood between different ages (P=0.000). The moisture content of *R. apiculata* wood of 8 to 15 years varied between 11.23 and 14.91% and the average was 13.89%. There was no significant difference in moisture content of the wood between different ages (P = 0.649). The specific gravity of wood of 8 to 15 years varied between 0.78 and 1.08 and the average was 0.92. There was highly statistical significant difference in specific gravities of wood between different ages (P=0.005).

## 5. Charcoal Production

Dome-shaped brick beehive was only type of kiln for charcoal making in Yeesarn. The study identified 8 charcoal production centers with consisted of 40 charcoal kilns in the area and the total charcoal production was estimated as 2,003.23 tons/year. The production of the centers varied between 153.09 and 383.40 tons per year. Based on wood input the average gross yield from in a 6 × 3.5 m kiln was approximately 36.86% of which lump charcoal and brands charcoal constituted as 33.13% and 3.73%, respectively. There were no significant differences in yield of lump charcoal (P=0.776) and brands charcoal (P=0.512) of the kilns. The study revealed that the number of charcoal production center and charcoal kiln in Yeesarn Sub-district had decreased considerably.

## 6. Charcoal Quality

The density of charcoal of the kilns varied between 0.49 and 0.97 gm/cm$^3$ and the average was 0.70 gm/cm$^3$. There was no significant difference in density of charcoal of the kilns (P=0.443). The moisture content of charcoal of the kilns varied between 3.60 and 4.94% and the average was 4.42%. There was no significant difference in moisture content of charcoal of the kilns (P=0.759). The study showed somewhat higher moisture content in charcoal and it was due to lack of proper packaging of charcoal after unloading from the kilns. The specific gravity of charcoal of the kilns varied between 0.60 and 0.93 and the average was 0.78. There was no significant difference in specific gravity of charcoal of the kilns (P=0.465). In moisture free condition, the percentage of volatile matter, fixed carbon and ash content of charcoal from *R. apiculata* wood were 31.60, 66.20 and 2.20%, respectively. In moisture free condition the heat value of charcoal from *R. apiculata* wood was 6,800 kcal/kg.

## 7. Financial Analysis

The study showed that the total cost of *R. apiculata* plantation for the period of 1 to 15 years was 18386.26 baht/ha and the minimum and maximum revenue was varied between 56,250 and 93,750 baht/ha, respectively. At the minimum revenue level the *R. apiculata* plantation could be provided the NPV, B/C and IRR at 708.03 baht/ha, 1.04 and 8.36%, respectively. In maximum revenue level the plantation could be provided the NPV, B/C and IRR at 711.47 baht/ha, 1.04 and 12.38%, respectively. At the 10% fluctuation of cost and revenue level the projection revealed that only in maximum revenue level *R. apiculata* plantation through private venture was economically feasible..

## 8. Cost and Revenue of Charcoal Kiln

The results showed that approximately 47,513.46 baht was required to charge a 6 × 3.5 m kiln for making charcoal. The average production of lump charcoal and brands charcoal per cycle of a kiln were about 6,624 kg and 772 kg, respectively. The price of lump charcoal and brands charcoal were 8.00 and 6.00 baht/kg, respectively. Therefore the total revenue from the kiln/cycle was estimated as 57,627.30 baht and the net profit was 10,113.84 baht/kiln/cycle. In an average the kiln owner charged the battery of 3 kilns for 7 cycles in a year, therefore the profit would be 212,390.64 baht/year. The study revealed that the profit from charcoal kiln operation was not enough to provide modern technologies and economic incentive for future operation.

# RECOMMENDATIONS

1. The traditional management of *R. apiculata* plantation in Yeesarn of Samut Songkram Province must be improved and scientific information can be adopted. The initial planting spacing can be made 1 × 1 m. instead of 0.6 × 0.6 m. Mother-tree plot could be selected to insure the seedlings qualities for commercial planting and prevention of genetic loss.

2. This research showed that *R. apiculata* attained maximum growth rate when the plantation are 12 years old. So early cutting affected the production of biomass and wood volume. Appropriate cutting cycle should therefore be reconsidered in order to allowing the trees to grow. The present study recommended that the cutting rotation for charcoal production might be 12 to 15 years instead of 8 to 15 years.

3. For this study, the allometric equation used for estimating the above ground biomass and wood volume were might be different from the other study side and this result might be an error. Besides this study was not included the ground root biomass and carbon content of each part of the plant. Even this study was not studied on development of charcoal production and quality. So, further extensive research and development on plantation productivity, charcoal production, quality, packaging and marketing are needed.

4. This research revealed that the net return from both *R. apiculata* plantation and charcoal making activities were low and not enough for future operation. So, government incentives are necessary for improving the attractiveness of mangrove plantation and charcoal making for the both producer groups. Some options might be support for seedlings and mother-tree selection, technological assistance for both plantation establishment and charcoal making, support for charcoal marketing and trade, and tax relaxation.

5. This study considered only the economic return of *R. apiculata* plantation from stumpage values. Other indirect benefits such as ecological, environmental, aesthetic, nutritional, tourist attractions and other plant products such as wood dyes and medicinal values etc should also be considered for calculation and assessment of net economic return from the mangrove plantation.

6. This research revealed some of the baseline information on *R. apiculata* mangrove plantation management, charcoal production, charcoal quality, and economic return from *R. apiculata* plantation and charcoal making activities. The results of this study could be considered as a guideline and also be a database for management of mangrove plantation and sustainable mangrove resources utilization for further study in mangrove areas in the future.

# LITERATURE CITED

Aksornkoae, S. 1975. **Structure, Regeneration and Productivity of Mangrove in Thailand.** Ph.D. Thesis, Michigan State Univ. USA.

______, Wattayakorn and W. Kaitpraneet. 1978. **Physical and Chemical Properties of Soil and Water in Mangrove Forest at Amphoe Khlung, Changwat, Chantaburi, Thailand.** Report Submitted to UNESCO, Paris France.

______, S., P. Iampa and B. Kooha. 1982. A comparison of structural characteristics of mangrove forest near mining area and undisturbed mangrove forest in Ranong, pp 149-163. *In* **Proc. Rattanakosin Bicentennial Joint Seminar on Science and Mangrove Resources.** 2-6 August, Phuket, Thailand.

______, J.H.Kongsangchai and V. Jintana. 1987. Ecological equilibrium and productivity of mangrove forests in Thailand. **Thai Jour. of Forestry**. 6: 160-187.

______, C. Khemnark and W. H. H. Mellink. 1992. **Mangrove For Charcoal.** A Vanishing Sustainable Woodfuel Resource System (The Case of Yeesarn, Upper Gulf of Thailand). Regional Wood Energy Development Programme In Asia. GCP/RAS/131NET; Field Doc. No. 30. FAO, Bangkok, January 1992. pp 1-41.

______. 1993. **Ecology and Management of Mangroves**. IUCN, Dyna Print Ltd. Part., Bangkok, Thailand.

______. 1996. Reforestation of mangrove forests in Thailand: A case study of Pattani Province, pp. 52-63. *In* C.D.Field, ed. Restoration of Mangrove Ecosystem. **The International Society of Mangrove Ecosystems (ISME),** Okinawa, Japan.

______. 1996. Scientific Mangrove Management in Thailand, pp. 118-126. *In* S. Aksornkoae, L. Puangchit and B. Thaiutsa, eds. **Tropical Forestry in the 21st Century**, **Vol.10. Mangrove Ecosystems. FORTROP'96 International Conference.** Bangkok Thailand.

Alongi, D.M., K.G. Boto and A.L. Robertson. 1992. **Nitrogen and Phosphorus Cycles**. *In* Coastal and estuarine studies. A.L. Robertson and D.M. Alongi (eds.). Tropical mangrove ecosystems. Amer. Geophys. Union, Washington, D.C.

Baileys, R.T. and P.R. Blankenhorn. 1982. Calorific and porosity development in carbonized wood. **Wood Sci**. 15 (1):19-28.

Beall, F. C. 1972. Introduction to thermal analysis in the combustion of wood. **Wood Sci**. 5 (2):102-108.

______. 1977. Properties of wood during carbonization under fire condition, pp. 107-114. *In* I.S. Goldstein, ed. **Wood Technology: Chemical Aspects**. **ACS Symposium Series 43,** Wash. D.C.

Booth, H.E. 1981. Realities of making charcoal**. Unasylva**. 33 (131): 37-38.

Boto, K.G. 1982. Nutrients and organic fluxes in mangroves. *In* Mangrove ecosystems in Australia. Structure function and management. B.F. Clough (ed.). **Proc. Of the Australian Institute of Marine Science.** Cape Ferguson, 18-20 April 1979.

Bunt, J. S., K. G. Boto and G. Boto. 1979. A Survey Method for Estimating Potential Levels of Mangrove Forest Primary Production. **Mar.Biol.** 52: 123-128.

______, W.T. Williams and H.J. Clay. 1982. River water salinity and the distribution of mangrove species along several rivers in Northern Queensland. **Aus. J. Bot.** 30: 401-412.

Chaichavalit, S. 1989. **An Economic Analysis of Intensive Giant Tiger Prawn Culture: A Case Study of Samut Songkram**. Faculty of Economics, Thammasat University, Bangkok, Thailand.

Chaiglom, D. 1982. Biological and ecological studies of insects in mangrove forests pp. 227-229. **Proc. Rattanakosin Bicentennial Joint Seminar on Science and Mangrove Resources.** 2-6 August, Phuket, Thailand.

Chan, H.T. 1990. **Proposal establishment and management of mangrove planting in the Duyen Hai District, Southern Vietnam.** FAO Field Doc. N.I VIE/86/027:13-15 p.

Chanprapai, T. 2005. **Comparative analysis on economic return including carbon storage value from *Rhizophora apiculata* plantations for conservation and commercial purposes in Pattani Province.** M.S. Thesis. Mahidol Univ. Bangkok.

Chantarasena, T. 1985. **Charcoal Making and Quality of Charcoal from Mangrove Timbers by Small Brick Kiln.** M.S. Thesis, Kasetsart University, Bangkok.

Chapman, V.J. 1975. Mangrove Biogeography, pp. 3-22. *In* Wash, G.E., S.C. Snedaker and H.J.Teas, eds. **Proc. Int. Symp. Mange. Mangr,** 8-11 October 1974, East-West Center, Honolulu.

Charuppat, T. and J. Charuppat. 1997. **The Use of Land-5 (TM) Satellite Immages for Tracing the Changes on Mangrove Forest Areas of Thailand**. Forestry Res. Office, Royal Forest Dep. Bangkok.

Cheevawut, J. S. 2003. **Economic Sustainability Analysis of Private Mangrove Plantation (Rhizophora apiculata) and Charcoal Production at Tambol Yeesan, Amphoe Amphawa, Samut Songkhram.** M.S. Thesis, Kasetsart Univ. Bangkok.

Chomcharn, A. 1983. **Country Statue Report on Charcoal Production and Technology in Thailand**. FAO/ESCAP Workshop. Bangkok.

______. 1984. **Charcoal Production Improvement for Rural Development in Thailand.** Published by the National Energy Administration, Ministry of Science, Technology and Energy. Bangkok, Thailand.

Christensen, B. 1978. Biomass and Primary Production of *Rhizophora apiculata* in Mangrove in Southern Thailand. **Aquatic Botany** (4): 43-52.

Chunkao, K., N. Tangtham and W. Niyom. 1982. Estuarine hydrological characteristics of mangrove forest in Ranong, Southern Thailand, pp. 134-148. **Proc. Rattanakosin Bicentennial Joint Seminar on Science and Mangrove Resources.** 2-6 August, Phuket, Thailand.

Chunwarin, W. 1982. Production of charcoal and charcoal briquette from mangrove timber, pp. 262-267. **Proc. Rattanakosin Bicentennial Joint Seminar on Science and Mangrove Resources.** 2-6 August, Phuket, Thailand.

Clarke, L.D. and N.J. Hannon. 1971. The Mangrove Swamp and Salt Marsh Communities of the Sydney District. IV. The Significance of Species Interaction. **J. Ecol.** 59: 535-553.

Clough, B.F. 1984. Growth and Salt Balance of the Mangroves. *Avicennia marina* (Forsk.) Vierh. And *Rhizophora stylosa* Griff. In Relation to Salinity**. Aus. J. Plant Physio.** 11: 419-430.

Cutter, B.E. and E.A. McGinnes, Jr. 1981. A note on density change patterns in charred wood. **Wood and Fiber.** 13(1): 39-44.

De Hann, T.H. 1931. Het Enn En Ander over de Tijlatjap Sche Vloedbosschen. **Tectona**. 24: 39-76 (English Summary).

Du, L.V. 1962**. Ecology and Silviculture of Mangrove**. Yale Univ. School of Forest. Unpublished mimeo.

Earl, D.E. 1974. **A Report on Charcoal**. Food and Agriculture Organization of the United Nations, Rome.

Earl, D.E. 1975. **Charcoal.** An Andre Meyer Fellowship Report, FAO, Rome.

______ and A. Earl. 1975. **Charcoal Making for Small Scale Enterprises.** An Illustrated Training Manual, ILO, Geneva.

English, S.C. Wilkinson and V. Baker. 1997. Survey manual for tropical marine resources. 2nd Edition. **Aust. Inst. Mar. Sci.**

FAO. 1985. **Mangrove Management in Thailand, Malaysia and Indonesia**. FAO Environment Paper 4. Rome, Italy. 60 p.

______. 1985[b]. **The Maturing Mangrove Plantations of the Coastal Afforestation Project in Bangladesh.** Field Doc. No.2 FAO/UNDP Project, BGD/85/085, Dhaka. 69 p.

______. 1993. **Mangrove for Production and Protection. A Changing Resource System: Case Study in Can Gio District, Southern Vietnam**. Field Doc. No. 43. GCP/RAS/131/NET. Bangkok. 59 p.

Florestal Acessita, S.A. 1982. **Charcoal Production in Brazil**. State of the Art, Report Submitted to USDA. Forest Service under Contract No. 53-319 R-0-144.

Foth, Henry D. 1978. **Fundamentals of Soil Science**. Six Edition. John Wiley & Sons. New York, USA.

Giglioli, M.E.C. and D.F. King. 1966. The Mangrove Swamps of Keneba, the Lower Cambia River Basin. III. Seasonal Variation in the Chloride and Water Content of Swamp Soils, with Observations on the Water Level and Chloride Concentration of Free Soil Water Under a Barren Mudflat During the Dry Season. **J. Appl. Ecol**. 3: 1-19.

Gittinger, J. P. 1982. **Economic Analysis of Agricultural Projects**. 2nd ed. The Johns Hopkins University Press, Baltimore and London.

Gledhill, D. 1963. The Ecology of the Aberdeen Creek Mangrove Swamp. **J. Ecol**. 51: 639-703.

Hamilton, L.S. and Snedaker, S.C. 1984. **Handbook of Mangrove Area Management**. Environment and Policy Institute, East-West Center, Hawaii. 123 p.

Hankaew, M. C. 2000. **Successional Trend of Peat Swamp Forests at Phru Toh Daeng and Phru Kuan Kreng, Southern Thailand**. Ph.D. Thesis, Kasetsart Univ. Bangkok.

Hassan. M.K. 1993. **Study on Population Ecology and Activity Patterns of Hanuman Langur (*Presbytis entellus*) in Keshabpur, Jessore**. M.Sc. Thesis. Department of Zoology, University of Dhaka, Bangladesh.

Higari, M. 1982. Overall utilization of mangrove, pp. 268-275. **Proc. Rattanakosin Bicentennial Joint Seminar on Science and Mangrove Resources.** 2-6 August, Phuket, Thailand.

Hoamuangkaew, W. 2002. Financial Analysis of *Melaleuca cajuputi* reforestation in Toe Daeng Peat Swamp Forest, Narathiwat Province, pp. 91-108**. The first Thai-Biomass Utilization Symposium, 22 March, Kasetsart University, Bangkok.**

Hong, P.N. 1994. **Reforestation of mangrove forests in Vietnam**. *In* Proceedings of the workshop on ITTO project. **Development and Dissemination of Re-afforestation Techniques of Mangrove Forests.** 18-20 April 1994. Bangkok, Thailand. ITTO, JAM, Thai NATMANCOM / NRCT: 141-151.

Hutchings, P. and P. Saenger. 1987. **Ecology of Mangroves**. University of Queensland Press, St. Lucia, Australia.

Hussain, M.Z. 1991. **The Management of the Sunderbans Forests, Bangladesh**. Paper presented at the International Workshop on Wetlands and Waterfowl Conservation in South and West Asia. Karachi, Pakistan. December, 1991.

IDRC/NRCT/RFD. 1991. **Final Report, Remote Sensing and Mangroves Project** (Thailand). August, 1991. Bangkok.

Ince, P. J. 1979. How to estimate recoverable heat energy in wood or bark fuels. **General Technical Report FPL 29**. USDA Forest Service. pp 1-7.

Jindanuch, K. 2003. **Carbon distribution in mangrove area of Tung Kha Estuary, Chumphon Province.** M.S. Thesis, Mahidol Univ. Bangkok.

Jintana, V. 1984. **Age Determination of Some Tree Species in Mangrove Forest.** M.S. Thesis, Kasetsart Univ. Bangkok. M.S. Thesis, Kasetsart Univ. Bangkok.

Karchesy, J. and P. Koch. 1979. Energy production from hardwood growing on southern pine sites. **General Technical Report 50-24**. USDA Forest Service. 59 p.

Khemnark, C., A. Eiumnoh, S. Muksombut and S. Aksornkoae, 1987. **Study on Mangrove Soils at Ban Don Day and Phang-nga Bay**. Report of Office of the National Environment Board, Bangkok, Thailand.

______, S. Aksornkoae, V. Jintana, U. Chaochalakorn and R. W. Jones, (eds.). 1995. Ecology and Management of Mangrove Restoration in East and Southeast

Asia: **Proceedings of the ECOTONE IV. 18-22 January 1995, Surat Thani.** Publ. Amarin Printing and Publishing Public Co. Ltd. Bangkok. 339 p.

Kollmann, F.P. and I.B. Sachs. 1967. The effect of elevated temperature on certain wood cells. **Wood Science and Technology**. 1(1): 14-25.

Kongsangchai, J.H. 1995. **Problems of Mangrove Degradation in Thailand**. pp. 119-129. **Proceedings of the ECOTONE IV. 18-22 January 1995, Surat Thani.** Pub. Amarin Printing and Publishing Public Co. Ltd. Bangkok.

______, P. Tanapermpool, S. Havanond and V. Jintana. 1990. **Report on Productivity of Mangrove Forest Plantation in Thailand**. Royal Forest Department, Bangkok.

Kryla, J. M. 1980. Characteristics of carbonized wood affected by extraction. **Wood Sci.** 13 (1):18-25.

Kuenzler, E.J. 1968. **Mangrove Swamp System**. Coastal Ecological System of the United States. pp. 83-353. *In*: Odum, H.T., B.J. Copeland and E.A. McMahon. (eds.). Chapel Hill, N.C.: Int. Mar. Sci., Univ. of North Carolina.

Kunstadter, P., Eric C. F. Bird, and Sanga Sabhasri. 1986. **Man in the Mangroves**: The Socio-economic Situation of Human Settlements in Mangrove Forests. The United Nations Univ. Tokyo, Japan. pp 1-117.

Kunstadter, P. (ed.) 1999. Mangrove Ecosystems. **Proceedings of Symposium on Significance of Mangrove Ecosystems for Coastal People**. 19-21 August, 1996. Hat Yai, Thailand. **ISME Mangrove Ecosystems Proceedings** No. 4. 1-132 pp.

Lee, W. F., Boehlje, M. D., Nelson, A. G. and Murry, W. G. 1988. **Agricultural Finance.** $8^{th}$ ed. Iowa State University Press. Ames, Iowa 50010, USA.

Lugo, A.E. and S.C. Snedaker. 1974. The Ecology of Mangrove. **Annual Review of Ecology and Systematic** 5: 39-64.

Majumdar, B. 1982. **From Country Kilns to Portable Kilns, An Experience of Charcoal Making In Maharashtra**. A country report to ILO/DANIDA/RFD/FIO regional seminar on fuel wood and charcoal preparation. Lampang, Thailand. 7-26 March, 1983.

Maslekar, Sri A.R. 1982. **Charcoal Production Using a Portable Metal Kiln, in Appropriate Technology in Forestry.** FAO, Rome. pp 70-74.

Macnae, W. 1968. A general account of the fauna and flora of mangrove swamps and forests in the Indo-West Pacific Region. **Adv. Mar. Biol.** 6: 73-270.

Meepol, W. 2002. **Litter Production and Site Characteristics in Relation to Structure and Composition of Mangrove Forest in Ranong Province, Southern Thailand**. Ph.D. Thesis, University of the Philippines Los Banos.

Muhammed, S. B. 1980. **Variability of Some Wood Quality Indicators in Four Malaysian Dipterocarps**. M.S. Thesis, University of the Philippines Los Baffos.

Nam, V. N., T. Viet My and Michael Jensen (eds.). 1993. **Mangrove for Production and Protection.** A Changing Resource System: Case Study in Can Gio District, Southern Vietnam. Regional Wood Energy Development Programme in Asia. GCP/RAS/131/NET; Field Doc. No. 43. Food and Agriculture Organization of the United Nations, Bangkok. pp 1-57.

Nishihira, M. (ed.). 1997. **Benthic Communities and Biodiversity in Thai Mangrove Swamps.** Biological Institute, Tohoku University, Japan. pp 1-224.

Odum, H.T. and E.C. Odum. 1976. **Energy Basis for Man and Nature**. McGraw-Hill.

Odum, W.E., C.C. Mcivor, and T.J. Smith III. 1982. **The ecology of the mangroves of South Florida: A community profile**. Washington, D.C.: Fish and Wildlife Service U.S. Department of Interior.

Oliver, J. 1982. **The geographic and environmental aspects of mangrove communities: climate.** *In* B.F. Clough (ed.). Mangrove ecosystems in Australia. Structure function and management. Australian Institute of Marine Science.

Panshin, A. J. and C. de Zeeuw. 1970. **Textbook of Wood Technology**. 3rd ed., Vol. 1. New York: McGraw – Hill Book Company.

Panya, O., George W. Lovelace, Prasat Saenchai and Panomsak Promburom. 1988. **Charcoal Making in Rural Northeast Thailand: Rapid Rural Appraisal of a Woo-based, Small-scale Enterprise**. KKU-FORD Rural Systems Research Project, Khon Kaen University, Khon Kaen 40002, Thailand. pp 1-81.

Paphavasit, N., M. Nishihira, A. Piuumsomboon and C. Sudtongkong. 1997. Historical Aspect of Samut Songkhram Mangrove Swamp: From Natural Forest to Mangrove Plantations. pp 205-218. *In* Nishihira, M. (ed.). 1997. **Benthic Communities and Biodiversity in Thai Mangrove Swamps.** Biological Institute, Tohoku University, Japan.

Royal Forest Department. 2004. **Forestry Statistics**. ISSN 0857 – 2711. Royal Forest Department, Bangkok.156 p.

Saenger, P. 1982. **Morphological, Anatomical and Reproductive Adaptations of Australian Mangroves**. pp. 153-191. *In* B.F. Clough (ed.). Mangrove Ecosystem in Australia: Structure, Function and Management. Aust. Nat. Univ. Press, Canberra.

______, E.J. Hegerl and J.D.S. Davie. 1983. Global Status of Mangrove Ecosystems. **Commission on Ecology Paper** No. 3. IUCN, Gland, Switzerland.

Santisuk, T. 1983. **Taxonomy of the Terrestrial Trees and Shrubs in the Mangrove Formations in Thailand**. The UNDP/UNESCO Regional Course on Introduction to Mangrove Ecosystems. NRCT, Bangkok. March 2-30.

Shafizadeh, F. and P.S. Chin. 1977. Thermal deterioration of wood. **Wood Technology: Chemical Aspects. ACS Symposium Series** 43, Wash. D.C., pp. 57-81.

Shingi, P. M. and S. P. Seetharaman. 1993. **Charcoal Production and Marketing in Gujarat.** Regional Wood Energy Development Programme in Asia. GCP/RAS/131/NET; Field Doc. No. 36. Food and Agriculture Organization of the United Nations, Bangkok, May 1993. 70 p.

Siddiqi, N.A. 2001. **Mangrove Forestry in Bangladesh**. Institute of Forestry and Environmental Science, University of Chattagong, Bangladesh

Slocum, D. H., E. A. McGinnes and F. C. Beall. 1978. Charcoal yield shrinkage and density changes during carbonization of oak and hickory woods. **Wood Sci**. 11 (1): 42-47.

Smith, D.M., Brucce C. Larson, Matthew J. Kelty and P. Mark S. Ashton. 1997. **The Practice of Silviculture:** Applied Forest Ecology. Publ. John Wily & Sons Inc. New York, USA. 537 p.

Spalding, M., Francois Blasco and Colin Field. (eds.). 1997. World Mangrove Atlas. **The International Society for Mangrove Ecosystems**, Okinawa, Japan.

Steenis, C.G. and Van, G.A. 1958. Rhizophoraceae. **Fl. Maly.** 5: 431 – 493.

Tanapermpool, P. 1989. **Productivity of *Rhizophora apiculata* Plantation in Changwat Pattani.** M.S. Thesis, Kasetsart Univ. Bangkok.

Thammincha, S., L. Puangchit and H. Wood (eds.) 1993. **Forestry Economics Research in Asia.** Proceedings of the Colloquium on Forestry Economics Research in Asia. 18-20 March 1991, Bangkok, Thailand. 158 p.

Thom, B.G. 1982. **Mangrove ecology- A geomorphological Prospective.** Mangrove Vegetation in Northern Australia. *In* B.F.Clough (ed.). Mangrove ecosystems in Australia. Structure function and management. Australian Institute of Marine Science.

Tillman, D.A. 1981. Review of mechanisms associated with wood combustion. **Wood Science** 13(4): 177-184.

Tomlinson, P.B. 1986. **The Botany of Mangroves**. Cambridge University Press, Cambridge, New York, USA.

UNDP/FAO. 1989. **Sampling Designs and Biometrics for Forest Inventories**. Report on Project Course C. College of Forestry University of the Philippines, Los Banos, 8 May – 2 June. 393 p.

U. S. Forest Products Laboratory. 1961. **Charcoal Production Marketing and Use**. Report No. 2213. July 1961.

______. 1974. **Wood handbook**: Wood as an Engineering Material. (USDA Agr. Handb. 72, rev), Washington, D.C.

Walsh, G.E. 1974. Mangroves: A review *In:* R.J. Reimold and W.H. Queen (eds.). **Ecology of halophytes**. New York: Academic Press, Inc.

Watson, J.G. 1928. Mangrove Forests of the Malayan Peninsula, Malay**. For. Rec.** 6: 1-275.

Wells, A.G. 1982. **Mangrove Vegetation of Northern Australia**. pp 57-58. *In* B.F. Clough (ed.). Mangrove ecosystems in Australia. Structure function and management. Australian Institute of Marine Science.

Wechakit, D. 1987. **Growth and Survival of Private Mangrove Plantation (*Rhizophora apiculata*) at Amphoe Amphawa, Changwat Samut Songkhram.** M.S. Thesis, Kasetsart University. Bangkok.

Whittaker, R.H. and G.M. Woodwell. 1971. Management of Net Primary Production of Forest. *Cited* Wechakit, D. 1987. **Growth and Survival of Private Mangrove Plantation (*Rhizophora apiculata*) at Amphoe Amphawa, Changwat Samut Songkhram.** M.S. Thesis, Kasetsart University. Bangkok.

Zicherman, J. B. and R. B. Williamson. 1982. Microstructure of wood charcoal part 1: Whole wood. **Wood Science and Technology.** 15: 237-249.

Zicherman, J. B. and R. B. Williamson. 1982. Microstructure of wood charcoal part 2: Fire retardant treated wood. **Wood Science and Technology**. 16: 19-34.

# APPENDIX

Appendix Table 1 Mean monthly temperature, relative humidity and rainfall of the study area during 1986 to 2005

| Month | Mean monthly temperature (°C) | | | Mean monthly relative humidity (%) | | | Mean monthly rainfall (mm), r-days, and daily max. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Mean max. | Mean min. | Mean | Mean max. | Mean min. | Mean amount | Rain-day | Ext. max. |
| January | 27.2 | 32.5 | 22.9 | 69 | 85 | 49 | 6.1 | 0.6 | 41.0 |
| February | 28.2 | 33.2 | 24.3 | 71 | 87 | 51 | 1.4 | 0.4 | 15.0 |
| March | 29.4 | 34.2 | 25.8 | 72 | 87 | 53 | 22.5 | 1.9 | 95.0 |
| April | 30.6 | 35.4 | 26.9 | 72 | 86 | 53 | 11.0 | 1.2 | 50.6 |
| May | 30.0 | 34.4 | 26.2 | 74 | 88 | 58 | 114.9 | 9.2 | 77.6 |
| June | 29.5 | 33.6 | 26.0 | 74 | 87 | 59 | 114.7 | 12.7 | 55.0 |
| July | 29.2 | 33.1 | 25.7 | 74 | 87 | 59 | 112.6 | 12.7 | 65.2 |
| August | 28.8 | 32.9 | 25.5 | 75 | 88 | 60 | 109.1 | 14.6 | 50.6 |
| September | 28.4 | 32.7 | 25.0 | 79 | 91 | 62 | 208.2 | 15.7 | 100.0 |
| October | 28.2 | 32.5 | 24.7 | 78 | 91 | 61 | 295.4 | 16.9 | 112.3 |
| November | 27.8 | 32.4 | 23.9 | 69 | 84 | 52 | 58.1 | 5.4 | 62.7 |
| December | 26.6 | 31.6 | 22.0 | 66 | 80 | 50 | 10.4 | 1.6 | 80.2 |
| Annual | 28.7 | 33.2 | 24.9 | 73 | 87 | 56 | 1064.5 | 92.9 | 112.3 |

Note: Temperature and relative humidity data were based on 'Bangkok Metropolis Meteorological Station' and rainfall data based on Amphawa Station' of Samut Songkram Province.

Appendix Table 2 Mangrove vegetation in Yeesarn Sub-district of Samut Songkram Province

| Scientific name | Vernacular name | Family |
|---|---|---|
| *Acanthus ebracteatus* 1 | Ngueak plaamo dok muang | Acanthaceae |
| *A. ilicifolius* 1 | Ngueak plaamo dok khao | Acanthaceae |
| *Acrostichum aureum* 2 | Prong thale | Pteridaceae |
| *A. speciosum* 2 | Prong nuu | Pteridaceae |
| *Aegialitis rotundifolia 1* | Samae | Plumbaginaceae |
| *Avicennia alba* 1 | Samae khao | Avicenniaceae |
| *A. marina* 1 | Samae thale | Avicenniaceae |
| *A. officinalis* 1 | Samae dam | Avicenniaceae |
| *Barringtonia asiatica* 2 | Chik le | Barringtoniaceae |
| *B. racemosa* 2 | Chik suan | Barringtoniaceae |
| *Bruguiera cylindrica* 1 | Thua khao | Rhizophoraceae |
| *B. gymnorrhiza* 1 | Pangka huasum dok daeng | Rhizophoraceae |
| *B. parviflora* 1 | Thua dam | Rhizophoraceae |
| *B. sexangula* 1 | Pangka huasum dok khao | Rhizophoraceae |
| *Ceriops tagal* 1 | Prong daeng | Rhizophoraceae |
| *Clerodendrum inerme* 2 | Prong daeng | Verbenaceae |
| *Dolichandrone spathacea* 2 | Khae thale | Bignoniceae |
| *Hibiscus tiliaceus* 2 | Po thale | Malvaceae |
| *Kandelia candel* 1 | Rang ka thae | Rhizophoraceae |
| *Lumnitzera racemosa* 1 | Fadd dok khao | Combretaceae |
| *Nypa fruticans* 1 | Chaak | Palmae |
| *Pluchea indica* 2 | Khluu | Compositae |
| *Rhizophora apiculata* 1 | Kongkaang bai lek | Rhizophoraceae |
| *R. mucronata 1* | Kongkaang bai yai | Rhizophoraceae |
| *Sonneratia caseolaris* 1 | Lampoo | Sonneratiaceae |
| *S. griffithii* 1 | Lampaen thale | Sonneratiaceae |
| *S. ovata* 1 | Lampaen | Sonneratiaceae |
| *Sueda maritima* 2 | Cha khraam | Chenopodiaceae |
| *Thespesia populnea* 2 | Pho thale | Malvaceae |
| *Xylocarpus gangeticus* 2 | Ta ban | Malvaceae |
| *X. granatum* 1 | Ta buun khao | Malvaceae |
| *X. moluccensis* 1 | Ta buun dam | Malvaceae |

Note: 1 Indicated 'trees and shrubs' absolutely bound to salt or brackish water (true mangrove species) and 2 indicated 'trees and shrubs' belonging to the littoral vegetations or inland vegetations which make their appearance in the back-mangroves (mangrove associates).

Appendix Table 3 Density, moisture content and specific gravity of wood samples of different ages of *R. apiculata* plantation

| Age / Year of wood | Sample no. | Density (g/cm$^3$) | Moisture content (%) | Specific gravity |
|---|---|---|---|---|
| | $8S_1$ | 0.821 | 14.58 | 0.78 |
| 8 | $8S_2$ | 0.779 | 13.28 | 0.87 |
| | $8S_3$ | 0.795 | 13.12 | 0.88 |
| | $9S_1$ | 0.795 | 14.91 | 0.89 |
| 9 | $9S_2$ | 0.839 | 12.96 | 0.89 |
| | $9S_3$ | 0.830 | 11.23 | 0.88 |
| | $10S_1$ | 0.873 | 12.86 | 0.89 |
| 10 | $10S_2$ | 0.892 | 14.43 | 0.90 |
| | $10S_3$ | 0.866 | 13.99 | 0.89 |
| | $11S_1$ | 0.856 | 14.39 | 0.91 |
| 11 | $11S_2$ | 0.858 | 14.19 | 0.92 |
| | $11S_3$ | 0.849 | 14.46 | 0.92 |
| | $12S_1$ | 0.807 | 14.22 | 0.92 |
| 12 | $12S_2$ | 0.892 | 14.43 | 0.93 |
| | $12S_3$ | 0.845 | 13.97 | 0.95 |
| | $13S_1$ | 0.848 | 14.29 | 0.94 |
| 13 | $13S_2$ | 0.88 | 13.72 | 0.93 |
| | $13S_2$ | 0.873 | 14.49 | 0.95 |
| | $14S_1$ | 0.892 | 12.75 | 0.95 |
| 14 | $14S_2$ | 0.917 | 13.89 | 0.95 |
| | $14S_3$ | 0.865 | 14.67 | 1.06 |
| | $15S_1$ | 0.954 | 14.39 | 1.08 |
| 15 | $15S_2$ | 0.927 | 13.68 | 0.94 |
| | $15S_3$ | 0.901 | 14.47 | 0.96 |
| Mean ± std of 24 Samples | | 0.86± 0.043 | 13.89± 0.83 | 0.92± 0.06 |

Appendix Table 4 Charcoal out-put from 3 different charcoal kilns in Yeesarn by using *R. apiculata* wood

| Kiln no. | Weight of green wood (kg) | Weight of air dried raw wood (kg) | Air dried firewood (kg) | Moisture content (%) | Operation time (hour) | Gross production (kg) | Brands charcoal (kg) | Lump charcoal (kg) | Brands charcoal yield (%) | Lump charcoal yield (%) | Net production rate (kg/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 28,068 | 20,734 | 1,982 | 33.27 | 594 | 7,405 | 789 | 6,616 | 3.81 | 33.17 | 11.13 |
| 1 | 27,575 | 20,392 | 2,080 | 33.13 | 588 | 7,413 | 768 | 6,645 | 3.77 | 33.86 | 11.30 |
| | 28,094 | 20,816 | 1,894 | 32.87 | 594 | 7,263 | 691 | 6,572 | 3.32 | 32.66 | 11.06 |
| | 28,286 | 20,936 | 2,119 | 33.02 | 598 | 7,427 | 736 | 6,691 | 3.52 | 33.12 | 11.19 |
| 2 | 28,097 | 20,767 | 2,045 | 33.19 | 599 | 7,369 | 784 | 6,585 | 3.78 | 32.95 | 10.99 |
| | 27,893 | 20,533 | 1,883 | 33.7 | 597 | 7,412 | 815 | 6,,597 | 3.97 | 32.46 | 11.05 |
| | 27,349 | 20,315 | 1,862 | 32.72 | 591 | 7,414 | 760 | 6,654 | 3.74 | 34.03 | 11.26 |
| 3 | 28,222 | 21,008 | 2,127 | 33.50 | 596 | 7,477 | 814 | 6,663 | 3.87 | 32.99 | 11.18 |
| | 28,043 | 20811 | 2,076 | 32.82 | 600 | 7,388 | 792 | 6,596 | 3.81 | 32.95 | 10.99 |
| Mean ± std | 27,958.56 ± 307.45 | 20,701.33 ± 237.95 | 2,007.56 ± 105.04 | 33.14 ± 0.32 | 595.22 ± 3.90 | 7,396.44 ± 58.04 | 772.11 ± 39.47 | 6,624.33 ± 40.55 | 3.73 ± 0.10 | 33.13 ± 0.51 | 11.13 ± 0.11 |

Appendix Table 5 Density, moisture content and specific gravity of the charcoal samples from 3 different kilns

| Kiln no. | Sample No. | Density ($gm/cm^3$) | Moisture content (%) | Specific gravity |
|---|---|---|---|---|
| | 1 | 0.49 | 4.46 | 0.78 |
| | 2 | 0.70 | 4.34 | 0.95 |
| $K_1$ | 3 | 0.85 | 4.23 | 0.67 |
| | 4 | 0.83 | 4.05 | 0.69 |
| | 5 | 0.56 | 4.94 | 0.73 |
| | 6 | 0.56 | 4.02 | 0.93 |
| | 1 | 0.83 | 4.64 | 0.73 |
| | 2 | 0.58 | 4.62 | 0.73 |
| $K_2$ | 3 | 0.62 | 4.58 | 0.60 |
| | 4 | 0.56 | 4.77 | 0.78 |
| | 5 | 0.76 | 3.60 | 0.74 |
| | 6 | 0.68 | 4.48 | 0.88 |
| | 1 | 0.86 | 4.22 | 0.92 |
| | 2 | 0.54 | 4.54 | 0.89 |
| $K_3$ | 3 | 0.76 | 4.59 | 0.74 |
| | 4 | 0.97 | 4.65 | 0.70 |
| | 5 | 0.71 | 4.50 | 0.81 |
| | 6 | 0.71 | 4.34 | 0.82 |
| Mean ± std of 18 samples | | 0.70±0.14 | 4.42±0.31 | 0.78±0.09 |

Appendix Table 6  Cost of per hectare *R. apiculata* plantation in Yeesarn of Samut Songkram Province

| Item | Unit Cost in Baht | Wage in Baht (Baht/Man day) | Cost in Year | | | | Total |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4-15 | |
| 1. Fixed Cost (Area 32.00 ha) | | | | | | | |
| A tug boat | 50,000 | - | 1,562.50 | - | - | - | 1,562.60 |
| Water pump | 5,500 | - | 171.88 | - | - | - | 171.88 |
| Tools and equipments | 4,500 | - | 140.63 | - | - | - | 140.63 |
| 2. Variable Cost | | | | | | | |
| Land clearing | | 150 | 937.50 | - | - | - | 937.50 |
| Site preparation | | 150 | 1,406.25 | - | - | - | 1,406.25 |
| Seedling collection | 0.10/propagule | - | 2,750.00 | - | - | - | 2,750.00 |
| Planting | | 160 | 2,080.00 | - | - | - | 2,080.00 |
| 1st Beating up | | 160 | 1,000.00 | - | - | - | 1,000.00 |
| Seedling | 0.10/propagule | - | 500.00 | - | - | - | 500.00 |
| Counting and watching | | 150 | 937.50 | 937.50 | 468.75 | - | 2,343.75 |
| 2nd Beating up | | 160 | - | 1,000.00 | - | - | 1,000.00 |
| Seedling | 0.10/propagule | - | - | 500.00 | - | - | 500.00 |
| Weeding | | 150 | - | 1,406.25 | 937.50 | - | 2,343.75 |
| Miscellaneous | | - | 650.00 | 550.00 | 450.00 | - | 1,650.00 |
| Total | | | 12,136.26 | 4,393.75 | 1,856.25 | - | 18,386.26 |