Chapter 2

Literature review

2. Description of the Resource and Habitat

Mangroves consist of halophytic (salt-tolerant), woody, seed-bearing plants. These range in size from tall trees to small shrubs; worldwide, there are more than 50 species (Snedaker and Getter, 1985). They are characterized by their common ability to thrive along sheltered, intertidal coastlines in sediments that are saline, often anaerobic and sometimes acidic. Many of the individual species are uniquely adapted to their environment with, for instance, prop roots, pneunatophores (pencil-like upright roots), lenticles (air holes), and viviparous propagules (seed that germinate on the tree)—all enabling them to survive in a relatively stressful environment. Although mangrove forests develop in a saline environment, they have the usual plant requirements for fresh water, nutrients, and oxygen. Salinity, which varies in the intertidal zone, exacts a metabolic cost on mangroves but also serves to eliminate competition from nonhalophytic species. Variation in topography, sediment types, and hydroperiod (seasonal period of saltwater/freshwater inundation), and salinity determine the spatial distribution of the species and the type of forest structure. Irrespective of the wide range in variation among mangrove species and forest types, this ecosystem is economically and socially significant because of its role in supporting near-shore fisheries, protecting coastlines, as a renewable resource, and as a location for permanent and temporary human settlements.

2.1 Distribution of mangroves

In 1991, the world's mangrove forests covered 113,428,089 rai in subtropical and tropical regions (Katessomban, 1991). Mangrove forests are most extensive in Asia, followed by South America and Africa. In Asia, mangrove forests cover about 52,559,339 rai, or 46.4% of the world's total mangrove areas; in South America, around 39,606,500 rai, or 34.9% of the world 's total mangrove area; and in Africa, 21,262,500 rai, or 18.7% of the world's total mangrove area. Indonesia has the largest area of the mangrove forest in Asia—and the world—with an estimated 26,568,818 rai. In South America, the largest mangrove area (15,625,000 rai), is in Brazil. In Africa, the largest area is in Nigeria (15, 625,000 rai) (Snedaker and Getter, 1985).

In Southeast Asia, there are mangrove forests with as many as 30 species, some growing as high as 40 m (UNEP, 1993). Santisuk (1983), cited in Aksornkoae, 1989) reported 35 classes, 53 genera, and 74 species in Thailand, with Rhizophoraceae dominating. Aksornkoae et al., (1982) studied the structural characteristics of mangrove forest near a mining area and an undisturbed natural forest at Ranong. They found 33 mangrove species in the undisturbed area.

2.2 Structural types

The management of mangrove forests is based on their structural and functional characteristics. The structural organization of mangrove forests traditionally results from species zonation, which, in turn, is determined, by gradients in topography and soil salinity. Each zone is dominated by the species that is best adapted to it. Although species zonation is frequently observed, the dominant influences on forest structure are more closely associated with differences in coastal landform, patterns of surface water flushing, and salinity.

Five major types of forest structures are recognized: 1) fringe, 2) basin, 3) riverine, 4) overwash, and 5) dwarf (UNEP, 1993; Day et al., 1987) (Snedaker and Getter, 1985).

Fringe forests are situated along the slightly sloping shorelines of terrestrial mainland areas and larger islands. Often, they are exposed to open bays and receive moderate to light wave action. They are best defined on islands with elevations that prevent daily overwashing by high tides. Tidal motion is therefore restricted to an in/out pattern, which at any given point within the fringe forest may be manifested as a rise and fall of the water level. Flow velocities are so small that they do not flush large debris into the adjacent waters on ebbing tides. Organic export from the forest interior occurs as particulate in the depression and is seldom completely exchanged during a full tidal cycle. These forest types are often situated on the mainland in strand-like formatting along the inland terrestrial drainage and in the centers of large islands. As such, they are exposed to less saline water for longer periods of the year than coastal forests. Saline water flushing probably occurs during extremely high tides and storm tides. In humid areas, the forests often have a well-developed epiphytic flora dominated by bromeliads and orchids.

Riverine forests occur in the flood plain of freshwater river drainage and are inundated with flowing water during periods of high rainfall and runoff.

Overwash forests tend to occur on tidal flats and islands that are completely inundated during most tidal cycles. Because coming and exiting water completely flush the island, litter and organic debris do not accumulate. The forests occur where there are severe limitations on the growth and development of mangroves. Typically, they form a sparse, scattered community stand, mangrove species seldom reaching two meters in height.

Dwarf forests commonly occur in carbonate environments and arid areas. Although all forests types share basic functions, each has a different pattern and timing related to specific environmental conditions that promote or restrict each function.

2.3 Productivity

Mangroves exhibit relatively high rates of primary productivity. Part of the production that is not used in respiration is accumulated as forest biomass. A significant fraction also goes to the production of leaf litter and organic debris. Snedaker and Getter (1985) found leaf litter production between 1 and 4 gm carbon/m^2/day. Litter fall seems to be strongly correlated with forest structure. Average total litter fall ranges from 120 gm dry mass/m^2/yr for scrub forest to 1,170 gm dry mass/m^2/yr for riverain forest (Day et al., 1987). Angsupanich and Aksornkoae (1991) studied litter production in Pang-nga Bay and found that the average litter was 550 gm dry weight/m^2/yr with 93-99% consisting of leaf material. Aksornkoae et al. (1982) compared the economic value of inland and mangrove forests. They reported that mangrove forests were more valuable per unit than inland forests.

Many factors affect mangrove production, mainly flooding regimes, lower salinity, higher nutrient levels, and lower H_2S level (Day et al., 1987). There is no latitudinal gradient in mangrove production because mangroves occur entirely within the tropical zone and there is little latitudinal gradient in sunlight and temperature.

2.4 Socioeconomic and ecological advantages of mangroves

The economic and ecological significance of mangrove forests are well understood, though not necessarily reflected in management policies. The United Nations Environment Programme (UNEP, 1993) reported that in Costa Rica, for instance, the five million shellfish harvested each year in that country's mangroves are worth US$85,000 to the local economy. In the Gulf of Mexico, 90% of the fish harvest, worth an annual US$70 million annually, consists of species that are dependent on mangroves and coastal wetlands. In addition, there is increasing demand for forest wood products for fuelwood and charcoal production. Mangroves provide resources for local people, ranging from wood for building and fuel to fodder for domestic animals. They play an important role in linking marine and terrestrial system, balancing the ecosystem, as a large food source, and habitat to many offspring marine animals.

2.5 Mangrove situation in Thailand

The extent of mangrove areas in each province depends on the length of the coastline. Thailand has 22 coastal provinces located along the Gulf and the Andaman Sea with a total coastline of 2,614 kilometers. Mangroves are scattered along coastlines in the east, the central region, and the south. The total area in 1991 was 1,085,000 rai. In the southwest the mangrove area covered 927,500 rai, with Phang-nga accounting for 209,375 rai (Table 2.1).

The major problem mangroves face in Thailand are related to residential, commercial, industrial, and agricultural development. According to Katessonban (1991), between 1975 and 1989 mangrove forests in Thailand were reduced by an average of 34,411 rai each year. Prawn farms account for 64.3% of losses, mining

3.2%, salt ponds 6.2%, and other activities 26.3%. According to Jaruppat (1993), between 1961 and 1991 mangroves in Thailand were depleted at an annual rate of 40,479 rai for a total of 1,214,375 rai. In many areas of the world, the destruction of mangrove forests has also reduced species diversity and the population size of marine animals.

Table 2.1 *Loss of mangrove forest area in Thailand by region: 1961-1991*

Region	Mangrove area in 1961 (rai)	Mangrove area in 1991 (rai)	Decrease area (rai)	Percent
Central	13,750	4,375	9,375	68.18
East	187,500	65,625	121,875	65.00
Southwestern	446,250	927,500	518,750	35.86
Southeastern	651,875	87,500	564,375	86.57
Total	2,299,375	1,085,000	1,214,375	52.81*

Note : ** = average*

Adapted from Jaruppat, 1993

2.6 Mangrove sediments

Sediments enter mangrove forests from the ocean, land, surrounding mangrove areas, and river systems (Gross et al., 1990). Sediment is also added by the atmosphere and *in situ* biological products.

At the source and mouth of estuaries, rapid river flow and strong tidal currents erode and transport the entire spectrum of sediment particles. Coarser particles such as sand, granules, and pebbles, may be found in both areas as water flow decreases and sediments are deposited. Clay and silt accumulate in the upper reaches because of flocculation and settling. In calmer middle reaches, where river and tidal currents meet, and in intertidal zones as currents weaken, mud is deposited. Sediment is transported to mangrove areas by wave action, tidal currents, and estuarine circulation, where the substrage is predominantly made up of clay and silt rather than sand (Keizer et al., 1989). Each mechanism of transport accounts for the accumulation of material with a specific range of grain size. Wave action is responsible for the landward transportation of course-grained sediments from the near-shore oceanic area, where water depths are less than 10 to 15 m. Tidal currents result in the accumulation of silt and sand, which may form extensive tidal deltas. Estuarine circulation, which is a two-layered flow, cause clay and silt to be trapped within the estuary.

Soil characteristics in mangrove forests in Australia were studied by Boto and Wellington (1984). They found that silts contained large quantities of fine and fibrous root material in vegetated areas. The clay fraction was 15-20% of the total dry weight. Physical and chemical characteristics of mangrove sediment in Phang-nga were studied by Khongsaengchai (1973). He found that sediment consisted mainly of clay, silt, and organic matter. Silt and clay tended to predominate in the middle or upper reaches and quiet sheltered areas.

2.7 Soil Properties

Soils under mangrove tree species are inundated daily by sea water or brackish water with a fine textured, soft, and muddy profile (Kongsaengchai, 1973). Surface horizons are shallow with high root content and show oxidation-reduction potential due to tide conditions. During high tide, sea water may flood the area to a depth of 2 m. During low tide, the water level may be 1 or 2 m below the land surface. However, the water table in the area does not drop more than 0.5 m. Therefore, the oxidation-reduction potential depends on the height of the land above sea level. On higher land, the redox layer will develop at a deeper level than on lower land. Aerated layers of sediment will form mottles in subsoil horizons if levels of iron sulphide are sufficiently high.

Litter fall is the major pathway for the return of organic matter to form nutrients. It consists of the above-ground portions of the plant community in the soil. The amount of litter fall is important for maintaining soil fertility (Angsupanich and Aksornkoae, 1991). Decomposition rates in mangrove soils are generally rapid but depend on tide conditions, sea animals, and aeration in the soil.

Redox potential is the term commonly used to indicate the relative availability of electrons in a particular chemical environment (Limpsaichol, 1978). Because there are no free electrons *per se* in the environment, every oxidation must be accompanied by a reduction. In sediment, there are normally three distinctive layers in the upper half meter. The upper surface layer is an oxidized layer, usually with oxygen, and with a redox potential higher than +100 mV (often > +400 mV). The bottom layer is a reducing layer, very often black, that contains sulphide below +100 mV. Between these two layers, there is a transitional layer with a steep redox gradient. These three layers are the result of the decomposition of organic compounds in the sediment (Limpsaichol, 1978; Van, 1978; Delaune et al., 1981).

2.8 Nutrient forms and distributions in the sediment

Nutrient nitrogen, phosphorus, and silicon occur in the sediment in many forms that can be described in terms of their oxidation state. The oxidation state of nitrogen ranges from +5 (NO_3^-) to -3 (NH_4^+), and compounds exist in between (Webb, 1981). Inorganic phosphorus occurs most often as the phosphate ion (PO_4^{3-}) in an oxidation state of +5. There are three structural configurations of phosphate: 1) ortho, 2) para, and 3) meta. Various organic phosphorus compounds occur in the same oxidation state in the cellular materials and dissolved in the external environment.

2.9 Nutrient patterns at different depths

Nitrate may exhibit peak concentrations at intermediate to near-surface depth (0-5 cm) because of nitrification in the sediments. Or, it may decrease from the surface into the sediments, where levels are high in the water above, with high rates of NO_3^- reduction (NH_4^+or N_2) occurring in the sediment (Delaune et al.,1981). Stefan and

Bengt (1989) studied the vertical profiles of interstitial ammonia and phosphorus. They found concentration increasing with depth. Robertson and Alongi (1992) reported the concentrations of interstitial nutrients were not the same in all areas, and also concentrations of dissolved nitrogen and phosphorus in creeks and estuaries were also different in different regions.

In an extensive literature review Nixon (1981) and Wolaver et al., (1980) regard salt marshes linked by tidal flushes to mudflats and contiguous estuarine water bodies as important sources or sinks in coastal-marine nutrients cycles; but not all findings support this view. Salt marsh sediments appear to be sinks for phosphorus, but remobilization and small net exports of phosphate occurs from the marsh habitat. This phosphate export is probably unimportant for the estuarine phosphorus budget. In regard to nitrogen, salt marshes seem to be transformers, importing dissolved inorganic forms and exporting dissolved, particulate-reduced forms. The marsh-estuarine nitrogen flux may be of local importance, but net exchanges are probably too small to affect the annual nitrogen budget of most coastal ecosystems. In estuaries nutrients behave in the same way as in salt marshes, that is, they are sources or sink to the bottom.

2.10 Nitrogen cycle

Day (1987) describes the esturine nitrogen cycle as consisting of three major steps (Fig.2.1).

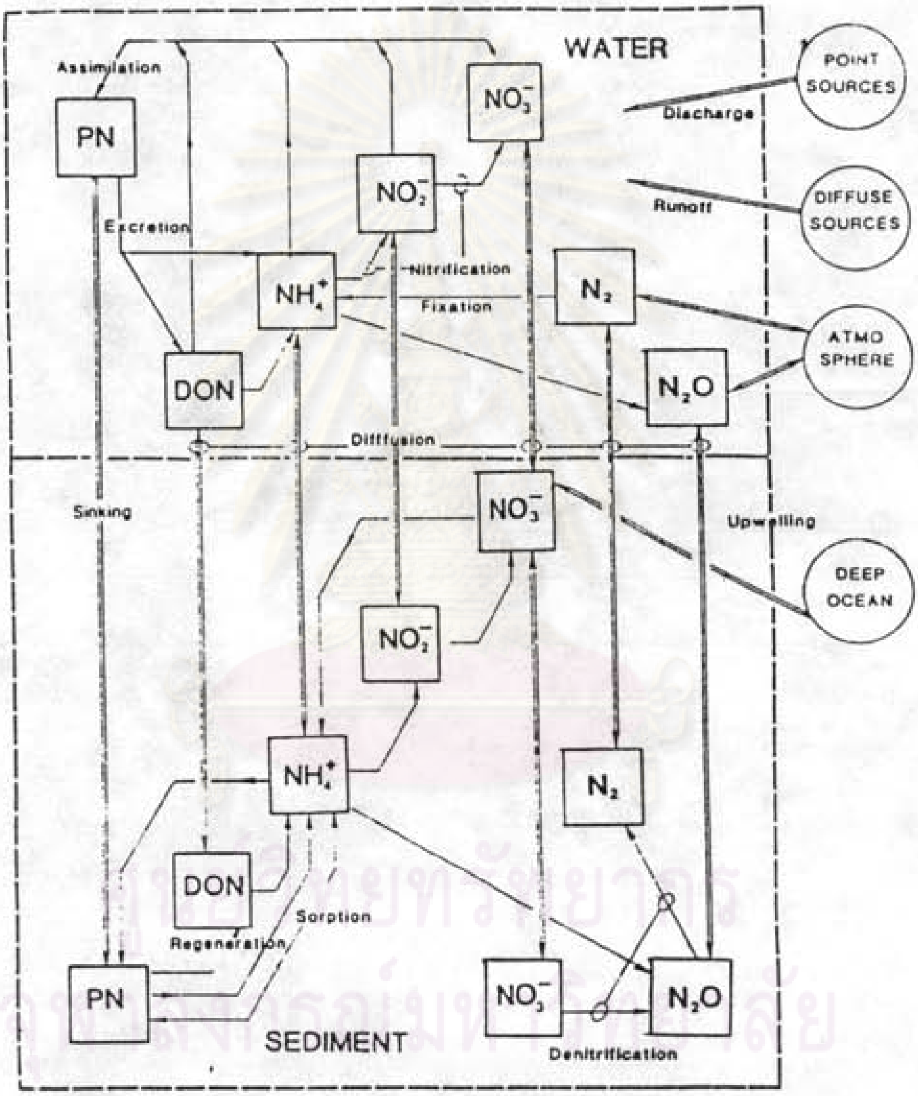

Figure 2.1 Biochemical transformations in the nitrogen cycle in the esturine systems
Source : Day (1987)

As can be seen in Figure 2.1, NH_4^+ regeneration, nitrification, and denitrification are all important processes in sediment nitrogen budget. The direct relationship between NH_4^+ regeneration and denitrification were described by Boto and Wellington (1984)

2.11 Microbial transformation of nitrogen in sediment

Microbial transformation processes serve to balance nitrogen distribution. There are a number of excellent papers describing these processes, for instance, Kennedy (1986), Seitzinger (1988), and Grundmanis and Murray (1977). An overview of microbial processes is presented in Figure 2.2.

Process	*Principal organisms*
Ammonification organic nitrogen →ammonium	Saprophytic and predatory heterotrophs, including bacteria, fungi and protozoa.
Nitrification ammonium →nitrite → nitrate	Mainly autotrophic bacteria, but other groups may contribute.
Nitrate reduction nitrate →nitrite → ammonia	Nitrate reducing bacteria
Denitrification nitrate → nitrogen and nitrous oxide	Mainly heterotrophic bacteria
Nitrogen fixation dinitrogen →ammonium	Bacteria, actinomycetes, and blue-green algae (cyanobacteria), both free living and symbiotic.

***Figure 2.2** Microbial transformation of nitrogen*
Adapted from Harris (1989)

2.12 Phosphorus cycle

The phosphorus cycle in the estuarine environment is not as complicated as the nitrogen cycle, because phosphorus is nearly always present in an oxidized state of +5, whereas nitrogen occurs in many different oxidized states (-5 to +3). A good diagram of the phosphorus cycle in estuaries was presented by Day et al. (1987) (Fig. 2.3), and also described in an excellent paper by Webb (1981).

At the transition between the fresh riverine and the open marine environment, estuaries and coastal seas play a major role in the global phosphorus cycle. Postma (1980) studied the phenomenon in Europe and demonstrated a general increase in the phosphorus content, especially as a result of anthropogenic discharges. On a global basis, the effects will be limited to a narrow coastal region, due to the large buffering capacity of the world's seas and oceans.

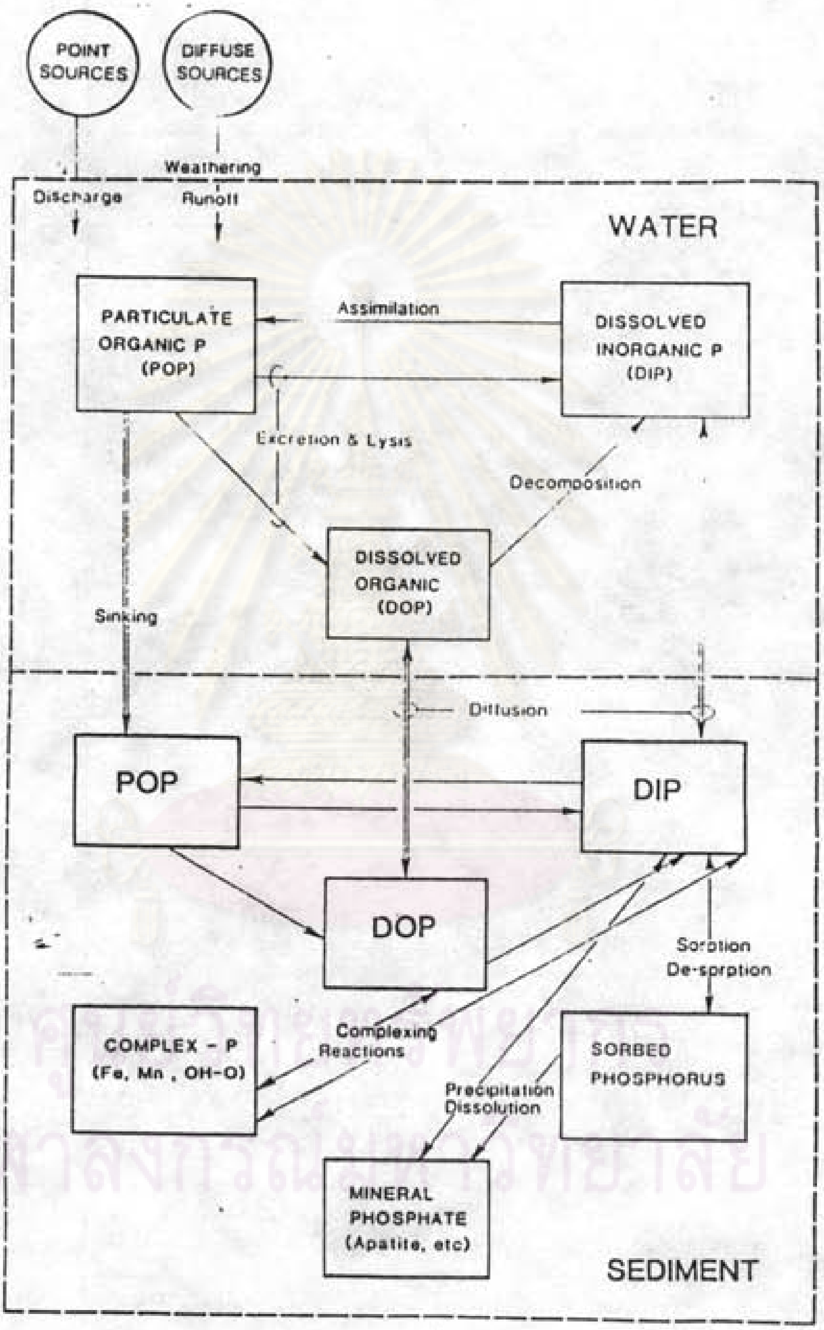

Figure 2. 3 *Phosphorus cycle in estuarine systems*

2.13 Phosphate buffer mechanism

In estuarine, coastal, and oceanic systems, the phosphate buffer mechanism refers to the influence of sediments, whether benthic or suspended, in controlling the dissolved reactive phosphate concentration in the water at near constant values regardless of biological removal and input reactions (Carton and Wetzel, 1988). Butler and Tibbetts (1972) found that particulates in the water are important factors in controlling the phosphate buffering process in estuaries (Fig. 2.4).

DESORPTION
PS ⇒⇒⇒⇒⇒⇒⇒⇒⇒ PD

ADSORPTION
⇐⇐⇐⇐⇐⇐⇐⇐⇐
PS-SORBED ON ‖ PD - DISSOLVED IN
OR IN SOLIDS ‖ BULK SOLUTION

Figure 2.4 *Phosphate buffer mechanism* (Butler and Tibbite, 1972)

Evidence for the process has been derived primarily from two types of observations (Fig. 2.4). First, phosphate concentrations in some estuarine waters are higher than can be explained by the mixing of surface sea water with river water. Additional phosphate must either be released from the bottom sediment or from particles in suspension. Second, sediments and suspended particulate from estuaries and rivers can be released and rapidly take up phosphate to or from solutions.

Syers et al. (1973) reported that release of P from the sediment to the overlying water occurs through suspension of particulate forms or transport of dissolved forms through turbulent mixing and diffusion. Ben (1973) and Phillips (1988) suggested that the movement of phosphate in the sediment to overlying water column occurs when the concentration of interstitial dissolved inorganic phosphate exceeds that in the estuaries' sediment. The uptake rates can be rather small and slow under constant environmental conditions, however, they can be extremely rapid in anaerobic condition (Phillips, 1988; Patrik and Khalid 1974).