PART I SYNTHESIS REPORT

1. INTRODUCTION

1.1 Background

The coastal ecosystems of Thailand, like many of the coastal ecosystems of the world, are in decline from direct and indirect disturbances as a result of population growth. Generally, the main causes of the problems are human activities induced by economic gain and development, which fail to recognize adverse environmental impacts and non-market value losses. Among the most productive coastal areas in the southern part of Thailand, Bandon Bay in Suratthani Province is one example of this heavy utilization of coastal resources. Bandon Bay is an important fishing ground for pelagic and demersal fishes in Thailand. However, a number of problems such as decreasing water volume due to rapid siltation, reduction in mangrove coverage, excessive fishing effort, the use of nets with very fine mesh and deteriorating water quality, have been hindering the ecological role of Bandon Bay and the surrounding mangroves as nursery grounds and feeding areas for juvenile fish and shellfishes.

To maintain the nourish coastal resources in parallel to the economic development of this area, we need to know how the coastal ecosystem of Bandon Bay responses and interacts with the economic development of the area. First, the nature of the coastal ecosystem and the socio-economics of the population in the area must be determined. Then the linkage between the coastal ecosystem and socio-economic data can be performed. This report assesses the anthropogenic drivers of change in the coastal zone of Bandon Bay from an integrated socio-economic and biogeochemical perspective. The nature of the coastal ecosystem of Bandon Bay, based on the trophic relationships and productions of the aquatic living resources in the bay, were also studied. This synthesis report, PART I, covers the results obtained in the 3-year practical study between 1997 and 1999.

1.2 Objectives

The overall objective of the research project is to develop a model of the effects of conversion of mangrove ecosystems, particularly to shrimp farming, on different biogeochemical aspects including forest structure; carbon, nutrient and sediment fluxes; fishery production and trophodynamic status for Bandon Bay; and on economic evaluation encompassing an assessment of Total Economic Value, including option and bequest values. The study aims to use techniques of economic valuation to assess the relation between shrimp-farming, mangrove forest removal and oyster farming in terms of carbon flows. Physical/chemical water quality parameters are key factors that drive the biological/system responses. They are measured in order to interpret the forcing factors that affect the ecological response. This interpretation is required to formulate and evaluate management responses.

1.3 Site description

1.3.1 Physical setting

Bandon Bay (9^o 12’ N and 99^o 40’ E) is located in Suratthani Province, southern Thailand. It covers the area from Chaiya District on the west side to Don Sak District on the east side, approximately 1070 km^2 (Figure 1.1). The bay is exposed to monsoon weather with northeast winds from October to April while southwest winds prevail from May to November. Therefore there are two pronounced seasons in the area: the dry condition, from January to May with scarce rainfall and high evaporation rate, and the wet season from June to December with higher rainfall and lower evaporation rate. From January to March, surface current circulation is counter-clockwise while from April to December, the surface current flows clockwise from Chumporn Province to Suratthani and Don Sak.

The inner bay, from Chaiya District to Kanchanadit District (Figure 1.1), covers an area of 480 km^2 with 80 km of coastline. The area of the mangrove swamps surrounded the bay is about 20 km^2. The coastal area has a gradual slope and the water is shallow. A large band of mudflats extends along the coast to about 2 km offshore, resulting from high sedimentation in the bay area. Water depths vary from below 1 m to 5 m near the mouth of the bay, with a mean depth of 2.9 m with respect to mean sea level. The system is a mixed tidal type with principally semidiurnal tides. Tidal amplitudes range from about 0.70 m at neap tides to about 1.90 m at spring tides. The average tidal range is 1.0 meter. The volume of the inner bay is estimated to be 1,392x10^6 m^3.

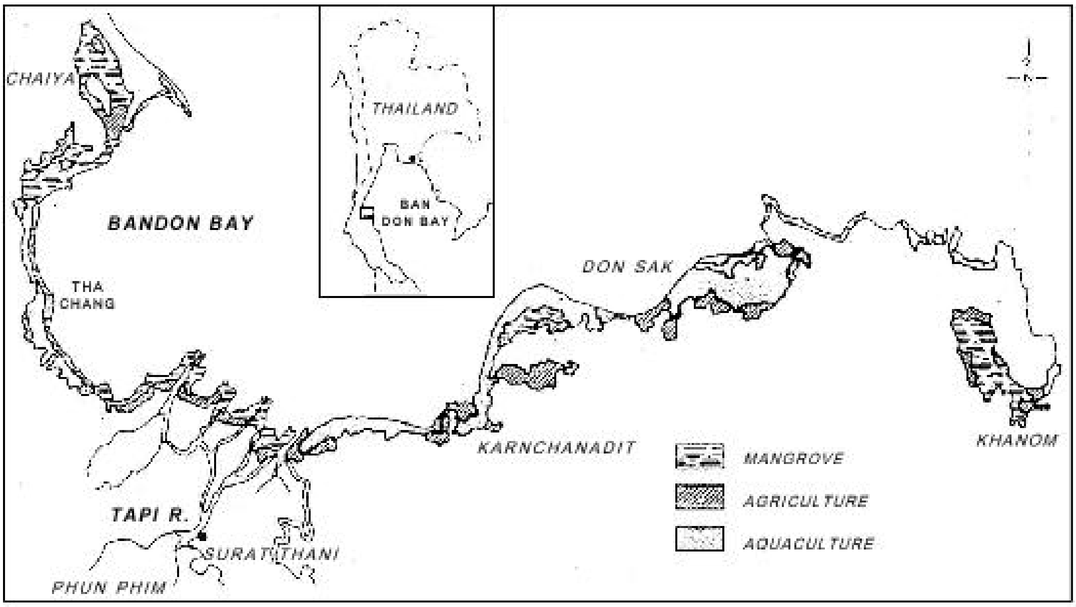


Figure 1.1 Map of the study area.

Meteorological data for Bandon Bay in 1997-1998 is based on the data compiled from the Suratthani Weather Stations and is shown in Figure 1.2. The wet season starts in May and lasts until December, with monthly rainfall ranging from 77 mm to 412 mm. The highest rainfall recorded during the study was in August. The dry condition, from January to April, is characterized by lower rainfall (< 50 mm) and higher evaporation rate. The average rainfall is 4.48 mm day^{-1} and average evaporation is 4.46 mm day^{-1}. Relative humidity is 81% (range from 61-95%). Annual rainfall for 1997 was 1500 mm, which is less than the mean annual rainfall for 1951-1996 (1690 mm).

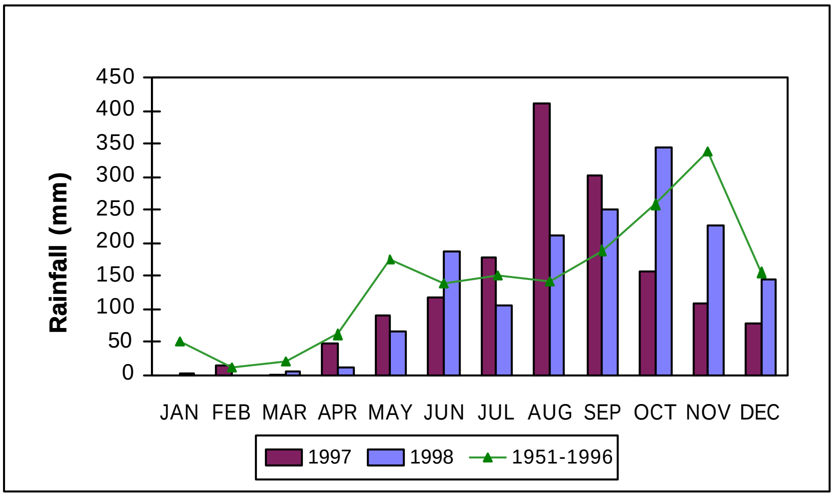


Figure 1.2 Monthly rainfall in mm for Suratthani in 1997-1998.

Bandon Bay receives most of the surface freshwater runoff from the Tapi-Phumduang River watershed (latitude 7° 58.2’ N – 9° 31.0’ N, longitude 97° 28.4’ E – 99° 46.0’ E), which is situated between the Nakorn Si Thammarat mountain range and the Phuket mountain range in Southern Thailand. The watershed consists of two catchment areas with an approximate area of 11,585 km^2. It has two major river basins, namely the Tapi River basin and the Phumduang River basin, with an area of 5,460 km^2 and 6,125 km^2, respectively. The Tapi River, approximately 230 km long, originates in the Nakorn Si Thammarat Range, while the Phumduang River originates in the Phuket Range. The two rivers join to become one at Phunphin District (30 km west of Suratthani), and flow through Muang District and Municipality then empties into Bandon Bay which is connected to the Gulf of Thailand.

Further upstream, a rockfill dam with clay core (Chiew Larn Multipurpose Dam), 94 meters high, was constructed across the Klong Saeng River, a tributary of the Phumduang River. The river is dammed and used to irrigate the agricultural land, so discharge is strongly regulated. The annual volume of water released from the Chiew Larn Dam to the lower basin depends on demand for salinity control, irrigation, navigation, industry and domestic consumption. However, the discharge hydrographic of the Tapi-Phumduang River still exhibits a periodic variation with a cycle of one year (Figure 1.3). Annual runoff in the Tapi-Phumduang river system normally amounts to more than 10 billion m^3. The hydrological characteristics of the Tapi and Phumduang rivers in 1997 are summarized in Table 1.1. The ratio of the maximum and minimum discharges appears to be high, which implies that monthly discharges fluctuate according to seasonal precipitation.

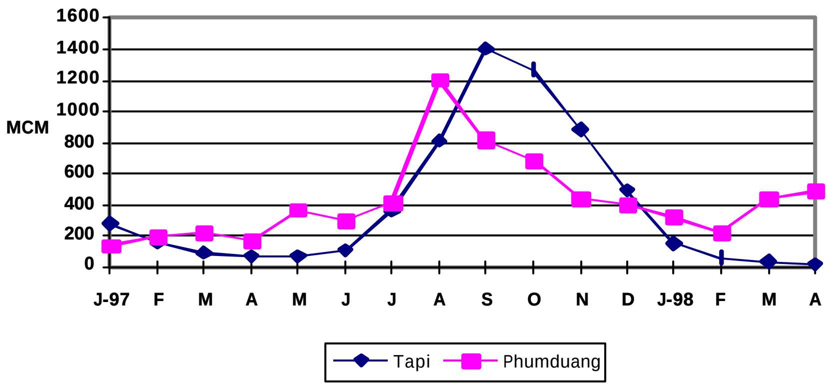


Figure 1.3 Monthly discharge of Tapi and Phumduang rivers into Bandon Bay in 1997-1998. (Source: Royal Irrigation Department)

Table 1.1 Hydrological characteristics of Tapi and Phumduang rivers in 1997.

River	**Drainage Area (km^2)**	**Discharge (m^3/s)**			**Ratio Maximum/ Minimum**	**Annual Runoff (million m^3)**
		Mean	Minimum	Maximum		
Tapi	5,200	135.4	14.4	803.9	56	4280
Phumduang	3,012	120.9	14.5	1253.4	86	3830

Source: Royal Irrigation Department

1.3.2 Ecological characteristics

1.3.2.1 Coastal habitats

Bandon Bay is among one of the productive coastal area in the southern part of Thailand. However it is also an example of the heavy utilization of coastal resources. The mangrove forests along the coast of Bandon Bay, covering the provinces of Chumporn, Suratthani and Nakhon Si Thammarat, are quite productive and extensive. Seagrass beds surrounding Samui, Ang Thong and Phangan islands are important nursery grounds for marine resources. These two productive natural resource habitats coupled with the nutrient discharges from the Tapi and Phumduang Rivers into the bay provide a rich and continuous supply of biogenic carbon for marine resources.

Riverine forests are common in the extensive mangrove forests of Bandon Bay. Riverine mangrove forests are recognized as most productive, partly due to seasonal flooding by freshwater from upland areas. The mangrove forests along the coast of Bandon Bay are estimated to cover 25,570 ha. The species composition of mangrove communities of Bandon Bay was observed at Muang District, Chumporn Province, Chaiya District and Don Sak District, Suratthani Province and Khanom District, Nakhon Si Thammarat (Aksornkoae, 1994). The dominant species at Chaiya District were *Rhizophora apiculata, Sonneratia alba, Avicennia alba, Xylocarpus pranatum*, *Excoecaria agallocha, Ceriops decandra* and *Nypa fruticans*. At Don Sak District, the dominant species are *R. mucronata, R. apiculata A. officinalis, X. molluscensis, E. agallocha* and *Phoenix* sp.

Five species of seagrasses were recorded from the seagrass beds at Koh Samui, Suratthani Province by Nateekanjanalarp and Sudara (1991): *Halodule uninervis, Halophila ovalis, Halophila ovata, Halophila decipiens* and *Enhalus acorides*. The seagrass biomass was estimated in the range of 0.004 - 1111.5 g dry wt m^{-2}.

The mangrove forests and seagrass beds in Suratthani have played significant roles as food sources, habitat, shelter and nursery grounds for numerous associated fauna. A study of macrofauna in the soft bottom community was carried out under the ASEAN-Australian Coastal Living Resources Project (1994) during May-June 1988. A total of 20 species belong to 6 families and 10 genera of shrimps were reported. The family Penaeidae was the most diverse consisting of 13 species. Three economically important genera, namely *Metapenaeopsis*, *Metapenaeus* and *Parapenaeopsis*, made up approximately 82% of the total density. The results agreed well with Boonyubol and Chaitiamvong (1994). *Metapenaeopsis, Metapenaeus* and *Parapenaeopsis* were dominant in this area. Boonyubol (1996) has studied the seasonal changes in shrimp larvae, *P. merguiensis* in Don Sak River, Suratthani. She found that the highest abundance of post-larvae was recorded during March, with two other peaks during September and November. Juvenile stages were detected throughout the year with the highest peaks in January, April, May and November. Chaitiamvong (1997) investigated the shrimp community in Don Sak area. Sergestid, caridean and penaeid shrimps in particular *P. merguiensis* were dominant in the mangrove forests. Shrimps of the genus *Metapenaeus, M. affinis* and *M. ensis* were more abundant in the estuarine area. Monkolprasit (1994) investigated the fish community in the Bandon Bay mangrove forests. She recorded 56 species in 26 families with the family Engraulidae the dominant group. *Stolephorus indicus, Engraulis kammalensis* and *E. baelama* were the three most dominant species. She concluded from her study that the mangrove forests in Bandon Bay played an important roles as feeding grounds for fishes. She found that approximately 56% of fishes that come in feed on zooplankton benthos and fishes. Detritivorous and herbivorous fishes were also recorded.

Copepods, mysidaceans, ostracods, tanaidaceans and brachyuran zoea were the dominant groups in the zooplankton community in Suratthani seagrass beds. (Nateekanjanalarp and Sudara 1991). Amphipods, polychaetes and molluscs were the three major groups of benthic fauna associated in the seagrass beds. Nekton in the seagrass beds can be divided into two groups: permanent residents such as caridean shrimps and gobiid fishes, and seasonal residents such as brachyuran crabs and economically important fishes including *Siganus spp.*; *Epinephelus tauvina, Psammoperca waigiensis* and *Gerres sp.*

Tookwinas *et al.* (1992) conducted an investigation on the potential for aquaculture in Suratthani Province. for 1988-1990. Their study revealed that the coastal environment was in an appropriate condition for aquaculture. Phytoplankton density was in the range of 4,533-62,128 cells/liter. The dominant genera of phytoplankton were *Thalassiothrix, Rhizosolenia, Nitzschia, Chaetoceros* and *Guinardia.* Zooplankton density recorded was in the range 118-897 cells/liter with shrimp larvae representing 5-10% of the total zooplankton. The benthic community recorded was in the range of 73.8 – 1,138 individuals/m^2. Stations inside Bandon Bay itself recorded the highest phytoplankton, zooplankton and benthic production.

1.3.2.2 Marine fisheries in Bandon Bay

Captured fisheries

Most of the fisheries in Bandon Bay are small-scale fisheries. The major fishing gears are gill net or drift net for catching crabs and threadfins, trammel net for catching shrimps, push net and other trawls. Penaeid shrimps largely *P. merguiensis*, *P. monodon, P. semisulcatus, P. latisulcatus* and *Metapenaeus spp.* are the important target species. Other invertebrates such as mantis shrimp, swimming crabs and squids are also caught. Bandon Bay has been declared by the Department of Fisheries as a conservation zone due to its importance as spawning and nursery grounds for penaeid shrimps, anchovies, club mackerel and mollusc species. The fish larvae survey by the Department of Fisheries revealed more than 42 families of fish larvae in the area with the dominant families Gobiidae, Leiognathidae, Clupeidae, Callionymidae and Engraulidae. Monkolprasit (1994) found that of the 56 fish species recorded from Bandon Bay mangrove forest, fishes in the family Engraulidae were the dominant group. Fish eggs and larvae were most abundant between March and May. The important demersal fishes in the area were Sciaenidae, Cynoglossidae, Engraulidae and Clupeidae. Rattanachote (1994) reported that the commercially important mullets in Bandon Bay were *Liza subvirides* and *Valamugil cunnesius.*

Bandon Bay is very productive in terms of benthic production. The benthic fauna serve as important linkages in the marine food chain as the aquatic food resources for large predatory fishes and crustaceans. A total of 40 species from nine families and 26 genera of brachyurans were reported from the area. Three major families were Portunidae, Goneplacidae and Leucosiidae. Although many of these were small-sized crabs, they served as food resources for large predatory fishes, crustaceans and squids (Aryuthaka *et al.* 1991). The results corresponded to those reported by Charoenruay *et al.* (1983) and Sanguansin (1986). Other important benthic aquatic food resources as revealed from the ASEAN-Australian Coastal Living Resources Project (1994) were polychaetes of predominantly families Terebellidae, Eunicidae and Nereidae. There were 29 families recorded in the area. Dominant echinoderms were brittle stars *Ophiocnemis marmorata*; sea urchins *Temnoplereus toreumaticus* and sea cucumber *Acaudina* spp. Jivalak *et al.* (1991) found 60 species of molluscs in this area. Five commercial bivalves were found namely, *Paphia undulata, Anadara spp., Scpharca sp., Modiolus senhausii* and *Placuna placentra. Paphia undulata* was the most abundant with a density of 81.51 individual/m^2 and biomass of 68.86 gm^{-2}. This findings corresponded to Chareonruay *et al.* (1983). They reported a total of 203 species of benthic organisms collected by dredges from Chong Angthong area adjacent to Bandon Bay. Of the total, 23 species were echinoderms, 60 were molluscs, 59 were decapod crustaceans, 31 were polychaetes and 30 were other organisms.

The fisheries resources in the Bandon Bay have been heavily exploited. Excessive fishing efforts and the capture of undersize fish were evidenced. Commercial fish and trash fish make up the commercial catches from small and medium-size trawlers. The commercial component of the catch from push net was also dominated by “small” and “large” shrimps. Fish and squid components were largely treated as by catch and seldom marketed. Lohsawatdikul and Eiamsaard (1991) reported the mean catch rate for push net boats in Bandon Bay at about 316 kg/boat/day with a “commercial” to “trash” fish ratio of 4:6. The “commercial” component of catches was composed largely of shrimps and swimming crabs, while the “trash fish” component was composed of more than 60 % “true trash fish” and less than 40 % undersize individuals of commercially important organisms. When compared with the push net catch survey in Tha Chang, Suratthani Province conducted by Eiamsaard *et al.* (1985), the catch rate was 187 kg/boat/day, with 57% “trash fish”. Of this “trash”, 47% were juveniles of commercially important organisms. This implied that over a quarter (27%) push net landing consisted of undersize fish of commercial importance. These two statistics indicate that approximately a quarter of the total landing was composed of undersize fish indicating a tremendous rate of over-fishing. There have been concerns on the destructive nature of push net operation in the shallow area especially in the bay, which are important spawning grounds for many commercial species Klinrod *et al.* (1993) reported the catch rate, species composition and size of marine invertebrates from push net and shrimp gill net from Don Sak area. They conducted monthly surveys from

1987 to 1991. The catch composition from the push nets revealed 41-63% “trash fish”, 7-13% large shrimps, 18-38% small shrimps, other invertebrates 5-12% and commercial fish 0.1-0.9%. Large shrimps, mainly *P. merguiensis* and *Metapenaeus spp.* contributed approximately 58-74% of the catch from shrimp gill nets. Small shrimps made up approximately 2-8%, other invertebrates 19-28% and commercial fish 3-14%. The maximum catch rate for push net and shrimp gill net were 29.4 kg/hr (1990) and 1.66 kg/hr (1989).

Figure 1.4 shows the decline in fishery production of Suratthani within the past ten years (1986-1995). Most of the fish production is trash fish resulting from excessive fishing effort, capture of undersize fish and the destructive nature of push net. Coupled with the degradation of mangrove forest, this further reduced the fishery production. However, the ratio of food fish to trash fish has slightly improved from the year 1992 onward partly due to strict fishery regulation. As revealed from the Department of Fisheries data, the catch rate for demersal fish and shellfish in Suratthani were 1.16 kg/hr and 0.34 kg/hr in 1993. These catch rates changed slightly over time.

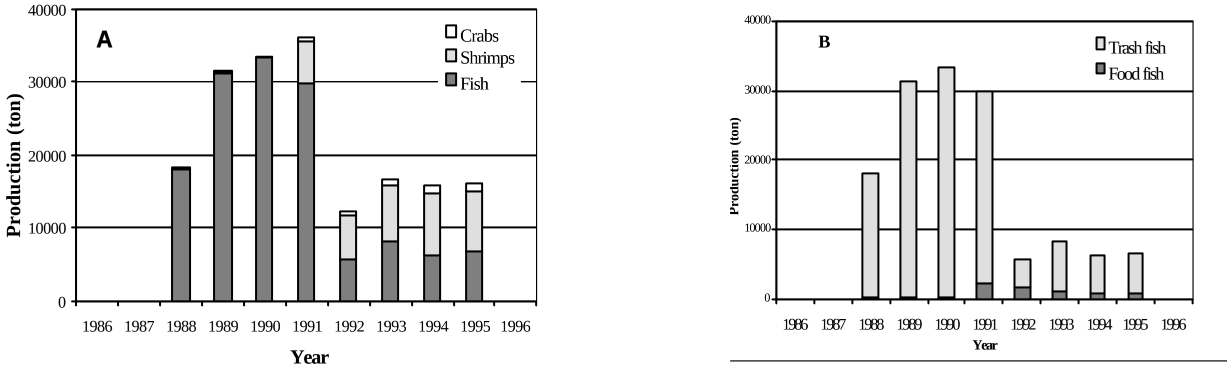


Figure 1.4. Fisheries production in Suratthani Province
A. Production of major fishery species. B. Composition of fishes landed.

Cultured fisheries

Coastal aquaculture in Bandon Bay has expanded rapidly. Shrimp culture is the dominant aquaculture activity. Other aquaculture activities are cockle (*Anadara granosa*, culture, oysters of two major species, *Crassotrea belcheri* and *C. lugubris* and fish culture. Kanchanadit District is the largest potential area for shrimp farms. The area for shrimp farms was 241 ha in 1979 (Haemaprasit and Paw 1988). The rate of increase in shrimp farm area were 6.6 and 13.5 fold respectively as compared with the original area in 1979. Table 1.2 and Figure 1.5 show the variations in mangrove coverage shrimp farm area and shrimp production in Suratthani Province from the period 1986–1996. The shrimp production increased several fold from 1986–1990 due to the increase in shrimp culture. The high shrimp production is maintained through the increase in the area of intensive shrimp farming. Boonprakob (1983) had once predicted the expansion of shrimp farms in Suratthani to its fullest capacity of 3,200 ha. Within two years, the shrimp farms at Bandon Bay had already expanded to its full prediction. However, the expansion of shrimp farm area continued to increase further to 9,642 ha in 1992 and to 13,780 ha in 1996, of which only 6,946 ha are productive. The shrimp culture technology has shifted from traditional and semi-intensive to intensive farming. The high rate of shrimp production maintained due to the ratio of traditional farms : semi-intensive : intensive farms in 1996 was 2.68 : 1.00 : 3:28 as compared to the ratio in 1989 of 4.11:3.45:1: 00. as in Figure 1.6.

Table 1.2 Variation in mangrove coverage and shrimp production in Suratthani Province.

Year	Mangrove coverage (ha)	Shrimp farm area (ha)	Total shrimp production (ton)	Shrimp production /area (ton/ha)
1986	4336.36	3740.57	2146	0.574
1987	4161.30	4915.79	2828	0.575
1988	3986.72	6728.74	3268	0.486
1989	3812.79	8270.28	9828	1.188
1990	3021.70	9025.10	14400	1.596
1991	2230.77	9596.11	18748	1.954
1992	2716.60	9642.11	20047	2.079
1993	3202.43	8771.17	25414	2.897
1994	3192.23	8136.03	25858	3.178
1995	3182.02	6655.55	22221	3.339
1996	3171.82	6946.07	21226	3.056

Fish culture and cage fish culture are other important aquaculture activities in Suratthani. Fish culture, mainly sea bass and groupers, have increased from 1990 to 1994. Total fish production from fish ponds and fish cages has increased from 14 tons to 32 tons. During the same period, the area under oyster culture has increased from 301 ha to 640 ha, and oyster production has increased from 492 tons to 10,295 tons. Cockle culture, mostly in Chaiya and Tha Chang districts, has also increased in area from 395 ha to 1,158 ha. However, the production recorded in 1990 and 1991 were 3,997 and 10,799 tons respectively with a major decline in 1994 to 4,509 tons.

1.3.2.3 Changes in mangrove forests and fisheries production

Declining fishery production in Thai waters is generally due to over-fishing, pollution and coastal habitat degradation. These three major factors seem inseparable. Several studies in Thailand demonstrated that decrease in mangrove area correlated well in time with the decrease in coastal fishery production. As with other mangrove forests of Thailand, coastal development and conversion of mangrove forests to aquaculture, in particular shrimp farming, were the two major forces of the loss of mangrove areas in Bandon Bay. The depletion of mangrove forests in Bandon Bay during 1961-1979 was due to coastal development with the highest rate of depletion of approximately 77 %. The overall depletion was 87 % from 25,600 ha in 1961 to 4,336 ha in 1986 and 3,171 ha in 1996. The rate of depletion during 1979-1989 was 35 %. The lowest rate of mangrove depletion, during 1989-1996, was 17 %.

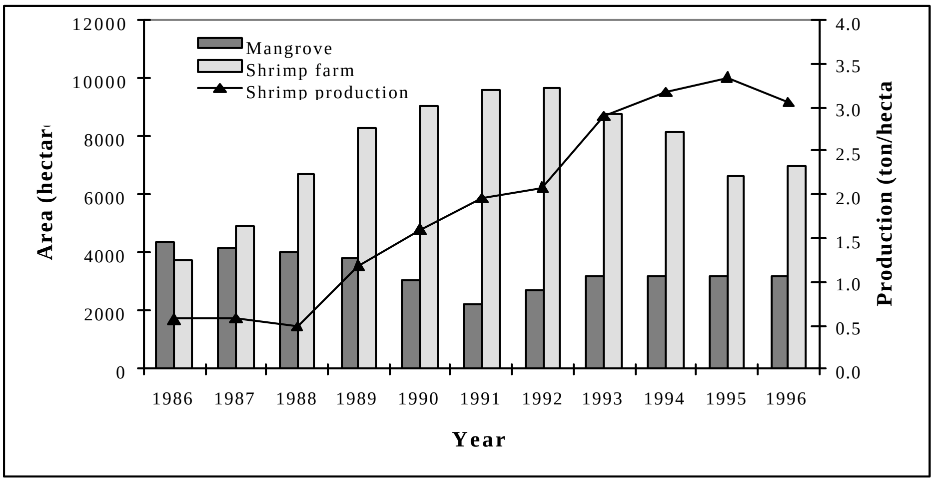


Figure 1.5 Variations in mangrove coverage, shrimp farm area and shrimp production in Suratthani Province.

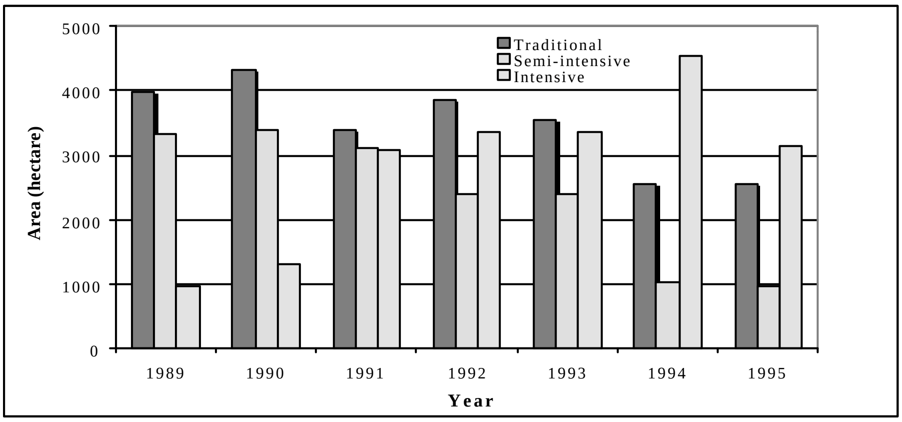


Figure 1.6 Shrimp farming technologies used in Suratthani Province.

In 1983, Boonprakob had predicted the expansion of shrimp farms in Suratthani to its fullest capacity of 3,200 ha. Within two years, the shrimp farms in Bandon Bay had already expanded to its full prediction of 3,262 ha in 1985 (Haemaprasit and Paw 1988). At the time of prediction in 1983, the shrimp farms area was 1,592 ha increased tremendously from the original 242 ha in 1979. However the expansion continued to 13,780 ha in 1996. Of this, the shrimp farm on the previous mangrove area comprised about 54% of the total shrimp area in this province. Coastal development is another major force for the loss of mangrove area. The total population has grown steadily over the years adding the demands for the natural resources.

As revealed from the fisheries statistics of Suratthani within the period of 1986 -1995, there was some correlation between the decreasing mangrove forests with the decrease in fishery production as in Figures 1.4 and 1.5. Over-fishing coupled with the degradation of mangrove forests were the major pressures for the reduction in fishery production. Figure 1.7 shows the oyster farm expansion in the Bandon Bay. The oyster farm expansion was quite rapid.

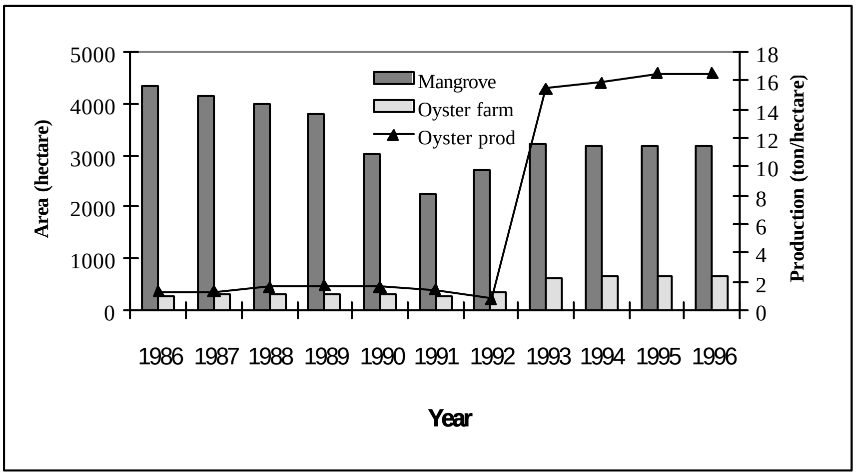


Figure 1.7 Oyster farming and production in Suratthani Province

The area for oyster culture had increased more than two-fold from 1986-1996. Oyster production jumped from 1.30 ton/hectare in 1986 to 16.5 ton/hectare. Recent studies in southern Thailand found that there were increased mollusc harvests in areas adjacent to major shrimp farming areas (Office of the Environmental Policy and Planning 1994). This could explain the increased oyster production in Suratthani during 1986–1996 apart from the rapid expansion of oyster farms.

It is always a major problem where waste production from aquaculture in particular shrimp farm area exceeds the capacity of the receiving environment to dilute or assimilate the waste materials. Self-pollution of shrimp culture areas by pond effluents and the major crash of the shrimp industry are apparent in Thailand particularly in Samut Sakhon, Samut Songkhram, Suratthani and Nakhon Si Thammarat provinces, and in Taiwan, the Philippines and Indonesia. The potential impacts from the discharges of shrimp pond effluents are the depletion of dissolved oxygen due to discharge of effluent with high biochemical oxygen demand and the breakdown of dissolved and particulate organic matter and other waste materials. There is urgent need for the development of a model to predict the carrying capacity of coastal areas for shrimp farms. This model will link the number and intensity of farms in a given coastal area with the ability of the area to assimilate waste materials. This model should take into account the physical and chemical processes of the area especially the chemical budgets, the biogeochemical processes of certain chemical compounds, tidal cycles and range, retention time and hydrology. At present, only a few studies on the carrying capacity of the receiving bay or estuaries have been carried out in Thailand such as in Khung Kraben Bay, Chanthaburi Province. However the model has not yet been implemented in the coastal management. This situation is similar to Suratthani that the expansion of coastal aquaculture in the area was quite rapid and without direction. This could easily lead to the accumulation of waste products that far exceed the carrying capacity of the receiving aquatic environment.

Table 1.3 shows our calculations using the equations proposed by Preedalumpabutr and Chaiyakum (1994) on the correlation between the total ammonia and BOD and the shrimp farm areas. The total ammonia and BOD loading are extremely high. Existing discharged loading from shrimp ponds has not been calculated. Many of the shrimp farms are along the coast, so most of the waste is discharged directly into the sea, but some is discharged into the river. For exact estimation, locations have to be considered as well as area and generated rate. Since 1990, according to Thailand National Water Quality Classification for Seawater, the water in Bandon Bay is unsuitable for aquaculture. The nutrient budget in this study revealed the average ammonia concentration in the bay was 0.10 mg/1 in April 1997, 0.07 mg/1 in October 1997, and 0.08 mg/1 in April 1998. These values are lower than the calculated values assuming that the shrimp farm area remained the same as in 1996. Thus the integrated model of carrying capacity in Bandon Bay should be further developed for the resource management.

Table 1.3 Predicted total ammonia concentration and BOD in water released from shrimp farms in Suratthani Province.

Year	Shrimp farm area (ha)	Total ammonia concentration (mg/l)	BOD (mg/l)
1986	3740.57	1.11	5.91
1987	4915.79	1.53	7.06
1988	6728.74	2.18	8.83
1989	8270.28	2.73	10.33
1990	9025.10	3.00	11.07
1991	9596.11	3.21	11.62
1992	9642.11	3.22	11.67
1993	8771017	2.91	10.82
1994	8136.03	2.69	10.20
1995	6655.55	2.16	8.75
1996	6946.07	2.26	9.04

1.3.3 Economy and society

Population

Suratthani province has an area of 12,890 km^2. The 1997 population of the province was approximately 861,200, of which 149,800 were in the urban community and 711,400 were in the rural area of the basin. In the basin area, Muang Suratthani district has the largest number of population (17.2%). The followings included Phunphin district (10.5%) and Nasarn district (7.8%).

Table 1.4 Population distribution in 1997.

District	Area (sq. km.)	Municipal Area	Population	Urban Population	Number of Households
Muang Suratthani	231.31	68.97	40,169	107,888	54,050
Kanchanadit	873.53		91,011		22,663
Koh Samui	227.25		34,792		12,397
Kiriratnikom	1,347.37		37,578		8,186
Chaiya	1,004.63		42,905		10,314
Don Sak	458		33,473		9,081
Tha Chang	1,160.42		28,819		6,577
Tha Chana	683.08		43,125		10,825
Ban Nasan	835.06	67.13	47,827	19,390	15,337
Panom	703.22		28,515		6,576
Phra Saeng	1,328.06		52,148		11,815
Punpin	1,201.16	14.1	67,724	22,520	22,444
Wiangsra	420.39		56,678		13,235
Koh pangan	193		9,029		3,218
Kiansa	580		35,503		8,191
Ban Ta Khun	1,300		13,211		3,572
Ban Nadoem	206		20,974		5,013
Chaiburi	112		18,552		4,381
Vipavadee	529.25		9,402		2,403
Total	**13,393.73**		**711,435**	**149,798**	**230,278**

Source: National Statistical Office

Land Use

The province is well endowed with natural resources, with forest covering about 25 % of the area, while the coastal zone has mangrove forest. The sea provides a livelihood for fishermen and aquaculturists, while the offshore islands have become well known internationally as tourist destinations. The rich natural resources of the province provide the raw materials for industries which have developed in the area.

Land use in 1998 (Table 1.5) is largely agricultural and forest. Agricultural land is mainly land for rubber and oil palm plantations. Most of the land is rolling foothills suitable for upland crops and tree cultivation. Flat areas suitable for rice cultivation are limited. However, a large area is still under forest, and is now protected by law as national parks, wildlife sanctuaries and non-hunting areas. A small amount of land is used for urban centres and industry.

Coastal development is a major cause of the loss of mangrove area. The total population of Suratthani has grown steadily from 588,400 in 1980 to 816,400 in 1990, and to 861,200 in 1997. The coastal resources of Bandon Bay are heavily utilized for economic development, particularly land reclamation and development for agriculture, aquaculture and human settlement. Comparison of land use in the Bandon Bay coastal area between the year 1993 and 1998 is shown in Table 1.6. In the past five years, a lot of the mangrove forest and inundated area in the coastal zone has been converted to shrimp farms and/or other uses. Land for rubber and oil palm plantations, as well as rice fields has increased whereas that for coconut plantations (or mixed orchards) has decreased in area.

Table 1.5 Classification of land cover/land use in Bandon Bay coastal area in 1998 (Sawangphol and Wattayakorn, 1999).

Categories	**% Image**	**Area (km²)**	**Area (rai)***
Forest	0.48	14.11	8,818.75
Mangroves	0.58	16.96	10,600.0
Rubber Plantation	24.83	730.29	456,431.25
Coconut Plantation	4.41	129.81	81,131.25
Oil Palm Plantation	3.44	101.24	63,275.0
Paddy Field	9.11	267.89	167,431.25
Shrimp Farm	3.72	109.50	68,437.7
Urban Area	1.21	35.67	22,293.75
Shrubs	0.54	15.89	9,931.25
Inundated Area	1.22	35.77	22,356.25
Others	7.33	215.59	134,743.75
Water bodies	38.03	1,118.53	699,081.25
Clouds	5.10	150.0	93,750.0
TOTAL	**100.00**	**2,941.24**	**1,838,273.44**

Table 1.6 Comparison of land use between the years 1993 and 1998.

Categories	**Area (km²)**		**Area Change**	
	1993*	1998^	km²	km²/year
Forest	6.86	5.83	-1.03	-0.21
Mangroves	23.32	16.07	-7.25	-1.45
Rubber Plantation	168.04	363.35	+195.31	+39.06
Coconut Plantation	**161.14	110.31	-50.83	-10.17
Oil Palm Plantation	0.65	42.10	+41.45	+8.29
Paddy Field	140.82	188.30	+47.48	+9.50
Shrimp Farm	64.56	80.88	+16.32	+3.26
Urban Area	19.10	26.77	+7.67	+1.53
Inundated Area	61.47	20.50	-40.97	-8.19

* from Siripong et al., 1996;
^ normalized to the same study area as that of Siripong *et al.* (1996)

Production

The main products of the province are: rubber, oil palm, fruit, fishery products, canned seafood, and tourism. The gross provincial product for 1994 is shown in Table 1.7

Table 1.7 Gross Provincial Products in 1994.

Sector	Current Prices (Baht)	% Share	Constant Prices (Baht)		% Growth
	1994		**1989**	**1994**	
Agriculture	13,389,171	37.64	8,665,187	12,010,134	6.53
Crops	9,138,789	25.69	6,501,716	8,753,855	5.95
Livestock	584,431	1.64	420,307	589,878	6.78
Fishery	2,285,042	6.42	778,488	1,541,236	13.66
Forestry	0	0.00	57,418	0	-100.00
Agric. Services	44,097	0.12	44,784	34,302	-5.33
Agric. Processing	1,336,812	3.76	862,474	1,090,863	4.70
Mining and Quarrying	666,666	1.87	392,801	384,885	-0.41
manufacturing	2,728,564	7.67	1,901,190	2,228,548	3.18
Construction	2,270,185	6.38	715,854	1,476,789	14.48
Electricity and Water Supply	830,443	2.33	364,530	643,102	11.35
Transportation and Communication	1,829,373	5.14	794,954	1,539,903	13.22
Wholesale and retail trade	4,472,944	12.57	2,495,807	3,318,153	5.70
Banking and Insurance	2,268,615	6.38	551,373	1,701,362	22.54
Ownership of dwelling	1,224,930	3.44	656,647	828,333	4.65
Public administration	1,747,087	4.91	718,024	955,115	5.71
Other services	4,143,827	11.65	1,778,276	2,409,640	6.08
Total	**35,571,805**	**100.00**	**19,034,643**	**27,495,964**	**7.36**

2 BIOGEOCHEMICAL PROCESSES

2.1 Approaches

Knowledge of the exchange of water and materials through the mouths of estuaries is crucial to an understanding of functioning of both estuaries and the coastal zone. This study examines the fluxes of carbon, nitrogen and phosphorus from Bandon Bay into the Gulf of Thailand in order to gain an initial understanding of the biogeochemical processes occurring in the system. In assessing the C, N and P fluxes, three approaches have been taken: the LOICZ biogeochemical flux model, the single cross-section hydrodynamic budgeting and the mixing diagram approach. Nutrient flux estimates from the three approaches will be compared and discussed.

2.2 Water, carbon and nutrient budgets

Water samples were collected at twenty-five stations in Bandon Bay and ten stations in Tapi Estuary (Figure 2.1), during April and October of 1997 and 1998. Samples were taken at two depths, near surface and near bottom, as applicable. Nutrient analysis was performed in duplicates for each sample. As quality control, at least five samples were replicated five times for each of the nutrient parameters. Data in April were collected to represent the dry season and October to characterize the wet season of the study area.

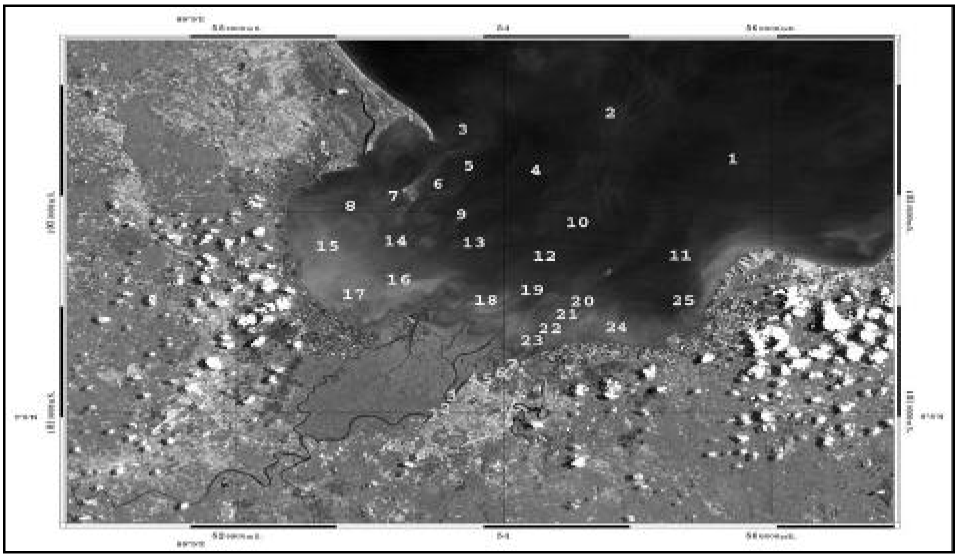


Figure 2.1. Sampling stations in Bandon Bay, 1997 – 1998.

The LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996) were used to calculate the stoichiometrically linked water-salt-nutrient budgets. River flow (V_Q) data were obtained from measurements carried out by the Royal Irrigation Department. Rainfall and evaporation data were obtained from the weather stations in Suratthani. Extensive pumping of groundwater for domestic and industrial consumptions in the area has caused saline intrusion into groundwater aquifers in the Tapi-Phumduang River Basin, hence groundwater inflow (V_G) to the system can be assumed to be zero. The water volume of sewage and industrial effluents is small relative to freshwater input and is assumed negligible. Organic loads from sewage, industrial wastes, and agricultural wastes (V_O) were estimated using data from the Pollution Control Department (1998), assuming 50% BOD assimilation rates. Salinity in precipitation and wastes is assumed to be zero. The system has been divided into two boxes: Tapi Estuary and Bandon Bay. For the purposes of the budgetary analysis, both basins are treated as well-mixed systems.

Results and Discussion

Figure 2.2 shows the salinity structures in Bandon Bay during the wet and dry seasons. Average salinity in the bay ranged from 17 psu in the wet season to 20 psu in the dry season. In the sea, salinity ranged from 29 psu in the wet season to 32 psu in the dry season. Salinity in the estuary ranged from 0 to 23 psu in the dry season, 0 to 14 psu in the wet season. A longitudinal transect in Tapi Estuary revealed that the estuary was vertically well-mixed at the head of the estuary but slightly stratified towards the mouth (Figure 2.3). In the wet season, the entire estuary showed near freshwater conditions at the surface.

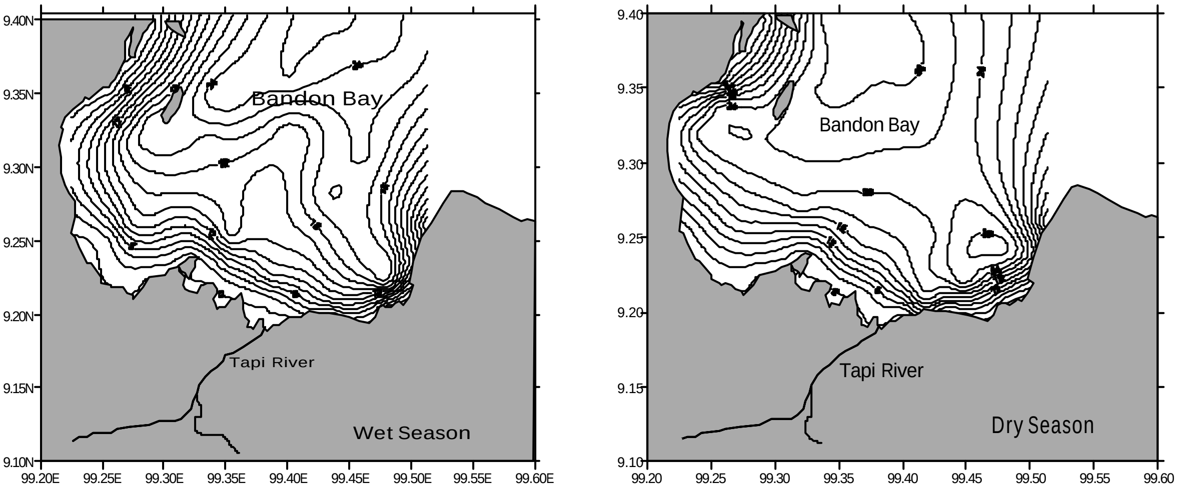


Figure 2.2 Salinity distribution in Bandon Bay.

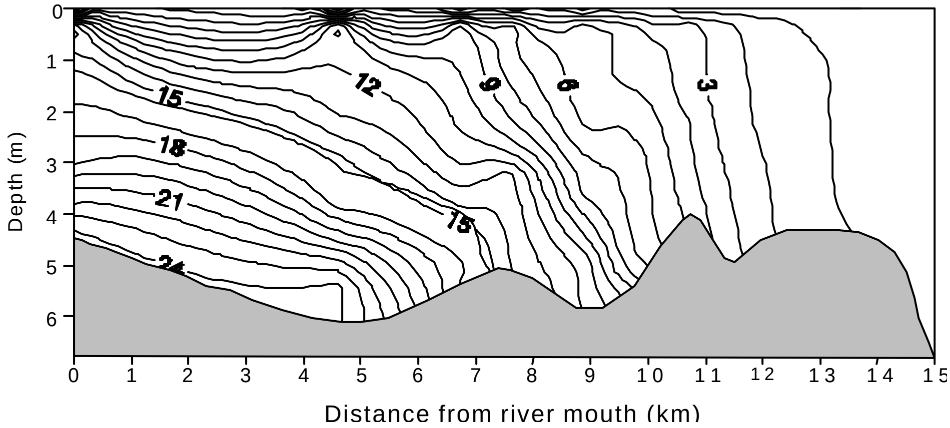


Figure 2.3. Longitudinal distribution of salinity in Tapi estuary in the dry season.

Major sources of wastewater discharge into the bay are communities, industrial factories and fishery ports and aquaculture activities along the Tapi-Phumduang river. Waste-load estimates of the economic activities are given in Table 2.1. Contribution of non-point agriculture runoff and livestock are also important during the wet season. Total N and P inflows were obtained by conversion of BOD loading, using the stoichiometric relationships of C:N:P ratios in organic waste materials (San Diego-McGlone 1999). A factor of 0.5 (PO_4 /TP) and 0.27 (DIN/TN) was used to determined the inorganic fraction (DIP) and (DIN) of the wastes from the estimated TP and TN.

Following the LOICZ Biogeochemical Guidelines (Gordon et al. 1996), the exchange time of water in the bay can be calculated as the total volume of the bay divided by the sum of V_X , mixing between bay and ocean, plus the absolute value of residual flow $|V_R|$. The water exchange time of the Tapi River estuary is estimated to be 1 to 7 days, and that for Bandon Bay is 12 to 77 days (Table 2.2 and Figure 2.4). It can be seen that the water exchange rate in Bandon Bay is faster in the wet season than in the dry season. Tides seem to be the main force driving water exchange with the adjacent Gulf of Thailand during the low flow period (April 1997).

Table 2.1. Estimated BOD generated and discharged by various economic activities. (Pollution Control Department, 1998)

BOD generated (kg/day)			BOD discharged (kg/day)			
	1995	1996		1996	1997	1998
Domestic	1360	1430	Domestic	715	744	773
Industry	173	727	Industry	145	148	151
Shrimp farm	12	12	Shrimp farm	12	12	12
Agriculture	814	828	Agriculture	-	-	-
Total, kg/d	2359	2997	Total, kg/d	872	904	937
			Total, kmol/d	73	75	78

Table 2.2. Water circulation, residual flow (V_R), water exchange rates (V_X) and water exchange time as calculated from the water and salt budgets for Bandon Bay. The subscript "Q" indicates river; "P" is precipitation and "E" is evaporation.

Date	**V_Q** $10^6 m^3 d^{-1}$	**V_P** $10^6 m^3 d^{-1}$	**V_E*** $10^6 m^3 d^{-1}$	**V_R*** $10^6 m^3 d^{-1}$	**V_X** $10^6 m^3 d^{-1}$	**Water exchange time, days**	
						Estuary	Bay
Apr-97	6	2	-2	-6	12	7	77
Oct-97	58	0	-2	-56	112	1	8
Apr-98	26	0	-2	-24	67	2	15
Oct-98	24	11	-2	-33	86	2	12

* the minus sign for V_E and V_R indicates an output from the system

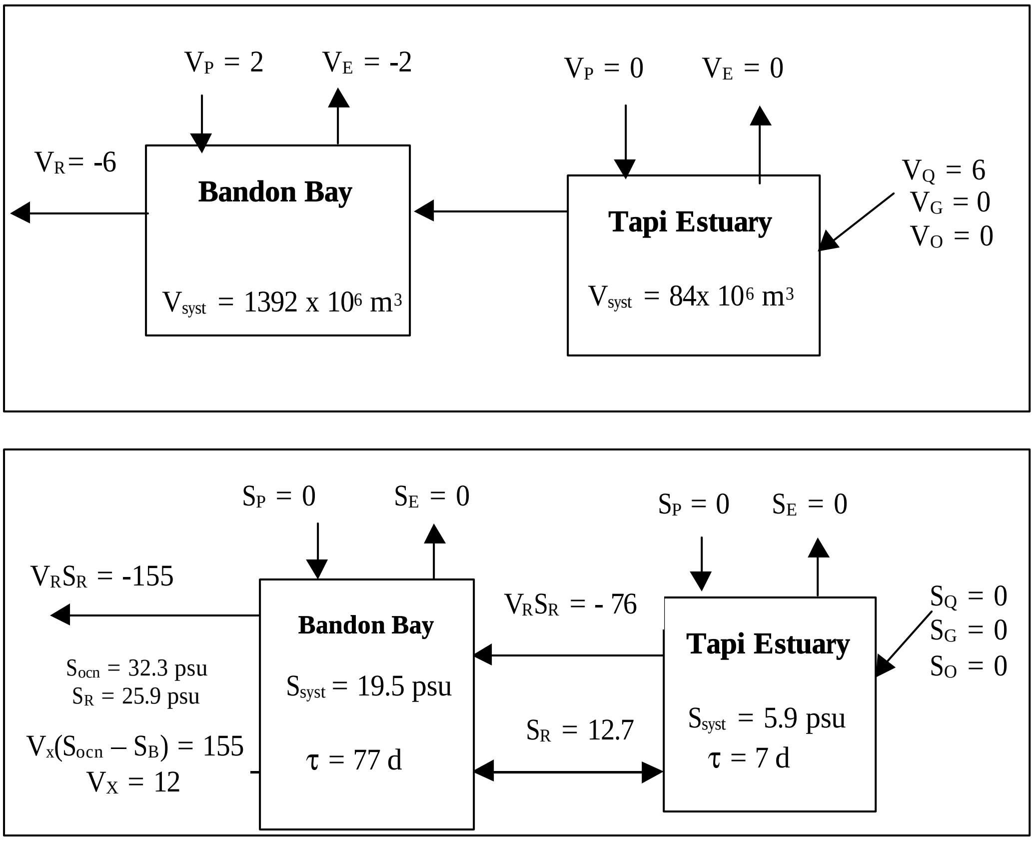


Figure 2.4. Water and salt budgets for Bandon Bay

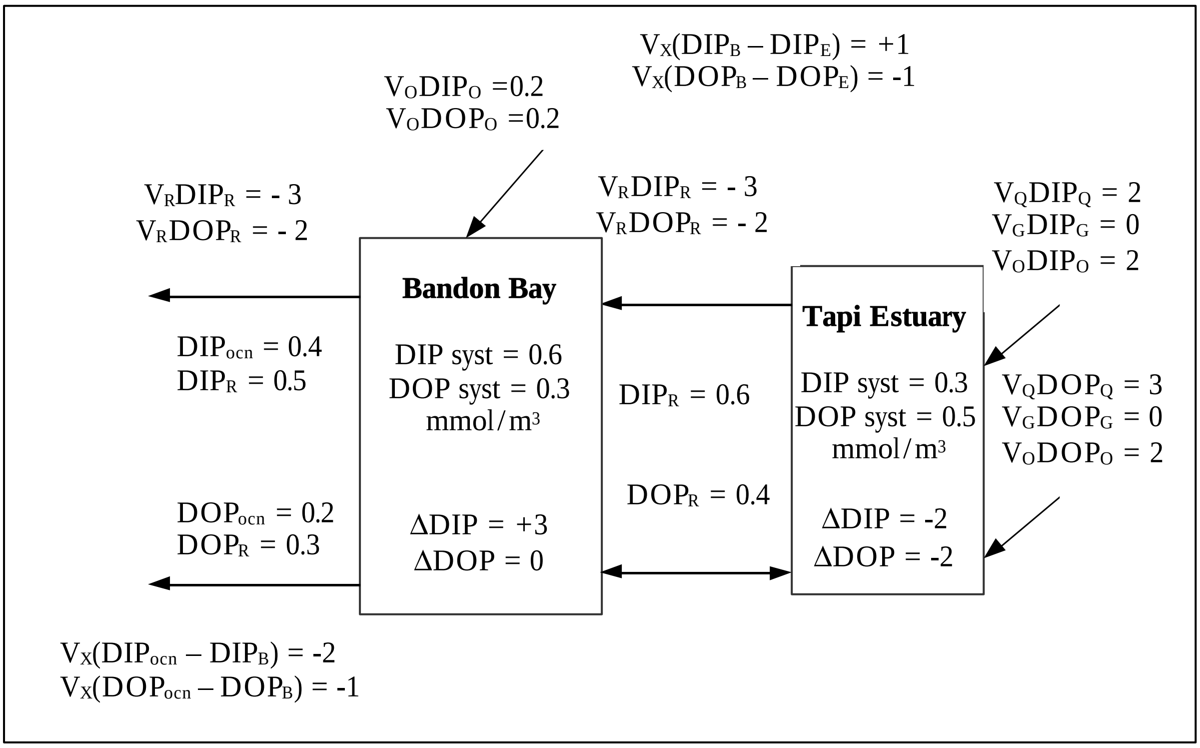


Figure 2.4 Phosphorus budgets, Bandon Bay and Tapi Estuary, wet and dry seasons 1997. Fluxes in 10^3 mol d^{-1}.

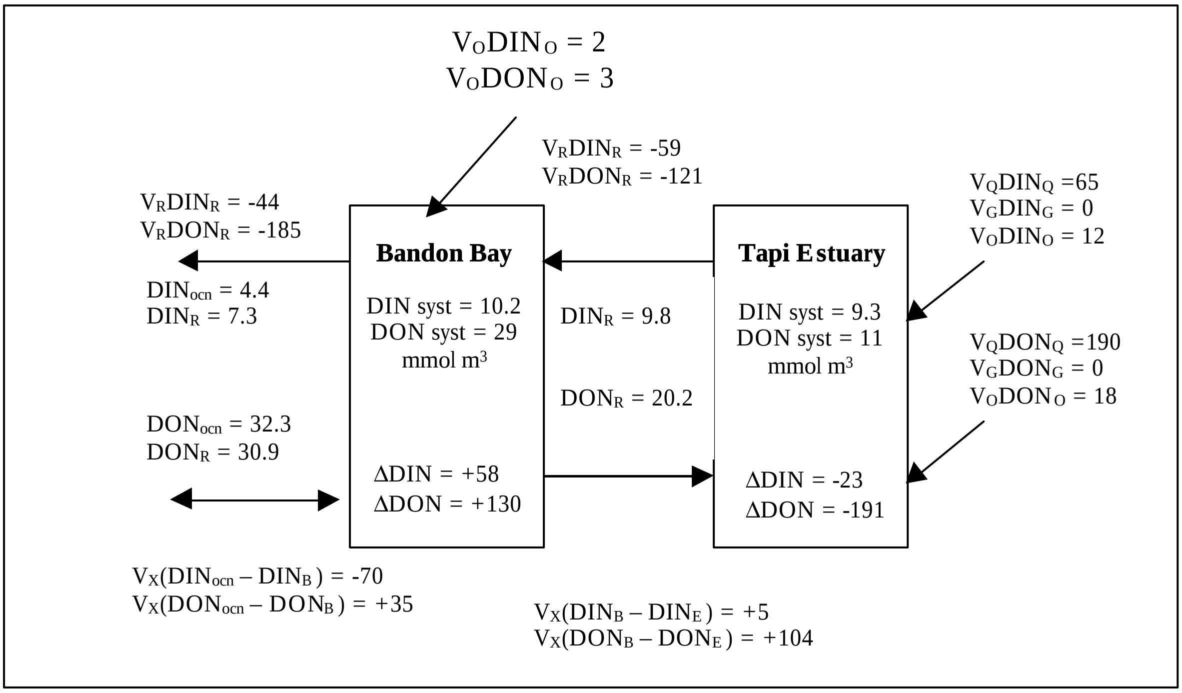


Figure 2.5 Nitrogen budgets, Bandon Bay and Tapi Estuary, wet and dry seasons 1997. Fluxes in 10^3 mol d^{-1}.

Budgets of non-conservative materials for the system are summarized in Figures 2.5 – 2.6 and Table 2.3.

Figure 2.5 shows the phosphorus budgets for the 1997 dry season. The Tapi estuary appears to be a net sink for both DIP and DOP during this period. However, DIP is slightly exported from Bandon Bay to the Upper Gulf of Thailand at a rate of 5 kmol/day. DOP is also exported to the Gulf at a rate of 3 kmol/day during this period.

Figure 2.6 presents the nitrogen budgets for the 1997 dry season. The Tapi estuary is a net sink for DIN (ammonium and nitrate) and DON, and Bandon Bay is a net source for DIN (ammonium) and DON. ΔDIN is exported from Bandon Bay to the upper Gulf of Thailand at a rate of 114 kmol/day and ΔDON at a rate of 150 kmol/day.

For the other periods of study, the results are presented in Table 2.3. In general, it can be seen that there is some variability for all the nutrients. ΔDIP for Bandon Bay ranged from -0.02 to 0.01 mmolm^{2} d^{-1} with a mean of ~ 0 mmolm^{2} d^{-1}; ΔDOP ranged from -0.06 to 0.03 mmolm^{2} d^{-1} with a mean of -0.01 mmolm^{2} d^{-1}· ΔDIN for ranged from 0.02 to 1.8 mmolm^{2} d^{-1} with a mean of 0.52 mmolm^{2} d^{-1}; ΔNH_4 ranged from 0.14 to 1.7 mmolm^{2} d^{-1} with a mean of 0.60 mmolm^{2} d^{-1}; ΔNO_3 ranged from -0.37 to 0.10 mmolm^{2} d^{-1} with a mean of -0.08 mmolm^{2} d^{-1} and ΔDON NO_3 ranged from -1.3 to 0.27 mmolm^{2} d^{-1} with a mean of -0.46 mmolm^{2} d^{-1} ·

Table 2. 3. Summary of non-conservative carbon, nitrogen and phosphorus fluxes (mmol m^{-2} d^{-1}).

	April 1997		**October 1997**		**April 1998**		**October 1998**	
	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon
ΔDIP	-0.12	0.005	-0.65	-0.02	0.10	0.002	0.07	0.01
ΔDOP	-0.17	0	0.57	-0.06	-0.17	-0.001	-0.53	0.03
ΔNH_4	-1.75	0.14	-6.53	0.39	0.17	0.18	-19.4	1.7
ΔNO_3	-0.17	-0.02	3.10	-0.37	1.1	-0.04	-10.2	0.1
ΔDIN	-1.92	0.12	-3.43	0.02	1.3	0.14	-29.6	1.8
ΔDON	-15.9	0.27	-23.7	-0.51	3.9	-0.28	-44.2	-1.3
ΔTA*	0	-13.3	725.6	-74.6	766.7	-42.1	333.3	49.6
ΔDIC	350.0	-34.2	-62.8	-249.7	483.3	-193.7	100.0	-172.8
ΔDOC#	-10.7	-0.03	-10.0	-0.22	-10.8	-0.02	-13.1	-0.15

* flux is in meq m^{-2} d^{-1}
# flux is in mol m^{-2} d^{-1}

	Average dry season		**Average wet season**		**Annual fluxes (mol m^{-2} yr^{-1})**			
	mmol m^{-2} d^{-1}		mmol m^{-2} d^{-1}		1997		1998	
	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon
ΔDIP	-0.01	0.0035	-0.29	-0.005	-0.157	-0.004	0.030	0.002
ΔDOP	-0.17	-0.0005	0.02	-0.015	0.096	-0.013	-0.139	0.006
ΔNH_4	-0.79	0.16	-13.0	1.04	-1.662	0.105	-4.126	0.391
ΔNO_3	0.465	-0.03	-3.55	-0.13	0.638	-0.082	-2.017	0.015
ΔDIN	-0.31	0.13	-16.515	0.91	-1.024	0.022	-6.138	0.406
ΔDON	-6.0	-0.005	-33.9	-0.90	-7.473	-0.068	-8.870	-0.320
ΔTA*	383.3	-27.7	529.45	-12.5	155.278	-17.973	187.098	4.257
ΔDIC	416.6	-113.9	18.6	-211.25	39.411	-58.600	94.378	-66.228
ΔDOC#	-10.75	-0.025	-11.55	-0.18	-3.756	-0.052	-4.434	-0.035

* flux is in meq m^{-2} d^{-1}
# flux is in mol m^{-2} d^{-1}

Table 2.3 indicates that most nutrients are trapped in the estuarine section of the Tapi River and in Bandon Bay. In general, DIP is in a steady state within the bay (average value of $\Delta DIP \sim 0$), while DOP is consumed in the system. The dissolved phosphorus source (ΔDIP values are positive) is interpreted to be the result of net organic oxidation and/or desorption from sediments. On the other hand, DIP can also be removed by uptake by phytoplankton and/or adsorption to particles which will later on be buried in the sediments. The Bandon Bay system appears to be very active in consuming dissolved organic phosphorus and generating DIP which, in turn is consumed by phytoplankton at about the same rate, hence $\Delta DIP \sim 0$.

In general, there is a release of NH_4, and uptake of NO_3 within the estuary-bay system. This appears to represent net respiration of organic matter, with nitrification of released NH_4. Because of the longer water residence time in the dry season (low flow conditions), decomposition of organic matter can take place better than in the high flow condition, where adsorption of phosphate seems to be the dominant process (ΔDIP values are negative).

The removal of DIP and DIN with NH_4 release reflects nitrogen recycling. Some nitrogen and phosphorus were, of course, lost by being bound into refractory organic matter in the sediments (adsorption to particles). By contrast with DIP, the system was a much bigger source of DIN (ΔDIN = 0.02– 1.8 mmol $m^{-2} d^{-1}$) and most of it come from NH_4.

Removal of DON, DOP and DOC in the system may be due to sedimentation of organic matter since in the coastal zone a large fraction of organic matter falls to the bottom where it is partly accumulated and buried and partly decomposed. Some of the nutrients will be returned to the water column; some will be lost through the internal sinks (denitrification for nitrogen and adsorption for phosphorus).

Stoichiometric calculations of aspects of net system metabolism

The internal sink of nitrogen may be attributed either to denitrification, or to burial of organic matter. Phosphorus may be lost through burial as either organic or adsorbed inorganic P. According to the LOICZ interpretation, nitrogen fixation-denitrification (*nfix-denit*) is given by: $\Delta N_{obs} - 16x\Delta P$ (assumed to be phytoplankton with a Redfield N:P ratio of 16:1) From Table 2.4, Bandon Bay is slightly net nitrifying in 1997 and become slightly net denitrifying in 1998, while the Tapi estuary is strongly net denitrifying system in both 1997 and 1998. The presence of benthic algae on the mud flats, as well as mangrove fringe around the bay, could account for nitrogen fixation in Bandon Bay.

Net ecosystem metabolism (NEM = *p-r*) can be estimated in a similar way, as the negative of the non-conservative DIP flux multiplied by the C:P ratio of the reacting organic matter. Assuming the bulk of the reacting organic matter is phytoplankton, then the C:P ratio is 106:1. Thus:

$$(p-r) = -106 \times (\Delta DIP)$$

The C:N:P ratio of the particulate materials (terrigenous organic detritus) entering the Tapi River estuary during 1997 survey was found to be 324:27:1 (substantially higher C:P and N:P ratios than Redfield ratio). Using this C:N:P ratio, the new (*p-r*) and (*nfix-denit*) were estimated (Table 2.4). The magnitude of the new (*p-r*) and (*nfix-denit*) in the estuary are different, but not the qualitative conclusion. From the (*p-r*) calculated for the 4 sets of data shown in Table 2.4, Bandon Bay appears to be slightly autotrophic and the Tapi estuary is strongly autotrophic in 1997. However, both systems turn to be net heterotrophic in 1998.

Table 2. 4. Stoichiometric calculations of aspect of net system metabolism for Bandon Bay (flux is in mmol $m^{-2} d^{-1}$).

	April 1997		**October 1997**		**April 1998**		**October 1998**	
	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon
(*p-r*)[1]	17.7	-0.7	70.7	2.0	-8.8	-0.2	-9.0	-1.1
Nfix-denit[2]	-12.5	0.3	-25.7	0.7	6.5	-0.1	-67.0	-0.1
(*p-r*)[3]	54.0	-2.0	216.0	6.1	-27.0	-0.7	-27.0	-3.4
Nfix-denit[4]	-8.8	0.2	-24.8	1.6	7.4	-0.1	-63.0	-1.0

[1] based on particle C:P of 106 ; [2] based on particle N:P of 16
[3] based on particle C:P of 324 ; [4] based on particle N:P of 27

	Average dry season		**Average wet season**		**Annual fluxes (mol.m^{-2}.yr^{-1})**			
					1997		**1998**	
	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon	Tapi	Bandon
(*p-r*)[1]	4.45	-0.45	30.85	0.45	17.80	0.32	-3.25	-0.27
Nfix-denit[2]	-3	0.1	-46.35	0.3	-7.39	0.20	-13.36	-0.04
(*p-r*)[3]	13.5	-1.35	94.5	1.35	54.38	1.00	-9.86	-0.83
Nfix-denit[4]	-0.7	0.05	-43.9	0.3	-6.64	0.37	-12.36	-0.23

[1] based on particle C:P of 106 ; [2] based on particle N:P of 16
[3] based on particle C:P of 324 ; [4] based on particle N:P of 27

The overall net production of organic matter by the bay-estuarine ecosystem is the total gross (*p-r*). This net production either accumulates within the system (as sediment accretion) or is exported by tidal action and by movement of large organisms, i.e. birds and nekton.

The net export fluxes from the bay to the Gulf of Thailand are presented in Table 2.5. These fluxes were calculated using LOICZ guidelines as

$$V_R . (C_1 + C_2)/2 + V_x . (C_1 - C_2)$$

where C_1 is the Bay centre concentration, and C_2 is the adjacent seawater concentration.

Table 2. 5. Net export fluxes of C, N and P (kmol/day).

	Apr-97		**Oct-97**		**Apr-98**		**Oct-98**	
	Tapi	**Bandon**	**Tapi**	**Bandon**	**Tapi**	**Bandon**	**Tapi**	**Bandon**
DIP	2.3	5	17.4	9.6	16.2	17.5	7.6	13.5
DOP	3.4	3	37.8	11.2	2.6	2.4	17.2	33.7
DIN	54	114.2	722.1	733.2	359.4	428.2	973.2	1849.3
NH_4	19	88.0	354.0	543.2	253.7	339.6	746	1577.7
NO_3	35.8	26.9	368.0	190.4	106.8	89.6	227.2	271.6
DON	17	150.0	457.3	217.8	827.0	693.0	1,183.6	586.2
TA	7.2	0.8	66.6	30.8	53.4	33.2	18.4	42.2
DIC	7.2	(9.2)	5.0	(114.8)	26.6	(66.4)	20.4	(62.6)
DOC	0.6	6.9	101.1	44.8	18.2	27.8	41.7	16.5

*<u>Note:</u> ( ) = import

	Average dry season		**Average wet season**		**Annual fluxes (x 10^6 mol.year^{-1})**			
	kmol.day^{-1}		**kmol.day^{-1}**		**1997**		**1998**	
	Tapi	**Bandon**	**Tapi**	**Bandon**	**Tapi**	**Bandon**	**Tapi**	**Bandon**
DIP	9.2	11.2	12.5	11.5	4.1	2.8	4.1	5.5
DOP	3.0	2.7	27.5	22.4	8.6	2.8	4.1	7.6
DIN	206.7	271.2	847.6	1,291.2	162.7	174.1	262.5	460.4
NH4	136.3	213.8	550.0	1,060.4	78.6	129.5	197.9	388.9
NO3	71.3	58.25	297.6	231.0	84.2	44.8	64.7	71.6
DON	422.0	421.5	820.4	402.0	100.4	69.3	378.2	230.1
TA	30.3	17.0	42.5	36.5	15.3	6.7	12.0	14.0
DIC	16.9	(37.8)	12.7	(88.7)	2.2	(26.0)	8.4	(23.4)
DOC	9.4	17.3	71.4	30.6	21.7	10.6	11.7	7.7

*Note: ( ) = import

Comparison was made between flux estimates with and without wastewater input (Table 2.6) and between the one- and two-box models (Table 2.7). When waste flux was included in the budget calculation, it is evident that waste is the major source of organic carbon to the estuary-bay system, and that most of it remains trapped in sediments, hence none of the organic carbon is exported to the coastal waters in the dissolved form. The two-box model clearly shows that most of the organic matter (DOC, DON and DOP) remains trapped in the estuarine section of the Tapi River.

Table 2.6. Comparison of C, N and P flux estimates (mmol m^{2} d^{-1}) with and without wastewater flux (one-box model).

	April 1997		**October 1997**		**April 1998**	
	No waste input	**With waste input**	**No waste input**	**With waste input**	**No waste input**	**With waste input**
ΔDIP	0.005	0.001	-0.025	-0.028	0.003	0
ΔDOP	0.001	-0.004	-0.04	-0.04	-0.001	-0.004
ΔNH_4	0.10	0.08	0.25	0.23	0.18	0.16
ΔNO_3	-0.01	-0.02	-0.25	-0.26	-0.005	-0.01
ΔDIN	0.09	0.06	0	-0.03	0.175	0.15
ΔDON	-0.09	-0.13	-1.04	-1.08	-0.17	-0.21
ΔTA*	-12.3	-12.30	-38.0	-38.0	-23.9	-23.9
ΔDIC	-22.3	-22.30	-241.8	-241.8	-1.0	-1.0
ΔDOC	10.6	-256.07	4.7	-297.4	38.3	-238.0

* flux is in meq m^{-2} d^{-1}

Table 2.7. Comparison of C, N and P flux estimates (mmol m^2 d^{-1}) using the one- and two-box models (with waste flux).

	April 1997		October 1997		April 1998	
	1-box	**2-box**	**1-box**	**2-box**	**1-box**	**2-box**
ΔDIP	0.001	0.005	-0.03	-0.02	0	0.002
ΔDOP	-0.004	0	-0.04	-0.06	-0.004	-0.001
ΔNH_4	0.08	0.14	0.23	0.39	0.16	0.18
ΔNO_3	-0.02	-0.02	-0.26	-0.37	-0.01	-0.04
ΔDIN	0.06	0.12	-0.03	0.02	0.15	0.14
ΔDON	-0.13	0.27	-1.1	-0.51	-0.21	-0.28
ΔTA*	-12.30	-13.3	-38.0	-74.6	-23.9	-42.1
ΔDIC	-22.30	-34.2	-241.8	-249.7	-1.0	-193.7
ΔDOC	-256.07	-29.3	-297.4	-216.4	-238.0	-22.5

* flux is in meq m^{-2} d^{-1}

2.3 Time series measurements of estuarine material fluxes

Water and material exchanges between the Tapi River estuary and Bandon Bay were also calculated for the major tidal river cross-section of the Tapi estuarine system from our hydrographic tidal cycle measurements. These daily material fluxes were calculated by multiplying velocity (measured by a current meter at three depths), cross-sectional area, and concentration at hourly intervals (Kjerfve and McKellar 1980) for four tidal cycles in 1997-1998. Lateral homogeneity was assumed since only one station was sampled. Two sets of observations, taken in the Tapi River estuary during 1997 corresponding to a period of dry (April) to high (October) river flow, are presented here. Results of nutrient flux estimations are presented in Table 2.7.

Table 2.8 Net constituent fluxes (kg/day) from the Tapi estuary. Positive values are exports, negative imports.

Net flux	**April 1997**	**October 1997**
Water (m^3/day)	-2.71 x 10^6	-8.46 x 10^5
Salt (Kg/day)	+2.86 x 10^7	+1.93 x 10^7
Ammonia	-841.38	+165.51
Nitrate plus nitrite	-447.81	-302.81
DIN	-1.29 x 10^3	-1.38 x 10^2
DON	-760	no data
DIP	-36.4	+62.3
DOP	-192	-159
DOC	-58.82	+264.7
Silicate	-2.95 x 10^3	+7.82 x 10^3
Part. Phosphorus	-74.2	+379
Part. Nitrogen	-2.22 x 10^4	No data
Part. Carbon	-544.32	No data
Suspended sediments	-2.42 x 10^6	+5.84 x 10^5

Dissolved and particulate nutrients were imported with flooding water as it traverses the mudflats in Bandon Bay and into the Tapi estuary during the dry season. However, in the wet season dissolved ammonia, phosphate and silicate were exported to coastal waters. Import of nutrients, particularly nitrate and nitrite, is probably due to denitrification occurring in the anaerobic mudflats in Bandon Bay, which was found to occur during the dry season (Wattayakorn *et al.* 1998). This phenomenon was also found in the Rhode River (Jordan *et al.* 1983). Some of these nutrients (i.e. phosphate and ammonium) may be released from pore water by either diffusion or seepage (Nixon 1980). Ammonium in sediment is readily exchangeable with other cations, so the high concentrations of sodium in saline soils tend to swamp the cation exchange sites, displacing NH_4. The ion is readily mobile and susceptible to being leached by heavy rain or flowing seawater. These nutrients were imported with flooding water as it traverses the mudflats in Bandon Bay, into the Tapi estuary during the dry season. Conversely, substantial freshwater input of nutrients may result in tidal export of ammonia, phosphate and silicate in the wet season.

2.4 Mixing diagrams

It is technically difficult and very costly to attempt to measure the flux of mass through a given cross-section of an estuary. In addition, nutrients may not behave conservatively within the estuary. Particular nutrient forms may be gained or lost by chemical reactions, by biological uptake or metabolic activity and/or adsorption on or desorption from suspended matter. Estuarine scientists have sometimes attempted to avoid the mass-balance problems in estuarine nutrient dynamic studies by relating non-conservative parameters to salinity or chlorinity. In the absence of biogeochemical processes occurring within an estuary or export to the atmosphere, the composition of a particular element within that estuary will be a linear function of its concentration in the river and the ocean. Chloride (or salinity) is the usual reference or conservative property upon which variations of other elements are measured (Liss 1976).

Nutrient data from the Tapi estuary were analyzed using a conservative mixing model to assess nutrient distribution and variability during the dry and wet season of 1997. The study shows that most nutrients behaved in a non-conservative manner during estuarine mixing (Figure 2.6). Variation of ammonia with salinity suggests the presence of an internal source of ammonia in the estuary. This could be a result of decomposition of organic matter within the system. Other sources, such as regeneration from sediments or the result of discharges from food processing plants and municipal wastes are also possible.

Mixing curves of nitrate (nitrate means sum of nitrate-N and nitrite-N) in the dry season showed that nitrate is removed from the water column at low salinity. This removal is generally takes as immobilization of nitrate by other geochemical processes (i.e. adsorption onto solid particles and thus removal of nitrate from the soluble phase). In the wet season, nitrate showed an increase in concentration followed by a gradual decrease downstream. The estuary, therefore, acts as a sink for nitrate in the dry season and as a source in the wet season.

Phosphate concentration in the estuary increased at low salinity region but gradually decreased towards the mouth during the dry season. The increase is probably due to either high input of phosphate from sewage, or desorption of phosphate during resuspension of sediments during early estuarine mixing. The removal of phosphate towards the mouth is probably due to uptake by phytoplankton. Mixing curve of phosphate in the wet season shows a distinct lack of variation. This behaviour is strongly indicative of buffering mechanism, as reported in Columbia River estuary by Steffansson and Richards (1963).

Mixing curves of silicate showed similar patterns to those of nitrate for both seasons, indicating that the system acts as a sink in the dry season and a source in the wet season. Utilization of nutrients by diatom growth is usually restricted by high turbidity. However the mixing diagram indicates biological uptake of silicate in the dry season.

2.5 Discussion

The LOICZ guidelines for constructing nutrient budgets assume an estuary or embayment which is well-mixed, both vertically and horizontally, and at steady-state. Errors might be incurred in neglecting spatial and temporal variation, as well as in treating an estuary with a two-layer circulation (particularly in the wet season) as a single box system. However, the technique is simple for assessing the biogeochemical function of estuaries including denitrification and nutrient retention rates. In estimating the C, N and P fluxes, it is not necessary to investigate all of these materials. Normally, P will be the usual parameter to be investigated, and it is often sufficient to make a detailed study of the P budget and calculate the others from their stoichiometric relationships to P. The mathematics involved is relatively straightforward and the method has been shown to give good results in a number of habitats, including our Bandon Bay system.

The mouth cross-section computation method of Kjerfve and McKellar (1980) was used to determine the discharge over each tidal cycle; these data were then used to calculate the volume of water at any time over the tidal cycle. By subtracting the volumes of water across the mouth of the estuary at successive time intervals, volume discharge was determined. Nutrient flux was then computed. Since most of the material in solution or suspension probably sloshes back and forth through the tidal channel, on average only a small fraction of the maximum instantaneous flux is likely to be added or lost from the system. Thus, it is difficult to determine net transport direction with any certainty. Furthermore, it is assumed that the variability of the cross-sectional concentrations is minimal, so that the one water sample can be used to represent the cross-sectional concentration. That will no doubt limit this technique to well-mixed estuaries. Hence, flux estimation for the dry season better fits with the other two approaches than does that of the wet season.

The mixing diagram approach has been used by estuarine chemists to characterize behaviour of an element along the estuarine salinity gradient, using salinity as a mixing index. Deviations of the parameters from linearity indicate non-conservative behavior in that there is a net loss or gain in the estuary. Although the approach appears straightforward, in many cases it has proved difficult to apply, and to interpret the results obtained. These curves do not provide insight into dynamic estuarine processes which may be occurring. A linear response of a nutrient along the salinity gradient does not necessarily mean that the substance is not participating in biogeochemical processes within the system; it means only that losses and gains are balanced and the estuary is in a steady-state with respect to that particular substance. However, the technique is also very easy to carry out and give some information which characterizes the role of the coastal zone as a source or sink for C, N and P.

Our studies have shown that the three approaches give similar results on fluxes of nutrients imported or exported in the Bandon Bay system, though not totally so. Some discrepancies obtained from the various methods are probably due to the difficulty in assessment of magnitudes and directions of net material transport between estuaries and the coastal ocean with large tidal variability. The ability to determine the flux of the medium containing the nutrients of interest, including spatial and temporal variability, sets the lower limit on the accuracy of the nutrient flux calculations. In addition, a properly preserved, adequate number of water samples must be taken so that the spatial and temporal variability with respect to nutrient concentrations is well documented. The difficulties outlined above, coupled with the inherent variability of results from estuaries, in common with most environmental data, mean that there is a limit to the sensitivity of each approach. In general, the dry season results are more comparable between the different approaches adopted than the wet season condition.

Thailand

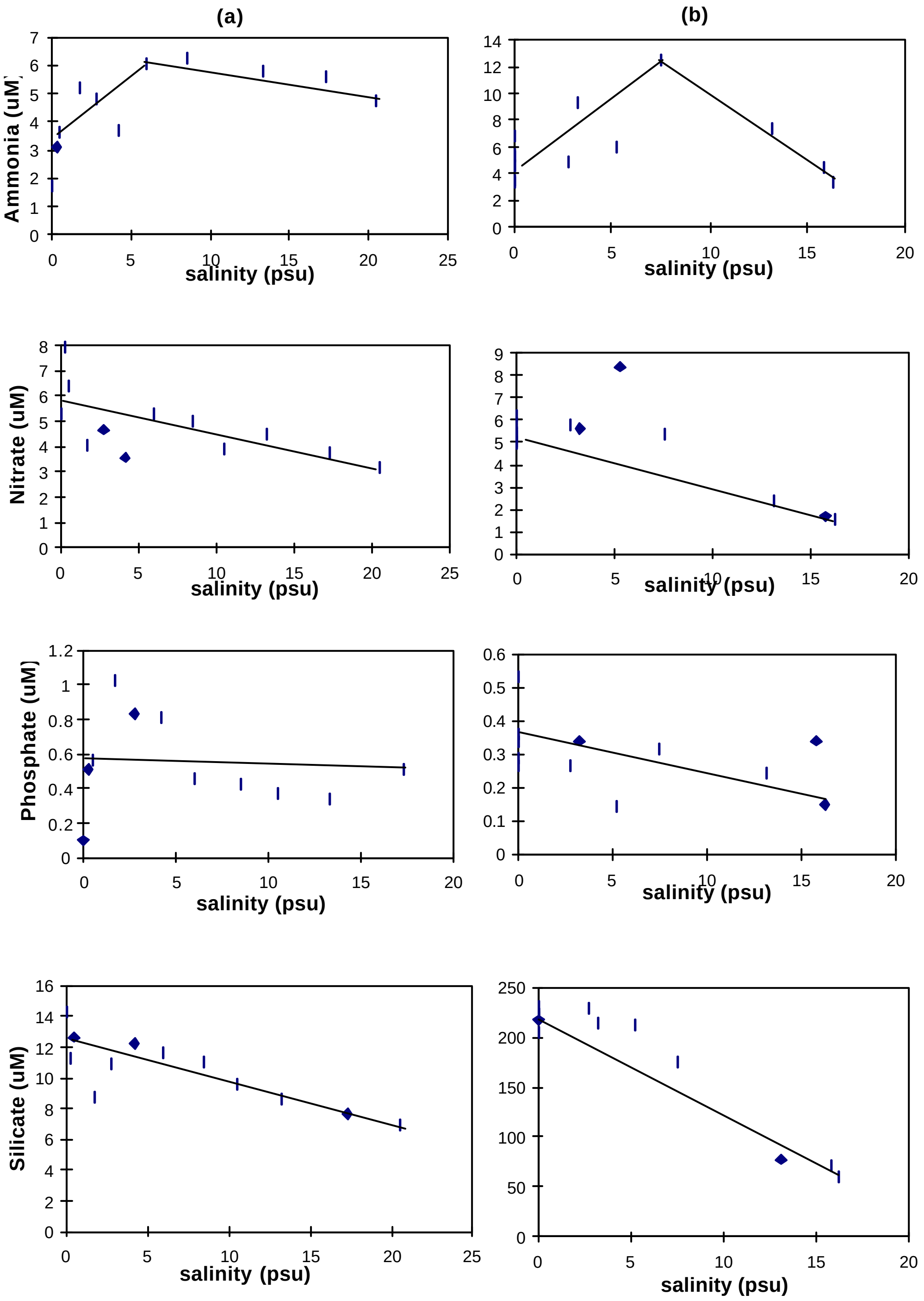


Figure 2.6 Relationship between dissolved nutrients and salinity (a) dry season (b) wet season.

3 PRODUCTION OF ORGANIC CARBON AND FISHERY PRODUCTION

Bandon Bay is one of the most productive coastal ecosystems in Thailand, with mangrove forest along the shoreline and the Tapi riverine system. Offshore to the bay are coral reef and seagrass communities. The bay also offers various types of habitat for economically important fishes and marine invertebrates such as clams and oysters. This makes the bay a suitable place for aquaculture activities. However, heavy utilization of both living and non-living resources due to urban and agricultural activities is now threatening the ecosystem and the socio-economics of Bandon Bay. Thus, it is important to understand the nature of the bay as well as the interaction and responses of both biotic and abiotic components of the economic development of the area in order to maintain the ecological and economical importance of Bandon Bay. This part of the project aims to elucidate the trophic relationships among the living inhabitants of the bay as well as to examine the response of these components to the changes in abiotic components of the system.

Nutrients and dissolved organic compounds from river runoff and various anthropogenic sources are incorporated into primary producer, phytoplankton, along the Tapi River estuary and in Bandon Bay. The assessment of this assimilation process was reported in term of primary production calculated from the relationship between primary production and chlorophyll_a biomass proposed by Shemshura *et al.* (1991) and the assumed season day of 270 days (Cushing 1969). The composition and abundance of the pelagic organisms in the bay as well as the standing crop of primary producer was investigated for three separate time periods during 1997-1998. Study of the plankton community was conducted by mean of net samplings. Quantitative measurement of extractable chlorophyll_a was performed based on the spectrophotometric method of Parson *et al.* (1984). Carbon production by phytoplankton was estimated from the chlorophyll biomass using the equation proposed by Shemshura *et al.* (1991) and fishery production was calculated based on the modification equation of Nixon (1988). Secondary data on the biotic components of both pelagic and benthic environments were also included to derive the conceptual model of trophic relationship among the organisms in the bay ecosystem.

Biomass of chlorophyll_a was measured directly in April and October 1997 and April 1998. Areal primary production was calculated from the conversion ratio of 9 between carbon and wet weight. In 1997, production was higher in rainy season (October 1997) than in the dry season (Table 3.1). Primary production in Bandon Bay reported from this study, 0.30 - 0.66 g C m^{-2} d^{-1}, was lower than those of 2.05 to 6.49 g C m^{-2} d^{-1} in Chong Arg tong and upper west of the Gulf of Thailand during 1968-1984 (Lursinsarp 1980; Lursinsarp 1983; Lursinsarp 1987; Lursinsarp and Thochalee 1985). This discrepancy is due to the offshore nature and the greater depths (more than 20 metres) of those areas in comparison to Bandon Bay.

Production of primary producer is then transferred to organisms in higher trophic levels via the grazing food chain. Thus, fishery production in this area is supported by carbon production of phytoplankton. Fishery production (Table 3.2) is estimated from primary production based on the relationship proposed by Nixon (1988) and modified by S.V. Smith and W. Boynton (Smith, personal communication), using a regression equation. Detrital materials derived from non-consumed primary production and decaying matter from flora and fauna in the bay are also calculated based on Pauly *et al.* (1993).

The estimated fish production from this study is comparable to the demersal fish catch of 319 ton yr^{-1} in 1993 (Department of Fisheries 1993) since annual fish catch is usually less than total standing stock and the production calculated here includes pelagic fishes as well.

Table 3.1 Primary production in the Tapi River estuary and in Bandon Bay during 1997-1998.

Area	**Period of study**	**Primary production ($gC\ m^{-2}\ yr^{-1}$)**	**Areal production (ton ww yr^{-1})**
Tapi estuary	April 1997	114	491,776
	October 1997	164	708,554
	April 1998	93	402,955
Bandon Bay	April 1997	81	351,238
	October 1997	178	770,747
	April 1998	174	751,683

Table 3.2 Fishery production and detrital biomass derived from phytoplankton production.

Area	Period of study	Fishery production (ton ww yr^{-1})	Detrital biomass (ton C yr^{-1})
Tapi estuary	April 1997	758	397
	October 1997	1360	462
	April 1998	551	366
Bandon Bay	April 1997	443	346
	October 1997	1556	479
	April 1998	1495	474

As well as the grazing food chain (Figure 3.1) starting with primary production from pelagic producers, the detrital food chain is also of ecological importance in this area. Phytodetritus and detrital materials from pelagic animals, and litter falls from mangrove forest along the shoreline all form an important food source for the benthic community in the Tapi River estuary and in Bandon Bay.

Plankton Communities in Bandon Bay

Biomass of chlorophyll_a was measured directly in April and October 1997 and April 1998. Total chlorophyll_a biomass was minimized, 2.27 mg m^{-3}, in fresh water area in October 1997 while the maximum chlorophyll content of 14.23 $mg.m^{-3}$ was found in the estuary in the same month. Most of the chlorophyll_a content found in Bandon Bay and the adjacent estuary and freshwater region was in fractions smaller than 20 microns. This result indicates the important role of pico- and nanoplankton as major producers in the pelagic food web. Among the microphytoplankton studied, diatoms dominated the population of net phytoplankton in the bay for the whole study period, while chlorophytes dominated in the freshwater region. In the estuary, the major component of primary producer varied. Chlorophytes, diatoms and dinoflagellates were found in higher densities than other phytoplankton in both the dry season and the wet season of 1997. In April 1998, the dominant phytoplankton group in the estuary was diatoms.

Copepods formed the dominant group of zooplankton in Bandon Bay with a density of more than 30,000.00 $ind.m^{-3}$. The second most abundant zooplankton in this area was the nauplius larvae of crustaceans. Mollusc larvae and decapod larvae were found in abundance in the bay area but not in freshwater or the estuary. The holoplanktonic hemichordates and arrow worms are the true inhabitants of the marine waters, since they are always found in greater abundance in the bay than in the estuary or the freshwater region.

Discussion

Primary production and fish production estimated for Bandon Bay are not very high in comparison with other coastal ecosystems in the region. This is due to the topographic nature of the bay - the average depth is only 2.9 m. Fishery statistics indicate over-fishing and decline in capture fishery in parallel with the decline in mangrove coverage. Pollution from excess waste and chemical compounds may also affect the fishery production in the area. However, the production of cultured oysters in the bay tends to increase with the increase in shrimp-farming area.

The changes in carbon and nutrient loading are the major processes in understanding the dynamics of the ecosystem and the socio-economy of Bandon Bay. The depletion of mangrove decreases nutrient input in the form of litter falls into the bay system, but on the other hand, nutrient loading from domestic, agricultural and aquacultural activities can promote fishery production of oysters and clams in the bay. The problem of whether the increase in carbon and nutrient concentrations is supporting or trampling the system production and socio-economy depends on the carrying capacity of the bay which has not yet been fully investigated.

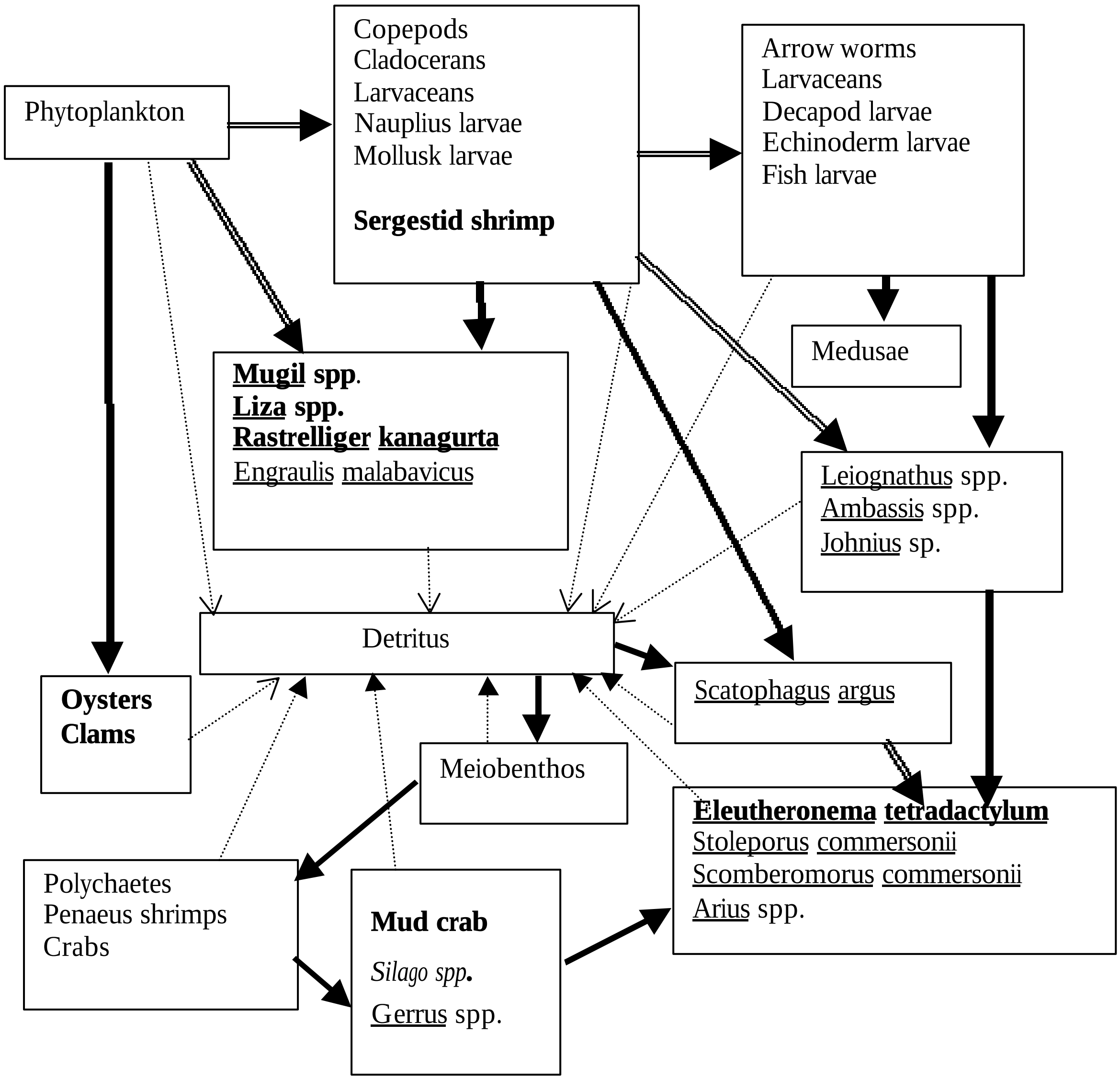
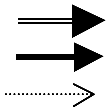


Figure 3.1 Trophic relationship in Bandon Bay ecosystem.
(Heavy letters denote commercial species)



4. ECONOMIC ACTIVITIES AND PROCESSES

4.1 Economic Profile

4.1.1 Shrimp Farming

The area of Suratthani province that borders on Bandon Bay has seen the most rapid changes over the last 30 years. The area was extensively converted from mangrove forests to shrimp farms, between 1973 when the mangrove area was 5,059 ha to 2,332 ha in 1993, and by 1998 the area of mangrove was 1,607. According to DOF source, the area under shrimp farm in 1993 was 8,666 ha, of which 42% was under intensive shrimp culture, while the remaining 40% was under extensive and 17% semi-intensive methods. However, there was a gradual movement toward intensive methods and now more than half of the shrimp farms are intensive.

The economic and financial return to intensive shrimp farming is shown in Table 4.1

In terms of financial return, a net profit of 18,327 Baht per crop can be earned from 1 rai of shrimp farm (6.25 rai equals 1 hectare), based on a total cost of 101,967 Baht, or a gross receipt of 120,294 Baht, which gives a profit rate of 18% over cost. Thus, shrimp farming becomes an attractive investment financially and attracted a lot of investors to take up shrimp farming especially in mangrove areas where access to seawater is possible at low cost. In terms of value added, namely the value net of material inputs used in the activity, but includes labour cost, profit and taxes, intensive shrimp farming produces 44,372 Baht per rai per crop.

Assuming that two crops of shrimps can be grown in one year, the value added from shrimp farming is 88,744 Baht per rai per year , or about 567 USD (at 25 Baht per USD in 1993 prices). Focussing only on the farming of black tiger prawns, the value added from the activity for the year 1993 was 1,006.2 million Baht.

4.1.2 Mariculture

The Bandon Bay area is a productive area for oysters and clams. The estuarine area is put under a concession system in which farmers have to rent land from the provincial authorities to farm the shellfish. There is an organized cooperative of shellfish farmers, which represents a large part of the farmers in the Bandon Bay area.

The financial returns to farming of oysters and clams are shown in Tables 4.2 and 4.3.

On a per rai basis, the financial return to oyster farming is 163,710 Baht per rai, and value added is 166,110 Baht per rai. This is due to the high price of oysters, which are sold in pieces.

The financial return for clam is 11,910 Baht per rai, and value added is 13,310 Baht per rai. Taking the areas of oyster and clam farming to be 7,300 and 34,000 rais respectively, the total value added from oyster and clam farming is estimated at 1,212 and 452 million Baht, or 1,665.1 million Baht in total.

Table 4.1 Cost structure of shrimp-farming

Shrimp cost-1990 per rai per crop (Midas,1995)			
Item	Cash	Non-cash	Total
Young shrimp	9,587		9,587
Feed	49,914		49,914
Gasoline,oil and electricity	7,993		7,993
Pond clearing, reparing pond and machine	6,245		6,245
Family labour		3,602	3,602
Hired labour	3,294		3,294
Others	2,183		2,183
Total variable cost	79,216	3,602	82,818
Land tax and land rent	832		832
Interest expense	3,639		3,639
Opportunity cost of land		5,301	5,301
Depreciation		9,377	9,377
Total fixed cost	4,471	14,678	19,149
Total cost	83,687	18,280	101,967
Yield per rai (kg)			957.92
Farm price (Baht/kg)			125.58
Value of production (Baht/rai)			120,294.30
Net income per rai			18,327.32
Value added analysis			
Material inputs:			
Young shrimp	9,587		9,587
Feed	49,914		49,914
Gasoline,oil and electricity	7,993		7,993
Pond clearing, reparing pond and machine	6,245		6,245
Others	2,183		2,183
Total material costs	75,922	0	75,922
Value added (Baht/rai)			44,372.32
Share of value added in gross output			36.89%
Value added per kg of shrimp			46.32

Source: cost data from Midas(1995): Volume 3, Annex 9, table 1.4.10
Yield and price data from Statistics of Shrimp Culture 1993, Fishery Department, (1995)

4.1.3 Fishery

Capture fishery is practiced in Bandon Bay by fishermen using pushnets. A study of catch per unit effort was conducted in 1988. The result of the study shows that the CPUE was 316 kg/boat/day. The catch consists of shrimps and crabs, accounting for 38% by weight, while the remaining 62% is trash fish. (Lohsawatdikul and Eiamsaard, 1991).

Table 4.2 Total value of oyster culture in the Bandon Bay area

Type of Culture Activity	**Oysters**				
	Unit	Quantity	Unit price	Total	Per rai
Area of culture (rai)	Rai	20			
Cost					
Bamboo fence	Stems	200	9	1,800	90
PVC pipe, cement block	Pieces/rai	4,000	25	2,000,000	
Plot preparation	Baht/piece	4,000	8	640,000	32,000
Fuel for boat	Month	12	3,000	36,000	1,800
Guarding labour	Month	12	4,000	48,000	2,400
Total Cost				2,725,800	136,290
Yield	Pieces/pole	8		600,000	30,000
Price per piece	Baht/piece	10			
Gross income				6,000,000	300,000
Net Profit				3,274,200	163,710
Rate of return over cost				120.12%	120.12%
Total value added					166,110
Total area of culture(rai)		7,300			
Total value added (million Baht)				1,212.60	
Weight of oyster (pieces per kg)					7
Value per kg of oyster					70
Value added per kg of oyster					38.75
Total values from aquaculture				1,617.54	
% Value added of oyster					55.37%

4.1.4 Mangrove Utilization

A study of mangrove utilization was reported in 1998, based on fieldwork conducted in 1996-1997 (Sathirathai, 1997). The study finds that local people collect products from the mangrove area, ranging from fish, crab and shrimp, to honey as well as the wood for domestic uses. The mean value of the mangrove use by the local people is 36,984 Baht per household. For the village studied, which has a rather degraded mangrove forest, the mean value per rai of mangrove was 562 Baht/rai, compared to a typical value of mangrove forest with charcoal production of 4,237.16 Baht/rai. The degraded mangrove was a result of shrimp farming on the coastal strip, which blocked the tidal flow of the seawater to the mangrove area.

The mangrove bordering the Bandon Bay also plays an important role in supplying the bay with nutrients. This aspect of mangrove use and the impact of mangrove forest loss will be discussed in later section.

Table 4.3 Total value of clam culture in the Bandon Bay area.

		Clams			Per rai
Type of Culture Activity	**Unit**	**Quantity**	**Unit price**	**Total**	
Area of culture(rai)	rai	20			
Cost					
bamboo fence	stems	200	9	1,800	90
Seedlings (200/kg)	ton/rai	1	15,000	300,000	15,000
sowing labour	Baht/ton	1	400	8,000	400
Fuel for boat	month	8	3,000	24,000	1,200
Guarding labour	month	8	3,500	28,000	1,400
Total Cost				361,800	18,090
Yield per rai (kg)	kg	4,000		80,000	4,000
Price per Kg	Baht/kg	7.5			
Gross income				600,000	30,000
Net Income				238,200	11,910
Rate of return over cost				65.84%	65.84%
Total area of culture(rai)		34,000			
Total value added (million Baht)				404.94	

4.1.5 Industrial development and urbanization

Suratthani province which is located upstream to the Bandon Bay is a small urban centre which is growing rapidly. In 1997, the urban centre already has a population of 107,888. In addition, the districts surrounding the bay and upstream altogether account for a population of 711,435. The major industries in the area are agriculture with rubber and oil palm are the main crops. Rubber is processed into rubber sheets and blocks for exports, and some products are also made. The rubber wood is used to support a local wood processing plant, which produces wood chip and particleboard for export. Oil palm is grown in upland areas and is used to produce crude palm oil, which is then exported to Bangkok for further refining. There is also small-scale industries serving the local population.

4.1.6 Tourism and other services

The major service industry of Suratthani is the tourism industry, due to the location of Koh Samui, which has been developed into an internationally known beach resort, attracting nearly 700,000 visitors a year. Little of this traffic remain in the Suratthani town, however, as the tourists are furried across the sea to the island as soon as they arrive.

4.2 Integrated modelling of Bandon Bay

4.2.1 Approach to modelling economy and ecology interaction

The approach for modeling the linkage between economy and ecology of Bandon Bay is based on de Kok (1998). This approach views the link in the form of flows of materials between the two systems. The economy takes nutrients from the ecosystem for producing goods, and in exchange the economy discharges wastes into the ecosystem.

The main links in the Bandon Bay area are:

- Uptake of nutrients:
  Oyster and clam production takes up the nutrients from the bay
  Fishery also removes nutrients from the bay.
  Conversion of mangrove to shrimp farms removes nutrient supply from the bay.
- Input of nutrients:
  Mangrove forest provides nutrients to the bay.
  Economic activities, including shrimp farms, discharge waste into the bay.

The value of nutrients in the bay can be estimated from the value of goods produced. In this analysis, we use the value of oyster as a proxy for the value of a ton of carbon.

4.2.2 Construction of I/O model

Construction of the Input-Output table for 1997

We ran the input-output model and integrated the emission data, based on previous studies and WHO (1993), for the economic activities into the input-output tables.

The basic data for the input-output table is obtained from the NESDB IO table for 1990. This is a 180x180 sector table for the whole country. The table is modified to reflect the sectors present in Suratthani, by means of matching with secondary data pertaining to specific economic activities. The industries are then grouped into sectors for analysis. For each sector, the column percentage is calculated, giving the input structure for the sector.

The derived input structure is applied to the value-added for the sector, in order to obtain the flow values for the transaction table. By matching the row sum and the column sum, the value of the final demand vector is obtained.

The IO table can be used to estimate the value of gross output by sector.
For the present study, the estimate of gross output is prepared using the projected final demand and the Leontief inverse. The IO table and the projected gross output estimates are shown in Table 4.4

4.2.3 Estimation of emission coefficients

The approach to estimating the emission coefficient is a mixed strategy. In principle, emission can be measured directly at the same time as production, and the coefficients can then be directly calculated. However, for the IO table, there are certain limitations: the production data are aggregated over different sectors, and are in monetary units, not physical. Thus there is the problem of conversion and aggregation over many industries and products to derive the emission for each sector.

Available data are obtained from various studies, which are reported in different units. These have been converted to emission per monetary units.

Using these output and emission coefficients, it is possible to estimate the value of total emission for a one year period corresponding to the rate of production of goods. The result of the analysis is shown in Table 4.5.

4.2.4 Estimation of carbon utilization

In this section, we focus on identifying the value of carbon in the Bandon Bay area, as set out in the approach toward integrating the biogeochemical with the socioeconomic analyses applied to Bandon Bay area. The LOICZ project began with the question of how much is the contribution of anthropogenic discharges to the stock of nutrients in Bandon Bay. We look at this question by estimating the flow of BOD from economic activities using the input-output table method. The result shows that the flow of organic carbon contained in BOD is estimated to be 10,642 ton Carbon per year (Table 4.6.1)

Shrimp farm wastes are considered to be a source of pollution. According to the estimate of the total shrimp farm waste from around Bandon Bay, the amount is 3,189 ton C/year (Table 4.6.2)

Anthropogenic emissions can be compared to natural discharges. One natural source of discharges is mangrove forest. This produces a steady flow of nutrients in the form of leaf fall and detrital matters to the water. The total amount of TOC from mangrove around Bandon Bay is estimated to be 19,006 ton C/year (Table 4.6.3).

The nutrient inputs contribute to the primary production in the bay area. It has been estimated elsewhere in the study that primary production in the bay area is 144 ton C/km^2. Based on this value, the total primary production, in terms of the standing stock of plankton biomass, in the bay area is 69,120 ton C.

A question may be raised at this point about the relationship between land-based nutrient inputs and primary production. Our approach is as follows:

We first assume that the nutrients which are important to primary production are N and P. These are used to produce phytoplankton. However, since there is a relationship between C, N and P, the amount of carbon associated with the primary production can be estimated. This amount of carbon can then be compared with the carbon that is contained in the nutrient inputs. Based on this estimation, the proportion of annual anthropogenic carbon input to the primary production is about 15% of the total primary production in the bay area (Table 4.6.5).

Table 4.4 Input Output table, final demand and gross output estimate for Suratthani, 1997.

Description	GPP or VA(97)	Share of Final Demand (90)	Final Demand from GPP(97)	Inverse(I-A)										Gross Output (97)
Agricutlture	14,901,911	0.27	9,674,151	1.07	0.02	0.16	0.29	0.00	0.05	0.00	0.07	0.04	0.01	12,182,218
Fishery	1,317,175	0.04	1,454,073	0.01	1.02	0.09	0.00	0.00	0.00	0.00	0.03	0.00	0.00	2,246,337
Manuf. I	2,561,235	0.19	6,812,666	0.00	0.00	1.14	0.01	0.00	0.01	0.00	0.07	0.00	0.00	8,101,072
Manuf. II	281,813	0.02	839,054	0.02	0.06	0.02	1.04	0.00	0.14	0.01	0.04	0.13	0.01	2,231,265
Utilities	858,550	0.02	572,600	0.00	0.00	0.01	0.01	1.10	0.01	0.01	0.03	0.01	0.02	1,035,234
Construction	2,436,322	0.10	3,682,094	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.01	3,774,140
Trade	4,073,446	0.08	2,755,145	0.04	0.04	0.09	0.04	0.01	0.07	1.01	0.09	0.03	0.02	4,619,934
RestHotel	2,620,224	0.09	3,372,740	0.00	0.00	0.01	0.00	0.00	0.01	0.02	1.01	0.01	0.01	3,581,947
TransCom	2,615,589	0.05	1,851,215	0.01	0.01	0.03	0.03	0.02	0.06	0.02	0.02	1.05	0.01	2,671,751
Other services	3,996,782	0.13	4,649,309	0.02	0.02	0.03	0.02	0.02	0.03	0.09	0.03	0.03	1.03	5,745,697
Total	35,663,047	1.00	35,663,047											46,189,593

Table 4.5 Estimation of emission.

Sector	Output (VA - based)	Coefficient	Total discharge	
	mB	ton/mB	ton/year	%share (total human=100)
Agriculture	12,182	0.1075	1,309.7	20.92%
Fishery	2,246	0.0537	120.7	1.93%
Manufacturing I	8,101	0.2150	1,741.8	27.82%
Manufacturing II	2,231	0.1075	239.8	3.83%
Utilities	1,035	0.2150	222.5	3.56%
Construction	3,774	0.1075	405.7	6.48%
Trade	4,620	0.0708	327.5	5.23%
RestHotel	3,582	0.0708	253.9	4.06%
TransCom	2,672	0.1075	287.2	4.59%
Other services	5,746	0.0708	407.3	6.51%
Total from production			**5316.5**	**84.92%**
Domestic household	679672	0.0013	943.8	15.08%
Total from Human activity			**6,260.4**	**100.00%**

We turn now to the use of primary production in the bay area. As described earlier, a major economic activity in the Bandon Bay is shellfish culture, particularly of oysters and clams. The primary production on the bay's ecosystem supports this activity. The economic value of oyster culture provides a measure of the value of carbon in the bay's ecosystem. According to the biological study component, the conversion from primary production to fishery production in the bay area occurs at the rate of 0.84%, based on total primary production of 69,120 ton Carbon and fishery production of 582 ton Carbon. This estimate is used to obtain the estimate of the value of carbon required to support 1 kg of oyster, namely approximately 6 kg of TOC. Since we also have the estimate of the value added of 1 kg of oysters, the value of 1 kg of carbon in primary production can be calculated to be 6,530 Baht (Table 4.6.2).

Table 4.6 The Value Flows of Carbon in Bandon Bay.

4.6.1	**Emission from Anthopogenic Sources**			
	Value added from Suratthani Economy in 1997	mB	35,663	
	Total emission of BOD	Ton/yr	6,260	
	Total carbon emission from BOD (1.7 factor)	Ton C/yr	10,642	
	Rate of carbon emission per value added	Ton C/mB	0.2984	
4.6.2	**Carbon Uptake from Oyster farming**			
	No of oyster by weight	Pieces/kg	7	
	Price of oyster	Baht/piece	10	
	Price of oyster	Baht/kg	70	
	% value added of oyster		55.37%	
	Value added of oyster	Baht/kg	38.75	
	Carbon content of oyster	% dry weight	5.00%	
	Carbon content of oyster	g.C/kg	50	
	Ratio of primary production to organic carbon in oyster	%	0.84%	
	Carbon as primary production for oyster production	g.C/kg C oyster	5,935.08	
	Value of carbon in oyster production	Baht/kg C	6.53	
	Value of carbon in oyster production	Baht/t C PP	6,530.48	
4.6.3	**Mangrove Input of nutrients**			
	Managrove input of organic carbon per km^2 (Wattayakorn *et al.* 1990)	Ton.C/km^2/yr	1,118	
	Mangrove Input of nutrients from coastal area around	Ton.C/yr	19,006	

	Bandon Bay			
	Mangrove Input of nutrients per km^2 of Bay area	Ton.C/km^2/yr	39.59	
4.6.4	**Carbon Input from Shrimp Farm Waste**			
	Shrimp farm BOD discharge	mg/L	11.6	
	Area of Shrimp farm	Km^2	80.88	
	Volume of shrimp farm waste water	Million.cu. m	80.88	
	Total BOD from shrimp farm	Ton BOD/crop	938.21	
	Total BOD from shrimp farm per year (2 crops)	Ton BOD/yr	1,876.42	
	Total Carbon from shrimp farm into Bandon Bay (ton BOD x 1.7)	Ton .C/yr	3,189.91	
	Area of Bandon Bay	Km^2	480	
	Rate of shrimp farm discharge per area of Bay	Ton C/km^2/yr	6.64	
4.6.5	**Carbon Balance in Bandon Bay**		**Total**	**per km^2**
	Area of Bay (km^2)	480		
	Input			
	Waste from economic activities		10,642	22.17
	Shrimp farm waste		3,189.91	6.64
	Mangrove nutrient cycling		19,006	39.59
	Total from Land		32,837.91	68.41
	Primary production: standing stock of plankton biomass		69,120	144
	Uptake			0
	Fishery (Including oyster)		582.3	1.21
	Ratio of fishery to primary production		0.84%	
4.6.6	**Impact of Shrimp farm conversion of mangrove**			
	Shrimp farm area from mangrove conversion	Km^2	80.88	
	Loss of carbon from mangrove conversion	Ton .C/yr	90,423.84	
	Input of carbon from Shrimp farm waste	Ton. C/yr	3189.91	
	Net loss of carbon from conversion of mangrove to shrimp farms	Ton.C/yr	87,233.93	
	Loss of primary production due to mangrove conversion to shrimp farm**	Ton.C/yr	87,233.93	
	Unit value of carbon as primary production in Bay	Bath/ton.C	6,530.49	
	Value of Loss of nutrients	Million.Baht	569.68	
	Value of Loss of nutrients per area of shrimp farm	mB/km^2	7.04	
	Value of Loss of nutrients per rai of shrimp farm	Baht/rai	11,269.64	

** Assume 1:1 conversion of nutrients to primary production

4.2.5 Discussion

(1) Economic value of carbon in Bandon Bay: trade-off between mangrove and shrimp farming

Having calculated the monetary value of carbon in the bay, in terms of oyster value added, we are now in a position to consider the question of the trade-off between mangrove conversion due to shrimp farming. It is known that conversion of mangrove forest to other uses will reduce the flow of nutrients to the natural ecosystem and will lead to reduction in the rate of primary production. Our calculation (Table 4.6.6) shows that for the study area of Bandon Bay, the net loss of carbon input to the bay due to mangrove to shrimp farm conversion may be estimated at approximately 87,233 tons Carbon/year. This is based on the total area of shrimp farm of 80.88 .km^2, and applying the rate of nutrient input from mangrove forest to the whole of shrimp farm area under the assumption that this would have been converted from mangroves, and deducting the carbon input to the bay ecosystem from shrimp farm waste.

The economic question is what is the value of this loss. For the specific study site, it may be hypothesized that an additional input of carbon nutrient would be used for oyster production, which generates by far the highest value in monetary terms from among alternative uses, and is therefore an appropriate measure of opportunity cost of carbon in the Bandon Bay ecosystem. Using this line of reasoning, and assuming a 1:1 correspondence between carbon nutrient input and primary production, we can thus consider the amount of the loss of carbon from mangrove conversion in terms of the loss of primary production that would have supported the associated quantity of oysters. As shown above, the monetary value associated with 1 ton of primary production for oysters is 6,530 Baht/ton Carbon. Thus, the total loss of value added from mangrove conversion to shrimp farm in the Bandon Bay area is 569 million Baht. On a per area basis, this is 7 million Baht per km^2, or approximately 11,269 Baht per rai. This can be considered as the external cost of mangrove conversion to shrimp farm, specifically for the Bandon Bay area.

(2) Implications for resource management

What is the significance of this result? According to the Polluter Pays Principle, the person causing environmental damage should be responsible for the cost of damage. In this sense, it is suggested that the shrimp farmer who establishes his farm on mangrove should be responsible for the damage, defined as the loss of nutrients, which would otherwise have been used to support oyster production. This can be imposed in the form of a tax on shrimp farms located in mangrove areas at the rate of the estimated damage, namely around 12,000 Baht per rai. In relation to the net income from shrimp farming, the farmer would still be able to make a profit of around 7,000 Baht per rai. This would reduce the financial rate of return on investment in shrimp farming. The tax would reduce the incentive to destroy mangrove area for shrimp farming in the Bandon Bay area, where mangrove serves a valuable function of supplying nutrients to the ecosystem of the bay to support farming of shellfish, especially oysters.

A more general implication of the result is that the approach provides a way of assessing the monetary value of the loss of natural capital, such as the mangrove forest, in terms of the net value of the use of that capital as input into a productive process. The government could regulate access to mangrove areas for shrimp farming purpose by using the tax as a market based instrument to reach a more optimal use of land resources in the coastal area.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Nutrient budgets

The following conclusions can be drawn from the nutrient budget study:

- According to the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), most nutrients are trapped in the estuarine section of the Tapi River and Bandon Bay.
- Bandon Bay is slightly net heterotrophic in low flow conditions. However, on a two-year average basis, Bandon Bay is in balance metabolically, whereas the Tapi River estuary is strongly autotrophic.
- In general, Bandon Bay is slightly net nitrifying while the Tapi estuary is strongly net denitrifying.
- The inclusion of waste flux in the budget calculations indicate that sewage is the major source of organic carbon to the Tapi estuary-Bandon bay system. The two-box model clearly shows that most of the organic matter (DOC, DON and DOP) remains trapped in the estuarine section of the Tapi River.
- The discrepancies obtained from the various methods adopted is attributed to the large tidal variability which makes the assessment of magnitudes and directions of net material transport between estuaries and the coastal ocean rather difficult. This coupled with the inherent variability of results from estuaries, in common with most environmental data, mean that there is a limit to the sensitivity of each approach.
- In general, more agreeable results are obtained with the low flow condition than at the high flow condition.

5.1.2 Carbon production and fisheries

- Primary production and fish production estimated for Bandon Bay are not as high as initially expected in comparison with other coastal ecosystems in the region. This probably is due to the reduction of water volume in the bay resulting from heavy siltation during the past decade.

- Fishery statistics indicates over-fishing and declining in capture fishery in parallel to the declining in mangrove coverage. Pollution from excess waste and chemical compounds may also affect the fishery production in the area.

5.1.3 Human dimensions and the ecology of Bandon Bay

The main conclusions from the study fall under three headings

- impact of human activities upstream from the bay,
- human use values from the bay area, and
- management issues.

Impact of human activities upstream from the bay

Human activities impact on Bandon Bay in terms of emissions and uptake of nutrients. The study calculates that input of BOD is 6,240 ton/year, or 10,642 ton Carbon/year. Shrimp culture adds approximately 3,000 ton Carbon/year from shrimp farm waste discharge. However, the main impact is due to the removal of mangrove forest fringing the bay area, which results in the loss of approximately 87,000 ton Carbon/year.

Human use values from the bay area

Bandon Bay provides a rich breeding ground for marine aquatic life, and is being used for culture of oysters and clams which have a high market value, estimated at around 1,200 million Baht per year in terms of value added.

Management issues

The resources of Bandon Bay have competing uses. We have focused on the trade-off between land-based shrimp farming in mangrove areas and aquaculture in the bay area. The removal of mangrove for shrimp farms results in the loss of supply of nutrients to the bay and thus affects the growth of aquatic life in the bay's ecology. This loss is calculated in terms of the market value of oysters to be around 12,000 Baht per rai of shrimp farm. It is proposed that this external cost of shrimp farming be internalised by imposition of a tax of the same amount on shrimp farmers.

5.2 Recommendations

- The biogeochemical study should be continued with the refinement of the model to better estimate residual and exchange fluxes, as well as the net ecological production of the Bandon Bay system. In addition, it would be useful to select more sites which have variability in socio-economic, and other parameters and compare sites.
- Studies concerning trophic models and waste loading into the bay are necessary in order to elucidate the interaction between anthropogenic activities and coastal ecosystems as well as fishery potential in Bandon Bay. The carrying capacity of the bay also needs to be estimated. Introduction of the transport model may help in better understanding the link between the terrestrial and marine environments in this area.
- The input-output model was adopted as an economic representation of the Suratthani economy. In addition to the usual reservations about input-output tables, there are some limitations of the present A matrix. The sectors have been selected on *a priori* grounds, so they may not truly correspond to the actual set of economic activities in the study area. The sector totals were obtained from the national table, so they should be regarded as a blown-up version of the economy of the study area. This was not so serious since we were interested in the coefficients, which was calculated on a per unit basis. However, there was a problem of proportions of the various sectors, which may not correspond exactly with the national totals. This aspect needs to be furthered considered.

- Another limitation of the economic study is that it only considers one aspect of the use value of the Bandon Bay ecology, namely the relationship between shrimp farming and oyster farming, which is mediated through the ecological processes occurring in the bay. However, the processes have been considered only in terms of inputs and outputs of organic carbon that can be quantified as annual flows. The analysis undertaken provides only a snapshot of the processes that occur in Bandon Bay during one period. There is a need to model the situation in Bandon Bay as a dynamic process, whereby the relevant links, from land-based discharges of nutrients to primary production and conversion of marketable value of biomass is produced, can be fully specified and quantified.

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