CHAPTER 4

NUTRIENTS BUDGET MODELS OF KUNG KRABAEN BAY

A. Geography and Hydrography of Kung Krabaen Bay, Chanthaburi Province

Kung Krabaen Bay located between latitude 12° 34'-12 ° 36'N and longitude 101 ° 53'-101 ° 55'E is a small semi-enclosed estuarine system on the west coast of Chanthaburi Province, eastern coast of Thailand (Figure 4.1). The bay morphological profile of 2.5 km x 4.0 km with an average depth of 2.5 m (Hydrographic Department, 1985) gives an approximate bay area of 10.0 km^2 and the total bay volume of $2.5*10^7$ m^3. Its only connection to the Gulf of Thailand is via a channel of 700 m wide on the southeastern corner of the bay. The fringing mangrove forest of approximate 2.58 km^2 or 1610 rai covers the northeastern bank as well as parts of the northwestern and southwestern banks providing appropriate feeding and nursing grounds for marine animals and makes Kung Krabaen Bay suitable for shrimp culture. The watershed area is about 26.0 km^2 including 16.0 km^2 for agriculture, terrestrial forest and domestic uses and 1.7 km^2 of shrimp ponds, which are approximate 5% of watershed area. The tides are diurnal with the mean tidal range of 1.22 m, 0.86 m at neap tide and 1.67 m at spring tide. Tidal current is about 0.14 m s^{-1} (Dept. of Land Development, 1981).

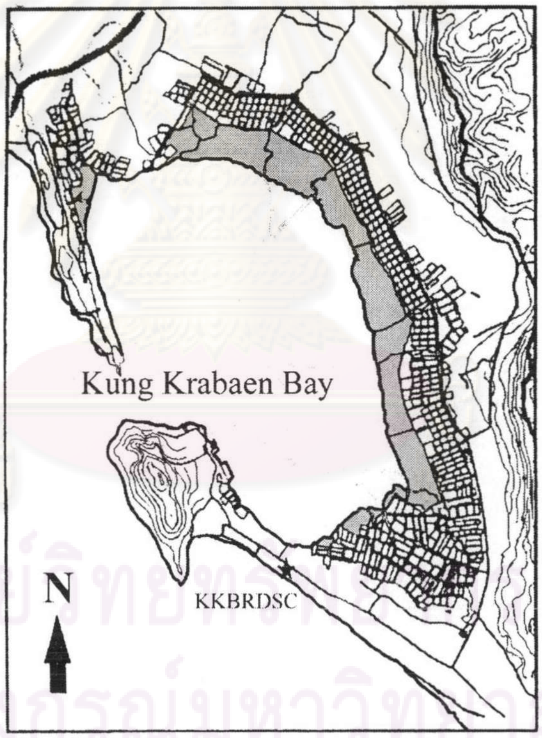


Figure 4.1 Map of Kung Krabaen Bay, Chanthaburi Province, surrounding mangrove forest (gray background) and shrimp farming (square sign).

As a discharged basin, Kung Krabaen Bay receives water runoff from upland passing through a number of natural canals while water inflow from the shrimp ponds is drained into the bay via drainage canals. The main drainage canal runs run along mangrove leeward fringe with several perpendicular canals passing through the mangrove forest into the bay. Seawater supply for shrimp ponds is pumped from the southwestern shoreline of the bay and transported through seawater irrigation canal system. The main irrigation canal runs along the back of shrimp farm area from the southwest to the northeast of the bay with supporting smaller canals to shrimp ponds (Kung Krabaen Bay Royal Development Study Center, 1998). Freshwater supply for consumption in the villages is from rainwater and small volume of ring wells (Boonsong, 1997).

1. Shrimp Culture in Kung Krabaen Bay

Intensive shrimp culture has been introduced to this area for the past 2 decades, when the traditional style of shrimp farming which keeps shrimp in natural ponds inside mangrove areas is dominated the area. Due to the expansion of shrimp farming activity started from 1987, the production of shrimp had reached the peak during 1990 –1991. The production of shrimp slightly decreased in the following years owing to adverse water qualities for shrimp culturing and to disease infection (Kung Krabaen Bay Royal Research Development Center, 1999). During and after the period of shrimp farming, the effluent water of high nutrient concentrations and organic particulate were drained from the ponds into drainage canals and flowed into the bay system. Thus, the major wastewater particularly N and P compounds had been discharged into the bay from shrimp farming activity upland. The seawater irrigation has been constructed in 1998 -1999 in order to improve water quality for shrimp culture and to diminish the disease-infected problems on shrimp.

At present, the intensive shrimp culture method became the normal practices that shrimp farmers can produce 2 crops a year in small area outside mangroves. The first culture period in December or January and with the harvest in April or May. The second crop begins in May or June and finished in September or October. Each crop lasted for 140 days (120-150 days). Total area for shrimp pond in 1995 was about 142.76 ha or 1.43 km^2 (Leeruksaiat, 1995). The shrimp pond area had expanded to 1082.55 rai or 1.73 km^2 in 2000 (KKBRDSC, 2000). With an average pond depth of 1.5 m, the total volume of pond system was calculated to be $2.14*10^6$ and $2.60*10^6$ m^3 for 1995 and 2000, respectively.

2. Meteorology of Kung Krabaen Bay, Chanthaburi Province

The climate in Kung Krabaen Bay is under the influences of the monsoon system where the southwest wind governs wet (or rainy) season starting from May to October and the northeast wind introduces the dry and cool season from November to early March. The period from March to April is characterized by warm climate and little rainfall and is included in the dry period. An average temperature is 26.8°C with the range of 25.2°C – 28.0°C. From 30 year meteorological data (1961-1990), average rainfall and average evaporation was 2,874 mm and 1521.7 mm, respectively (Climatology Division, Meteorological Department). Meteorological data on the annual of evaporation, precipitation and number of rain day was used to calculate daily average evaporation and precipitation. These parameters should be derived to represent the seasonal variation and the time of seawater irrigation installation which included the period before the installation of seawater irrigation system (1994-1999) and the period after the system was installed (1999-2000) as showed in Table 4.1.

Table 4.1 Average monthly evaporation and precipitation in Kung Krabaen Bay and its watershed area from 1994 to 2000 (dry season: November to April; wet season: May to October; unit: precipitation and evaporation in mm d^{-1}).

Time period		Average evaporation	Average precipitation
Before seawater irrigation installation (1994-1998)	Dry season	230	90
	Wet season	180	720
After seawater irrigation installation (1999-2000)	Dry season	80	60
	Wet season	70	300

* Meteorology Department (1994-2000)

3. Physico-chemical Characteirstics of Kung Krabaen Bay

Physico-chemical parameters: salinity, temperature, dissolved oxygen, total nitrogen, nitrite, nitrate, ammonia, total phosphorus, phosphate in the drainage canals, the bay water body and the open sea (outside the bay) from routine monitorings during 1994 – 2000 were obtained from the Kung Krabaen Bay Royal Development Study Center. The average values of dissolved inorganic and organic nutrients during different water irrigation schemes and seasons were calculated. The result indicated that major forms of dissolved nutrients are in organic phases. In dry season of both time periods, saline water came from shrimp ponds via drainage canals this water was characterized with high inorganic and organic phosphorus and nitrogen in comparison to those in the bay and in seawater. Salt contents were lower in the drained water than in the bay and in the sea in wet season indicated the influence of freshwater runoff and/or rain-diluted saltwater from shrimp ponds. High contents of nutrients in the water in drainage canals may due to the re-suspension of surface accumulated nutrients from topsoil in the canals (Table 4.2).

Table 4.2 Averaged quantitative values of physico-chemical parameters at the period before irrigation (in 1994-1998) and after (in 1998-2000) irrigation installation in Kung Krabaen Bay and neighboring systems in wet and dry season (modified from Kung Krabaen Bay Research Study Development Center, 1994-2000). Unit: salinity in psu; nutrients in mmol m^{-3}.

Time period		Site Measurement	Salinity	Nutrients			
				DIP	DOP	DIN	DON
Before seawater Irrigation installation (1994-1998)	Dry season	Drainage canal	34.20	0.3352	0.9864	6.6786	121.4816
		Bay system	32.94	0.1374	0.5314	5.1458	94.0600
		Open sea	33.52	0.2087	0.6626	2.6688	101.8658
	Wet season	Drainage canal	19.80	0.4223	1.1413	13.6320	89.8570
		Bay system	26.24	0.1513	0.5646	4.9772	86.9172
		Open sea	29.08	0.1351	0.5396	2.4986	79.8458
After seawater Irrigation installation (1994-1998)	Dry season	Drainage canal	32.90	0.0484	0.5667	4.8465	96.4570
		Bay system	32.75	0.0839	0.3935	1.1000	85.7750
		Open sea	32.90	0.0548	0.3450	1.7820	88.6000
	Wet season	Drainage canal	19.85	0.3081	0.5179	13.7430	98.9750
		Bay system	26.45	0.0532	0.4740	3.6320	79.3930
		Open sea	29.50	0.0500	0.3145	1.6785	83.8965

B. Water and Salt Budgets

The water budget of Kung Krabaen Bay was determined mainly by the average precipitation (V_P), the average evaporation (V_E) rather than the average water from drainage canals (V_Q). Freshwater input to the bay system was mainly from precipitation over the watershed area and the bay. During the period before the operation of water irrigation system, residual flows of $83*10^4$ m^3 d^{-1} and $226*10^4$ m^3 d^{-1} moved outside the bay toward the sea to balance the inflow and outflow of water in the bay in dry season and wet season, respectively (Figure 4.2). At the period after irrigation installation (1999-2000) where the average precipitation was less than those of the previous period, the residual flow also moved out of the bay toward the sea at the rate of $37*10^4$ and $94*10^4$ m^3 d^{-1} in dry season and wet season, respectively. The residual salt fluxes indicated an advective export from the bay in order of 10^7 kg d^{-1} during all time periods. Certain amounts of salt were imported in to the bay to replace the export one. The exchange time of water in the bay is estimated to be less than 1 day in dry season and about 1 days in wet season. Water exchange time is shorter than 1 days for dry season and about 3 days for wet season after seawater irrigation system (Table 4.3). The longer water exchange time after the operation of seawater irrigation system in wet season may due to the low precipitation and the expansion of number of shrimp pond in 1999 and 2000. It is obvious that salt fluxes in Kung Krabaen Bay system in both seasons was under influence of tidal intrusion of high salinity water from outside sea in both before and after the seawater irrigation installation as well as salt input from shrimp culture in dry season.

Table 4.3 Water and salt circulation parameters estimated from the water and salt budgets for Kung Krabaen Bay during the period before and after seawater irrigation system. (V_Q = water flow from shrimp ponds, V_R = residual flow, VP and V_E = volume of precipitation and evaporation, V_X = water exchange rate; in 10^4 m^3 d^{-1}, $V_X(S_{sea} - S_{syst})$ = exchanged salt flux in 10^7 kg d^{-1} and τ = water exchange time in day).

Water and salt parameters	Before seawater Irrigation system		After seawater Irrigation system	
	Dry season	Wet season	Dry season	Wet season
V_Q	1	2	1	3
V_P	22	177	15	73
V_E	60	47	21	18
V_R	- 83*	- 226*	- 37*	- 94*
V_X	4761	2202	12087	876
$V_X(S_{sea}-S_{syst})$	2.76	6.25	1.21	2.63
τ	0.5	1.0	0.2	2.6

The minus sign indicates flows out off Kung Krabaen Bay.

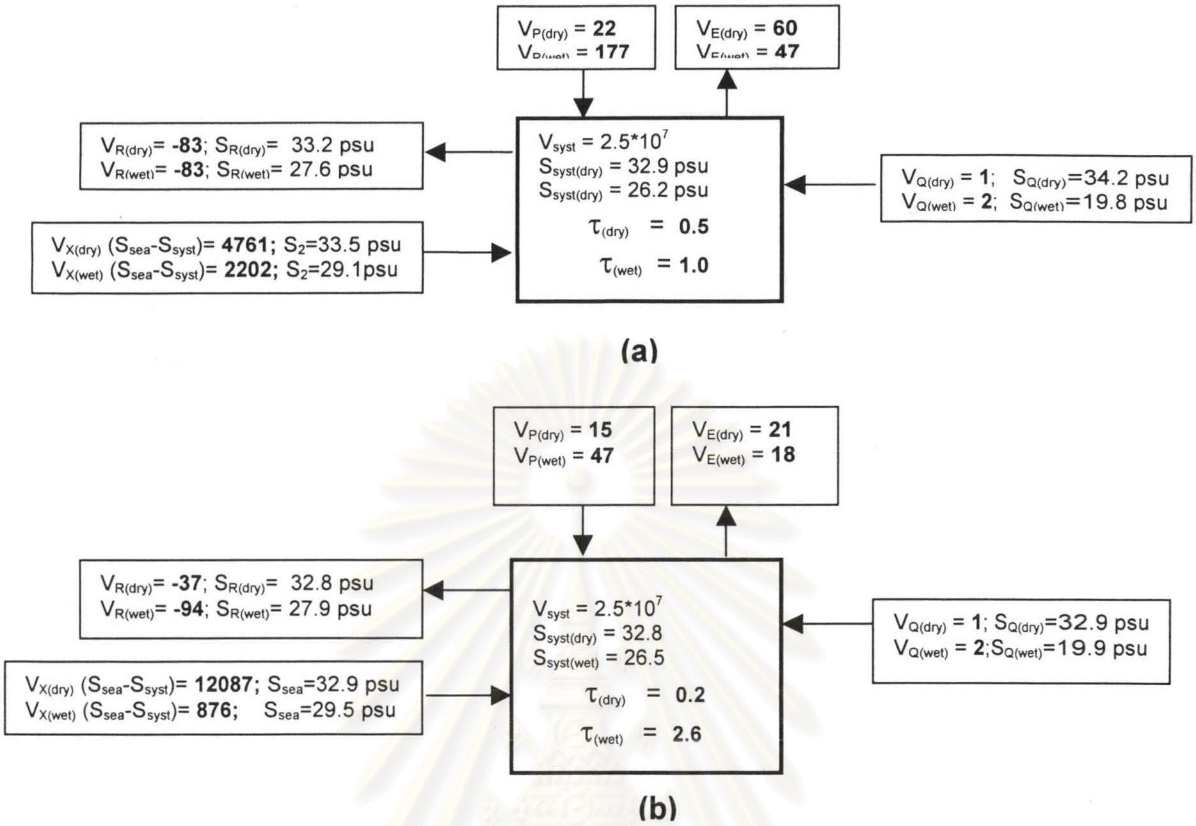


Figure 4.2 Water budget in Kung Krabaen Bay in the period before (a) and after (b) seawater irrigation system installation. (Flux in 10^4 m^{-3} d^{-1})

C. Nutrient balance and biogeochemical processes in Kung Krabaen Bay

Before the seawater irrigation system was installed, Kung Krabaen Bay acted as sink of both organic and inorganic phosphorus except in the wet season where small residue of DIP and DOP was released to the sea (Table 4.4 and Figure 4.3). In dry season, these DIP and DOP were delivered into the bay from shrimp ponds as well as from the input by seawater (Table 4.4) and were removed in the bay. This removal of dissolved phosphorus was due to biological activities since the net ecosystem metabolism (p-r) was + 95.61 mmol m^{-2} d^{-1} in dry season (Table 4.5) indicating autotrophic state of the bay. Fringing mangrove forest as well as sea-grass in the bay may play an important role in absorption dissolved phosphorus during dry season. In wet season, the system was slightly heterotrophic since the (p-r) was – 25.89 mmol m^{-2} d^{-1} with the release of small amount of dissolved phosphorus to the sea. After the irrigation system installed, the bay acted as the source of DIP and DOP in both dry season and wet season. The very short exchange time of <1 day in dry season between the bay and the Gulf of Thailand may not long enough for any uptake of these nutrients for autotrophic process. This is confirmed by the corresponding heterotrophic nature of the bay as indicated by the (p-r) of –100 (Table 4.5). During wet season, the water exchange time was prolong to about 3 days due to freshwater discharge as indicate by low salinity and high dissolved phosphorus concentrations of water in the drainage canals. Eventhough the bay acted as a source of both dissolved phosphorus forms, heterotrophic activities was more intense than autotrophic activities in the bay.

Table 4.4 Fluxes of non-conservative materials (phosphorus and nitrogen) in dry and wet season of Kung Krabaen Bay at the period before (1994-2000) and after (1999-2000) irrigation installation. (unit in kg mol d^{-1})

	Before seawater irrigation system		After seawater irrigation system	
	Dry season	Wet season	Dry season	Wet season
ΔDIP	- 3.26	+ 0.7	+ 3.53	+ 6.80
ΔDOP	- 5.76	+ 1.77	+ 5.99	+ 1.49
ΔDIN	+ 121.10	+ 62.70	- 81.98	+ 19.21
ΔDON	- 291.66	+ 507.37	- 310.77	+ 34.38

The plus sign indicates source of materials in Kung Krabaen Bay and export to the sea. The minus sign indicates net sink of materials in Kung Krabaen Bay.

Table 4.5 Net ecosystem metabolism (p–r) and stoichometric analysis (nfix-denit)for Kung Krabaen Bay (unit in m mol m^{-2} d^{-1}).

	Before seawater irrigation system		After seawater irrigation system	
	Dry season	Wet season	Dry season	Wet season
(p – r)*	+ 95.61	- 25.89	- 100.96	-19.29
Nfix – denit **	- 11.85	+ 55.93	- 44.93	+5.25

* (p-r) means production – respiration.

** Nfix – denit means nitrogen fixation – denitrification.

DIN was released from the bay at the rate of + 121.10 mmol m^3d^{-1} and + 62.70 mmol m^3d^{-1} in dry season and wet season, respectively before the irrigation system operated. On contrary, the bay removed DON at rate of - 291.66 mmol m^3d^{-1} in dry season but released + 507.37 mmol m^3d^{-1} in wet season. This net sink of DON corresponded well with the denitrifying process that dominated the bay in dry season while nitrogen fixation by some bacteria and bluegreen algae was pronounced in wet season where excess nitrogen is produced (positive DIN and DON). Similar trend exhibited in the year after the seawater irrigation system installation, where the bay behaved as net sinks of both DIN and DON in dry season and as the sources of DIN and DON to adjacent coastal water (Table 4.4 and 4.5, Fig.4.4). This again coincided with the presence of denitrification in dry season and nitrogen fixation in wet season.

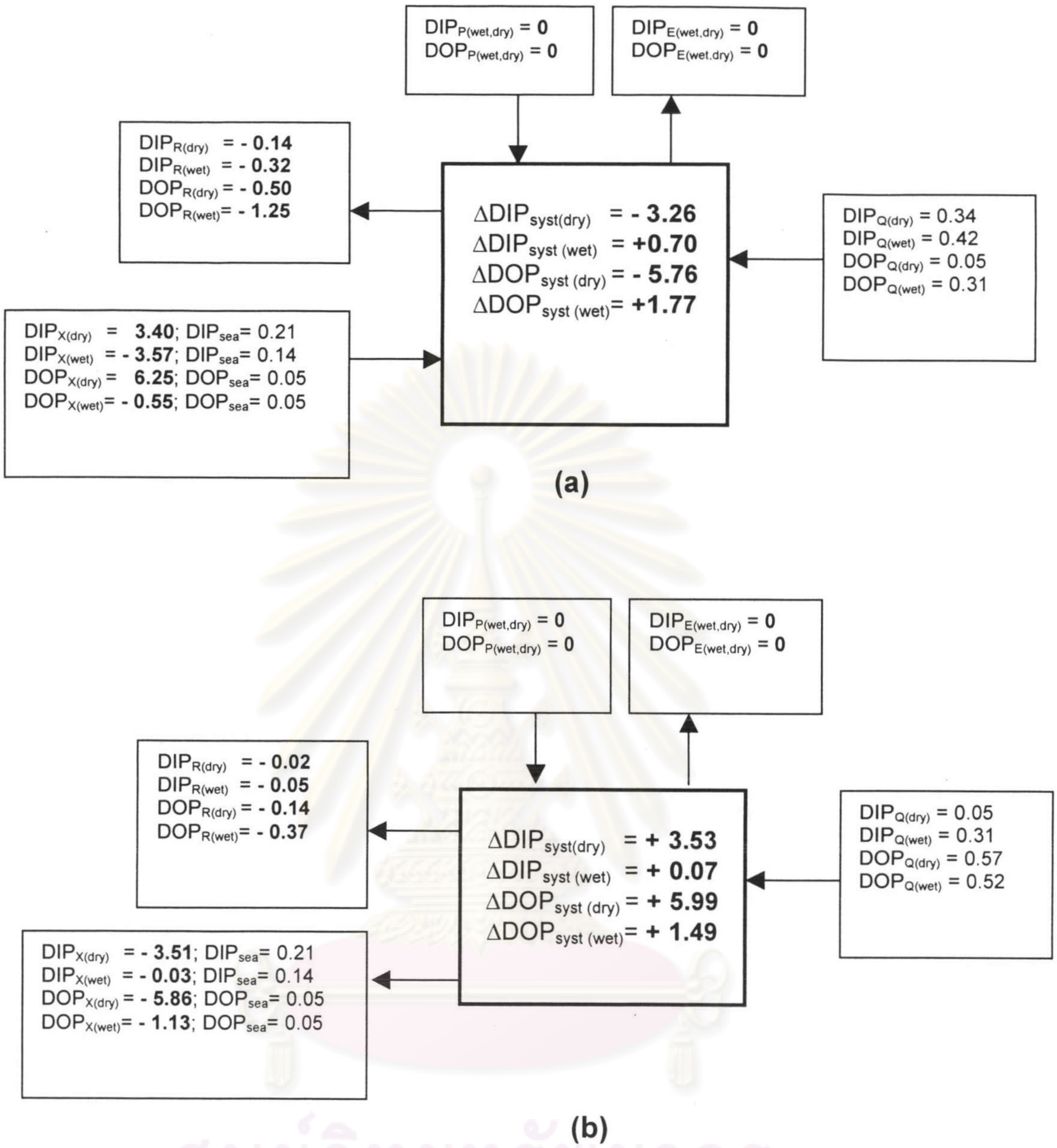
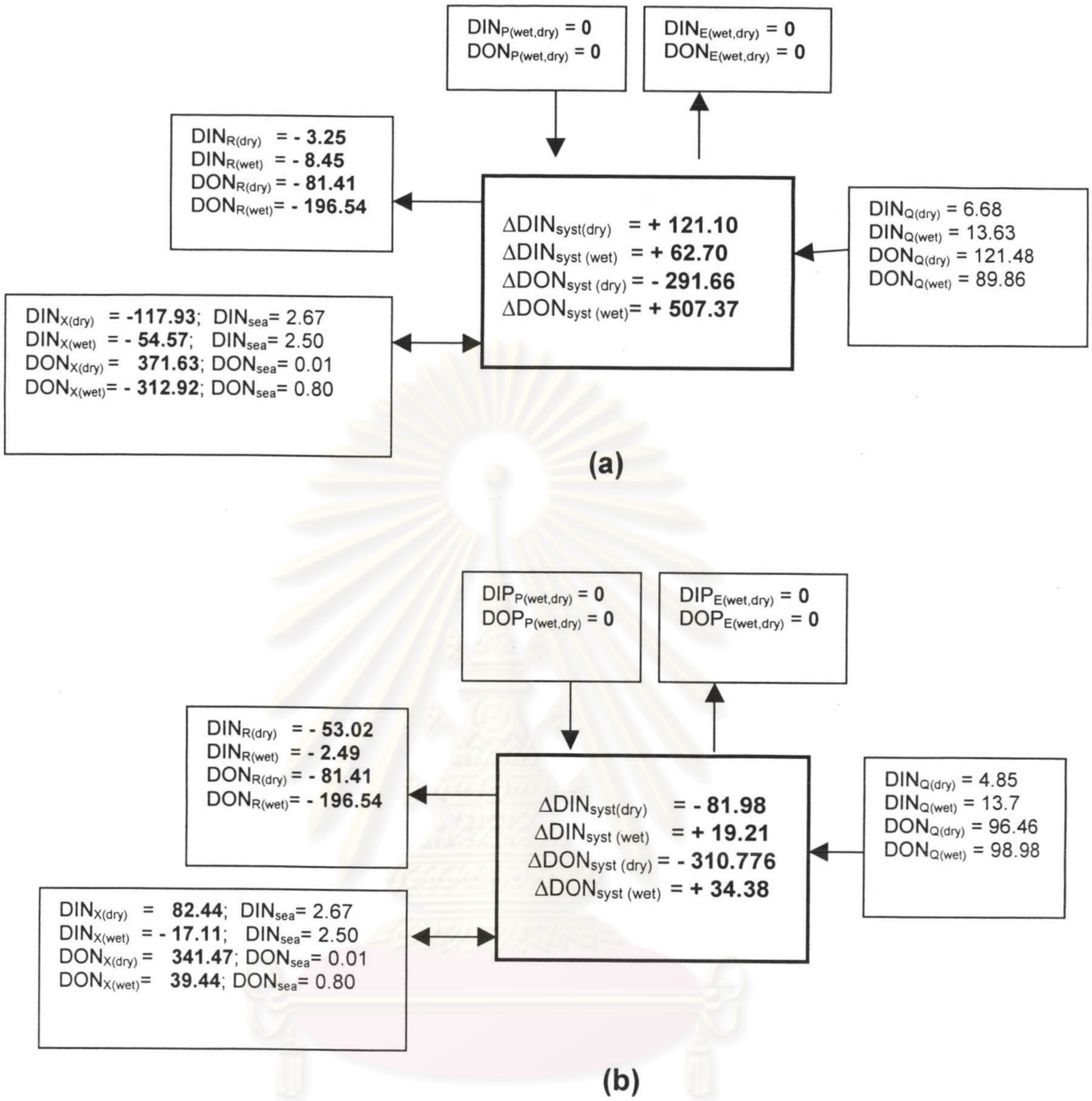


Figure 4.3 Dissolved phosphorus budgets in Kung Krabaen Bay in the period before (a) and after (b) seawater irrigation system. (nutrients:mmol.m^{-3}, flux: kmol.$m^{-3}d^{-1}$)



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D. Discussion and Conclusion

The result suggested that water released from shrimp ponds had little influence on the water budget of the bay. The residual flow in the bay before and after the period of irrigation system was distinctly driven out of the bay. This probably occurred during the low tide since the study on the hydraulic force of tides in this area shown that about 83-86% of the bay water was removed at ebb tide (Sasaki and Inoue, 1985; Boonsong, 1997). This exported flow was balanced by tidal flow from the sea into the bay. Water exchange time changed drastically after the irrigation system was operated. The exchange period in the dry season was shorter while it was prolonged in the wet season. The water exchange of seawater and the bay water in Kung Krabaen Bay consumes considerably shorter time than several river estuary systems in Thailand (Smith, *et al.*, 2000).

Kung Krabaen Bay is a semi-enclosed estuarine system with its shoreline settled by shrimp culture ponds behind the mangrove fringe. This bay ecosystem is flourish by phytoplankton, mangrove forest and sea-grass beds in tidal flat, *Enhalus accoroides* and *Halodule pinifolia* in particular (Sudara, *et al.*, 1991; Aryuthaka, 1992). These plants play a role as primary producers utilizing nutrients in the bay system. Dissolved phosphorus and DIN in particularly is necessary sources for those primary producers autotrophic process. Regarding to phosphorus net budget, DIP net value of +0.70 k mol $m^{-3}d^{-1}$ and DOP net value of +1.77 k mol $m^{-3}d^{-1}$ in wet season in the period before the seawater irrigation installation indicated that dissolved inorganic phosphorus is released from the bay sediment. After the set up of water irrigation system, there were slightly accumulation of DIP and DOP that may be the result of heterotrophic process as the (p-r) were negative in both seasons. This result suggests that dissolved phosphorus is involved in both autorophic and recycling process during dry season while in the wet season, it is used in bacterial decomposition in wet season. The excessive DOP content in the system before the irrigation system might due to DOP input from shrimp culture activity. Some phosphorus is adsorbed to the calcium ion in shrimp ponds and settled in the pond (Boyd, 1979; Tunvilai, *et al.*, 1993) thus high culturing activities in dry season is considered as a source or input of DIP and DOP to the environment. The release of dissolved phosphorus enhances eutrophic condition in the bay during the dry season at the period either before or after the installation of irrigation.

Before the construction of seawater irrigation, the nitrogen flux is shown to be as net source DON to the system in both seasons but DIN in wet season. These release of both species of nitrogen may due to the active shrimp culture in dry season and the re-suspension of nitrogen from surface sediment from the canals during wet season. This is supported by the study of Vorathep and Lin (1996) who figured that during shrimp culturing period 27% of re-suspend nitrogen previously accumulated in sediment will be in dissolve phase and another 45% will be in suspension about and 45% will be suspended in the water column. For the period after the seawater irrigation installation, the DIN and DON were removed by the utilization of primary producers in dry season to synthesize organic matter to be fuel heterotrophic activity in the following wet season. The system is subject to the high organic nitrogen (DON) during the period before the seawater irrigation has installed. This condition coincides with the overcome of nitrogen fixation to denitrification in wet season. The period after the installation of irrigation the system is characterized with small DIN and DON accumulation in wet season which may due to the release of nitrogen from surface sediment of shrimp ponds as reported by Songsangjinda, *et al.* (2000). The utilization of dissolved nitrogen in the bay is more effective in wet season than in dry season.

In conclusion, the situation of high organic nitrogen in this bay system before the installation of seawater irrigation was affected by shrimp culture activities. The number of shrimp ponds under the Kung Krabaen Bay Royal Development Study Project operation was 404, 309, 351 and 504 in dry season and 471, 323, 559 and 1006 ponds in wet season in year 1997, 1998, 1999 and 2000, respectively. The number of shrimp ponds is slightly decreased during the construction of the seawater irrigation and gradually increasing in later year after the seawater irrigation was already installed. Songsangjinda & Tunvilai (1993) studied the budget of N and P in shrimp ponds in southern of Thailand. They found that the N and P concentration was higher in shrimp ponds than the water sources at beginning. This caused by the input of artificial feed which contains high contents of protein, lipid and phosphorus. Besides, wastes from shrimp pond and decomposed organic matter could accumulate to water and sediment (Clavier *et al.*, 1995; Boyd, 1979). This can be recognized that the net input of N and P from drainage canals into the bay at period after the installation of irrigation is obviously less than the concentrations in the period before the irrigation installation.

According to the results of this study, the period before the seawater irrigation installation, Kung Krabaen bay is autotrophic especially in dry season where DIP, DOP and DON were assimilated to produce organic materials. After the irrigation system installation, Kung Krabaen bay system is net heterotrophic in both seasons. This indicates that the bay can utilize organic materials and export the breakdown products in form of dissolved materials to the adjacent sea with some portion may retain in the sediment. With this point, Kung Krabaen bay is less eutrophic because most of the dissolved nutrients produced in the bay will be exported to the sea since the residual flows are moving toward the sea. It is considered that the level of eutrophication situation in the Kung Krabaen Bay system is obviously depend on the level of shrimp culture activities which reflected as the relative flux discharged to the system. This bay system gets advantage that the water circulation distinctly enforces by tidal action that can help reduction of eutrophication of the system. In addition, the geographic location of the bay which flourish of mangrove forests, sea-grass beds and open bay can help naturally improving water quality crisis that is not dominate by the seawater irrigation itself.