Chapter 5
Discussion

5.1   Soil characteristics

In general, sediment enters mangroves from rivers and the ocean (Fisher et al., 1982). Types of sediments can be clay, sand, and silt. This study is not concerned with types of mangrove soil*s per se*. Wattayakorn et al., (1993) analyzed mangrove sediment at Klong Lad Khao Kao and found it to be mainly sandy clay loam and at nearby Klong Panyee it was mainly silty clay.

Water content from the surface to a depth of 70 cm in all stations was 43-51% in dry season and 42-56% in wet season. Water content decreased with depth suggesting that sand might be the main component in deeper sediment. Sediment also enters mangrove forests in the form of litter, such as branches fallling off trees then being decomposed by microbial action. The latter is a crucial component in the mangrove's food chain.

5.1.1   Eh and pH in sediment

Measurements of redox potential (Eh) of core samples indicated that the sediment was anaerobic at all stations. During both seasons the oxidizing layer was from the surface to approximately 25 cm. Below about 35 cm, Eh was consistently below < -100 mV.

The pH of the sediment was consistently within the range 6.3-6.6 in March and 6.4-6.7 in October. pH in March 1990 decreased slightly with depth. pH increased with depth in October 1990. The reason for this is possibly because of the effect of plant roots (Motomura, 1962 cited in Boto and Wellington, 1984), and decomposition of organic material in sediment. According to Boto and Wellington (1984), pH values decreasing with depth suggests the effect of root exudates during periods of rapid plant growth. Other factors in pH determination in flooded soils are concentrations of reduced iron, manganese hydroxides, carbonates, and carbonic acid (Patrick and Mikkelsen 1971; Ruttner, 1963 cited in Boto and Wellington, 1984). pH values in the sediment indicate weakly acidic soils (< 7) at all stations. This is possibly because of

microbiological activities that result in H_2S and CO_2 from anaerobic decomposition (Gnaiger et al., 1978).

Generally, the redox potential in the sediment decreased with depth. This was true for both seasons. There were differences, however, in the thickness of the oxidizing layer. In March 1990 the oxidizing layer was 10-15 cm, whereas in October 1990 it was 25-30 cm (Figure 4.2). The Eh at the sediment surface was always higher than +100 mV, suggesting that similar oxidizing conditions prevail in the upper part of sediment during both seasons, which supports the findings reported by Vanderborght et al., (1977) for fresh water lake sediment and Limpsaichol (1978). Electron values of +100 mV signify a transition from aerobic to anaerobic conditions. In depper sediment, the rate of decomposition of organic matter determines aerobic and anaerobic conditions .

5.1.2 Nutrient status at different depths

Levels of nutrients decreased with depth during both seasons. However, in March the mean concentration of nitrite plus nitrate in interstitial water was 34.56 μg-at/l and in October 65.88 μg-at/l. As can be seen in Figure 4.4, vertical interstitial nitrite plus nitrate profiles were higher at the surface than at lower depths. This may be related to Eh values that decrease with depth (Figure 4.3). Decreasing concentrations of nitrite plus nitrate with depth are probably explained by the decomposition of organic matter in the sediment by denitrification process. Bacteria in sediment quickly use up dissolved oxygen in sediment. When the concentration of oxygen falls to near zero, nitrate is used as a preferential terminal acceptor for the oxidation of organic matter and the result is the production of ammonia instead of nitrate. A similar situation in the sediment was described by Sorensen et al., (1985) and Grundmanis and Murray, (1977).

Ammonia concentrations generally increased with depth but the lowest concentrations were observed at a depth of 30-40 cm in wet season. Vertical ammonia profiles during both seasons were related to those for nitrite plus nitrate. Ammonia increased with depth while concentrations of nitrite plus nitrate decreased with depth,

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probably due to nitrification at surface sediment and nitrate reduction in deeper sediment. This illustrated a general trend of increasing concentrations of ammonia with depth and, in deeper vertical sediment profiles, the microbial decomposition of organic material by sulphate reduction (Vanderborgh et al., 1975).

Dissolved organic nitrogen in interstitial water generally decreased from the surface to a depth of 25- 35 cm in March 1990 and to 20-25 cm in October 1990. In both seasons concentrations then increased with depth. It was found that 53% of nitrogen in the sediment was in organic forms and 47% in inorganic forms during the dry season. The relationship between organic and inorganic nitrogen is probably explained by the ammonification and nitrification processes where organic nitrogen $\rightarrow$ ammonia $\rightarrow$ nitrite $\rightarrow$ nitrate, which is particularly obvious in the wet season.

A zonal model of nitrogen based on this study can be illustrated as follows:

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------------------------------------------------------sedimentsurface----------------

Ammonification          Organic N ----------→NH₄⁺

                        ZONE

Nitrification           NH₄⁺       ---------→ NO₂⁻ +NO₃⁻

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Lower Depth

Nitrate reduction       NO₃⁻       ----------→ NH₄⁺

            ZONE

Sulphate reduction      |Organic N-----------→NH₄⁺

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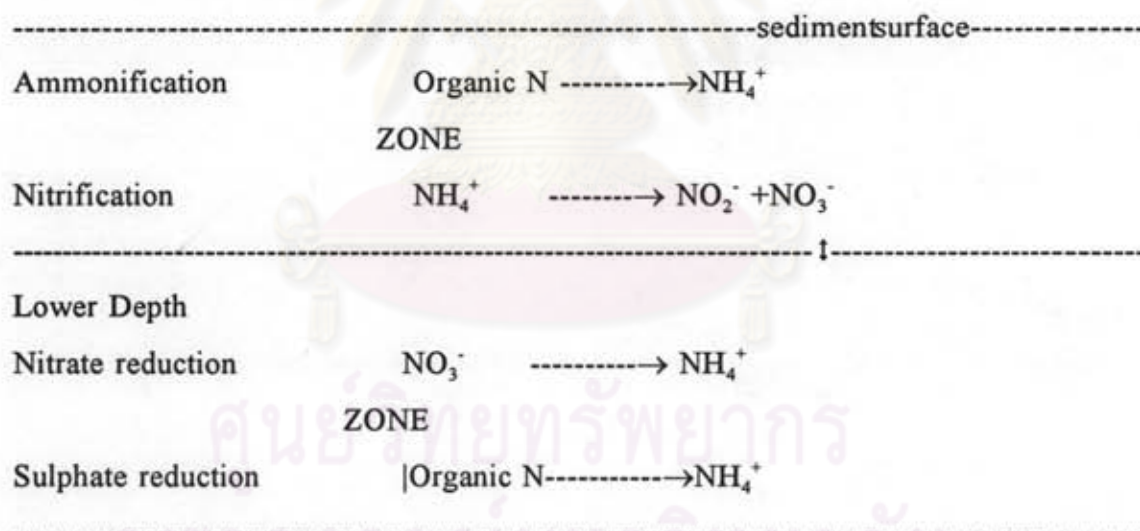
Figure 4.7 shows changes in concentrations of interstitial phosphate at different depths in dry season (March 1990) and wet season (October 1990). As can be seen, from a fairly high level at the surface, concentrations tend to increase with depth starting at about 10 cm, especially in wet season. Phosphate concentration generally increased with depth (Figure 4.7) in both seasons. These changes are probably due to different electron acceptors. In general, sediments in mangrove are classified into three layers: 1) yellow layer (surface), 2) gray layer, and 3) black layer

(Fenchel and Riedl 1970). At the surface (yellow layer), oxygen is the most important oxidizing agent. In the middle (gray) layer nitrate is the preferred electron acceptor, followed by sulfate and carbonate in the deeper (dark) layer. The depth at which free oxygen dissapears and hence Eh goes to zero is called the *redox discontinuity layer* (RDL) (gray layer), iron (Fe) serves as an electron accptor, resulting in changes in oxidation number. The deepest part of the sediment has a black shade as a result reduced ferous sulfide (FeS) and pyrite (FeS_2), while the region in between is greyish as result of other iron-sulfile cimpounds. As a consequence, high concentrations of phosphate bound with Fe (III) ion will be relased into interstitial water.

Concentrations of dissolved organic phosphorus in interstitial water increased with depth. This indicated high decomposition of particulate oragnic matter. As result, high levels of inorganic phosphates were also found because organic phosphorus is changed into inorganic phosphate. Moreover, when we compared the percentages of organic posphorus and organic nitrogen, it was found that organic nitrogen in mangrove sediment decomposes more rapidly than organic phosphorus in either seasons. (Organic phosphorus = 84% in March, and 65% in October; organic nitrogen = 47% in March, and 60% in October).

One of the principal objectives of this enquiry was understanding nutrient distribution at different depths. Data from such could serve as an index to soil fertility in mangroves as well as surrounding water.

5.1.3 Nutrients released from sediment

Concentrations of nutrients released from sediment over a tidal cycle were investigated in October 1990 and March 1991. To understand nutrient source or sink for the sediment is important because nutrients are important for phytoplankton, macrophyte, bentric algae, and plants. Nutrient release from or absorption by sediment can explained by environmental conditions.

Concentrations of nutrients released from the sediment were investigated at Klong Lad Khao Kao following a tidal cycle. The findings are described below.

Table 5.1 *Selected sediment-water fluxes of various areas with sediment flux estimate.*

Locations	NO_2^-	NO_3^-	NH_4^+	DON	PO_4^{3-}	DOP	References
				(mmol m^{-2} h^{-1})			
Fourleague Bay	-	-.019	+.129	+.305(lower bay)	-.008	+.124	Teague et al.,
Louisiana				-.710(upper bay)			1988
Fundy Bay	-	.005	.037(August 1,1980)		-	-	Keizer et
Nova Scotia			.017(October 3,1980)				al., 1989
Thachin	-	-	-	-	.04-.40(anaerobic)		Prapong,
Thailand							1992
Klong Lad	.005[1]	-.005[1]	.177[1]	24.76[1]	.022[1]	-.011[1]	This study
khao kao,	.003[2]	.011[2]	.009[2]	4.466[2]	.001[2]	.039[2]	
Phang-nga,							

Note: [1] = October 1990

　　　[2] = March 1991

Exchanges of dissolved nutrients between intertidal and overlying water were measured by enclosing water in the tubes over undisturbed sediment. Concentrations were generally lower at the beginning (flood tide) then increased during ebb tide.

Nitrite was released during flood tide in October (mean = 0.012 mmol $m^{-2}h^{-1}$)and uptaked during ebb tide, but the opposite was found in March (Table 5.2). Net fluxes of nitrite were found during both uptake and release in Klong Lad Khao Kao. In October, the release rate was 0.005 mmol m^{-2} h^{-1} and in March the uptake rate was -0.003 mmol m^{-2} h^{-1}.

Table 5.2 Average released rates of nutrients during flood and ebb tides: October 1990 and March 1991

| | October | | | | | | March | | | | | |
	NO_2^-	NO_3^-	NH_4^+	DON	PO_4^{3-}	DOP	NO_2^-	NO_3^-	NH_4^+	DON	PO_4^{3-}	DOP
Flood	.012	-.025	-.007	-4.7	-0.018	-0.082	-0.041	-0.138	-0.212	-53.9	-.097	-0.124
Ebb	-.002	.015	.360	54.2	0.026	0.104	0.046	0.116	0.231	62.9	.096	0.202

Note : unit = mmol $m^{-2} h^{-1}$

Nitrate (NO_3^-), concentrations were elevated during ebb tide (Table 5.2). Concentrations were similar in October and March. Net fluxes of nitrate uptake occurred in October and March (mean = -0.005 mmol $m^{-2} h^{-1}$ in October and 0.011 mmol $m^{-2} h^{-1}$ in March). A similar uptake of nitrate was repoted by Teague et al., (1988), but it is possible to find nitrate released from the sediment, as was the case at the Bay of Fundy (Keizer et al., 1989) (Table 5.1). Increasing concentrations of nitrate may be the result of increased flux from surface sediment disturbed by strong waves. A similar situation was reported by Wyer (1988) who suggested wave action and nitrification in surface sediment. Ammonia concentrations were low during flood tide and increased steadily during ebb tide. However, ammonia released from sediment was higher in October (0.017 mmol $m^{-2} h^{-1}$) than March (0.009 mmol $m^{-2} h^{-1}$). Ammonia released from the sediment at Klong Lad Khao Kao acts as a source of ammonia to overlying water. The redox potential of the sediment in this area, which is more than +100 mV at the surface, indicates an aerobic condition (Limpsaichol, 1978). This suggests that nitrification is the major process in the sediment surface during ebb tide and denitrification during flood tide. In nitrification, ammonia nitrogen is oxidized by microbial organisms to the nitrite anion. Thus, concentrations of nitrite were high during ebb tide. On the other hand, during flood tide denitrification is the major process. As a result, concentrations of ammonia are being regenerated in the sediment and used by the bethic microalgae. Teague et al., (1988)

and Keizer et al., (1989) also found ammonia released from the sediment (Table 5.1).

Spatial patterns of DON fluxes were similar in October and March. Released rates were 24.76 mmol m^{-2} h^{-1} in October and 4.466 mmol m^{-2} h^{-1} in March. Uptake of DON occurred during flood tide and released during ebb tide for both seasons (Table 5.2). Patterns of DON fluxes were similar to ammonia fluxes, with higher released rates in October. However, DON fluxes were higher than ammonia fluxes and the highest released rate occurred in March. A similar condition was reported by Teague et al., (1988) in Lower Bay but the opposite in upper Bay. This study suggests that the efficiency of this removal ensures the maintenance of water quality in terms of nitrogen and may contibute to the productivity of the ecosystem via the bethic food web. The amount of phosphate released from the sediment during ebb tide was determined (Table 5.2). The average released rate in October was 0.022 mmol m^{-2} h^{-1} and the average uptake rate in March was -0.001 mmol m^{-2} h^{-1}. This suggests that sediment is a source of phosphate in October and and a sink in March. The released of phosphate from the sediment is probably explained by the fact that aerobic and anaerobic conditions in the sediment play a major role in controlling the released rate (Istvanovics, 1988). The difference between reduced and oxidized soil in release and sorption of phosphate suggests that under reducing conditions there is an increase in the amount of solid material that reacts with phosphorus. The well established role of hydrated iron oxide in at least partially governing phosphorus sorption and release in soils and sediments suggests that ferric oxyhydroxide is apparently capable of binding orthophosphat ions more frimly than the ferrous form. Changes in the hydrated iron oxides as a result of oxidation or reduction are due to changes in concentrations of dissolved orthophospate. Also, several chemical processes are known to affect phosphate mobility in sediments as a function of [O$_2$] and [H$_2$O], as reported by Brylinsky and Mann (1973). In addition, some elements, such as Fe, Al, and Mn, are bound with inorganic phosphorus in normal soil conditions. These will be reduced and dissolved in water when the soil becomes anoxic. Consequently, phosphate is released into water (Furumai and Ohgaki, 1989). Some investigators have reported increased phosphorus flux at high pH, however, and speculated that hydroxide ions competed

with phosphate for binding sites on the oxidized iron gels, thus increasing mobility of PO_4^{3-} (Istvanovics, 1988).

Both DOP uptake and release occur in Klong Lad Khao Kao sediment. The highest uptake rate was in October and the highest released rate was in March (Table 5.1).

It was found that DOP was released during ebb tides, but uptaked during flood tide for both season (Table 5.2). The high, positive DOP fluxes may offset the effects of the PO_4^{3-} released in the phosphorus pool in the water column and particulate from the sediment. Teague et al., (1988) at Fourleague Bay, found a high released rate of DOP (0.124 mmol m^{-2} h^{-1}) (Table 5.1). The explanation is that PO_4^{3-} and TDP (total dissolved phosphorus) fluxes greatly influencd DOP fluxes.

These results suggest that Klong Lad Khao Kao sediments have a moderately active metabolism, released NO_2^-, NH_4^+, DON and DOP to the overlying water, and take up NO_3^-, and PO_4^{3-} (in March). The sediments are sources of DOP for overlying water much of the time and in October (wet season) are an important source of nutrients. Nutrients released from sediment could be a factor in determining adjacent water quality. This knowledge could be of use in reforestation, general mangrove management, and fisheries management.

5.1.4 Nutrients released from stirred and unstirred sediment in laboratory

The experiment was undertaken to determine the effect of stirring on nutrient release. The objective was to simulate wave action as well as human activity, such as boating. Measurements were taken over a 24-hour period.

Nitrite patterns in the water were similar in stirred and unstirred sediment. The $\Delta N/\Delta T$ ratio (changes in concentration over time) for all four tubes indicated that nitrite was released from 0 to 6 hours and also from 12 to 18 hours and uptake from 6 to 12 hours and 18 to 24 hour (Table A.42). However, net nitrite fluxes were different in stirred and unstirred sediment.

Nitrate patterns showed uptake from 0 to 12 hours, release from 12 to 18 hours, then uptake from 18 to 24 hours (Table A.42). The released rate of nitrate

from stirred sediment suggests that it is not affected by stirring (mean = -0.010 $\mu mol\ m^{-2}\ h^{-1}$)

Ammonia was released from 0 to 12 hours and 18 to 24 hours, and uptake from 12 to 18 hours. The findings, however, suggest that release and uptake patterns from stirred sediment are not clear.

Dissolved organic nitrogen was uptake from 0 to 6 hours, released from 6 to 12 hours, then uptake again 12 to 24 hours. Results indicate that DON was not released from sediment.

Phosphate was released from 0 - 6 hours (positive value), uptake from 6 to 12 hour (negative value), then released again from 12 - 24 hours (Table A.42).

DOP (dissolved organic phosphorus) was uptake from 0 to 12 hours and released from 12 to 24 hours (Table A.42). Stirring did not have a significant effect on the released rate (Table 4.8)

These findings suggest that stirring was not the only factor that determined nitrogen and phosphorus release. Chemical factors (nitrification, denitrification, pH or Eh) might also be involved. It was found that only nitrite and phosphate were released from stirred sediment. This may be explained by water movement dispersing particulate in the water. Nutrients adsorbed at the surface of particulates are also disturbed and then released into the water.