The Environmental Impact of Marine Shrimp Farming Effluents and Carrying Capacity Estimation At Kung Krabaen Bay, Eastern Thailand

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Abstract

Water quality parameters in marine shrimp farms around Kung Krabaen Bay were surveyed from 1989-1994. The average transparency was 0.425 m± 0.024 in shrimp ponds, 0.680 m±0.012 in the water supply canal, 1.008 m± 0.110 in Kung Krabaen Bay and 1.635 m± 0.530 in the surrounding coastal areas. Total ammonia-nitrogen was 0.120 mg/l± 0.0012 in shrimp ponds, 0.032 mg/l±0.002 in the water supply canal, 0.017 mg/l±0.001 in the bay, 0.012 mg/l±0.001 in coastal waters and 0.401 mg/l±0.002 in discharge canals. Total bacterial plate count was 19,003 CFU/ml±15.4 in the bay and 23,801 CFU/ml±17.33 in the discharge canal. Total area of the farms engaged in intensive marine shrimp farming at Kung Krabaen Bay was around 142.76 ha. The total effluent discharge loading into the bay was around 67,400 ton/ha/crop. The BOD and ammonia loading were 699.60 kg/ha/crop and 12.81 kg/ha/crop, respectively. Carrying capacity of Kung Krabaen Bay, which has a total water surface area of 640 ha, was estimated using a mass balance model. Ammonia-nitrogen in receiving water or in the bay was set as the optimum safe concentration for sea water standard at 0.1 mg/l. The carrying capacity for intensive marine shrimp farming loading at Kung Krabaen Bay can be allowed upto 543.93 ha. The water balance model for carrying capacity and water quality prediction in the bay were discussed in detail.

Introduction

Kung Krabaen Bay is located at latitude 12°36'-12°33'N and longitude 101°53'E in the province of Chanthaburi, eastern Thailand. The bay is surrounded by a 500-800 m wide band of mangrove forest (Raine 1992) (Fig. 1). Intensive marine shrimp farming of *Peneaus monodon* goes on around the bay behind the mangrove area. The cultured area is approximately 142.76 ha, consisting of 348 ponds (Leeruksakiat 1995).

Stapornvanit (1993) studied the environmental impact of the effluents (discharged water and accumulated sediment) from intensive shrimp farming on Kung Krabaen Bay in 1993. Farm practices were the main factor that affected the quality and quantity of effluents. Effluent quality was extremely poor with high concentrations of ammonia and un-ionized ammonia during harvesting of shrimp because of the disturbance to the sediment; impacts on water quality
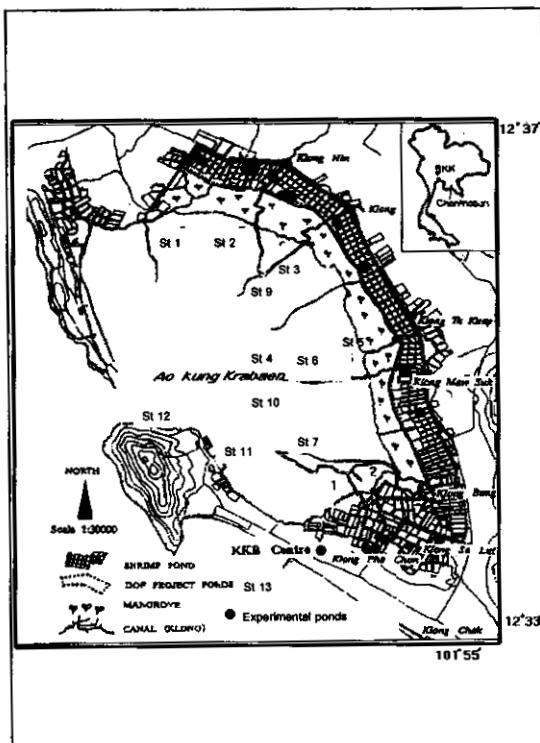
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Fig. 1. System of shrimp ponds and canals around Kung Krabaen Bay, and experimental ponds in eastern Thailand.

in the bay were most serious during harvesting. During normal farming operations, the combination of high flushing and low nutrient loadings appeared unlikely to cause significant eutrophication of Kung Krabaen Bay.

Tookwinas (1995) reported on the quality and quantity of discharged water from marine shrimp farms at Kung Krabaen Bay during the first crop of 1992. The total effluent discharge loading into Kung Krabaen Bay was around 67,400 tons/ha/crop or 134,800 tons/ha/yr. BOD_5[20] loading was around 6,735.63 tons/yr while total ammonia-nitrogen loading was 4.205 kg/yr.

The intensive marine shrimp farms are located around the bay in the unproductive mangrove areas. The majority (64) of the ponds, with an area of 97.88 ha, fall under the "Royal Development Project" while the remaining 84 ponds, consisting of 44.88 ha, are privately-owned. Total area of the shrimp farms, including supply and drainage canals, were about 180 ha. The "Royal Development Project" ponds were of similar construction and averaged an area of about 2,500 m². The ponds sloped toward the outlet gate, which in turn is connected to public canals. Most of these cultured ponds began shrimp farming operations in 1981 (Prasertcharoensul 1992; Stockwell 1991).

Seawater is supplied to the shrimp ponds around Kung Krabaen Bay via supply canals, which are separate from the drainage canals that drain the shrimp pond effluents directly to Kung Krabaen Bay. The water surface area of the bay, which is about 5 km long and 3 km wide, is 15,000,000 m² (Dean 1992). Water depth is usually 70-300 cm. in the bay and 60-150 cm in the channels, with the average depth at around 1.85 m (Marumo 1985). Tidal amplitude is about 2 m which means that at low tide up to 80% of the bay consists of exposed flats (Dean 1992). Volume of inflow from the mouth of the

bay is $135.01 \times 10^5 m^3/12hr$. and water volume at low level water is 22.59×10^5 m^3 (Sasaki and Inoue 1985). Sasaki and Inoue (1985) reported that the tidal of Kung Krabaen Bay is diurnal tide, and described that 86% of the bay waters at low levels is replaced by open sea waters in one tidal cycle. Thus, tidal flushing of the bay is extensive, with an almost complete change of water during each tidal cycle which occurs once every 24 hours (Dean 1992). The sea water can sufficiently fill the canal system in intensive marine shrimp farms for only about one week during the spring tides. For the rest of the time, during the neap tide period, there is little water in the canals to serve the ponds.

In this study, the water quality of Kung Krabaen Bay (KKB complex, the shrimp farm effluent, Kung Krabaen Bay's and coastal water) were investigated. The carrying capacity for an intensive marine shrimp farm was estimated using mass balance model. This model would be disccussed and compared to water quality prediction.

Materials and Methods

Data collection

Water samples from Kung Krabaen Bay, from the marine shrimp farm areas, water supply canals, shrimp ponds and drainage canals, and from coastal waters were collected monthly for water quality analysis from 1989 to 1994.

Water depth, water current and water samples for total ammonia-nitrogen analysis were measured and collected at the mouth of Kung Krabaen Bay every hour for 24 hours in June of 1994 to estimate the bay's carrying capacity.

Surveyed Station

Seventeen surveyed stations were set for water sample collection monthly from 1989 to 1994 (Figure 1). These are:

Station 0   Shrimp ponds (St oo) (19 ponds)
Station 1   Water supply canals to shrimp ponds (St01-St08)
Station 2   Kung Krabaen Bay (St09-St11)
Station 3   Mouth of Kung Krabaen Bay (St12)
Station 4   Coastal waters along Kung Krabaen Bay
Station 5   Drainage canals from shrimp ponds (St14-16)

Water Analysis

Water samples were analyzed using the following methods:
Transparency was measured by a Secchi disc (Tookwinas 1985). Salinity was checked by a refractosalinometer (Atago), pH by a laboratory pH meter (Jenco; Model 671). Dissolved oxygen, biochemical oxygen demand (BOD_5^{20}), alkalinity, suspended solid and orthophosphate were analyzed according to APHA (1989). Silicate was analyzed by Strickland and Parsons (1972). Total

ammonia-nitrogen was analyzed according to the phenol-hypochlorite method (Grasshoff 1974). However, the calibration curve was done using the unit of mg/l (ppm). Nitrite-nitrogen was analyzed according to Grasshoff (1974). Total alkalinity was analyzed according to APHA (1989). Total organic carbon (TOC) was analyzed by Astro 2001 system 2 Total Organic Carbon Analyzer (KKB, 1992). Current was measured according to Current meter Model CM-2SA, Toho Dentan Co.Ltd. Total bacterial plate counts (TPC) and Vibrio counts (VC) were analyzed using the method of Ushiyama (1978).

Data Analysis

(1) Multiple regression among parameters and year were calculated using SAS version 6.0 (SAS 1990) at 95% significance level.

(2) Carrying capacity estimation by the concept of mass balance model (Tchobanoglous 1990 and Predalumpaburt 1996) was as follows;

Carrying Capacity (C) = $\dfrac{\text{Net ammonia loading (NAL)}}{\text{Ammonia loading (AL)}}$

$\dfrac{\text{MAO-AO}}{\text{AL}}$ = $\dfrac{\text{Max. ammonia outflow (MAO) - Ammonia outflow (AO)}}{\text{AL}}$

$\dfrac{\text{R.MAI-AO}}{\text{AL}}$ = $\dfrac{\text{Removal rate (R) x Max. ammonia inflow(MAI)-AO}}{\text{AL}}$

R = $\dfrac{\text{Ammonia outflow(AO)}}{\text{Ammonia inflow (AI)}}$

C = $\dfrac{\text{R.MAI-AO}}{\text{AL}}$

where ammonia outflow (AO) = $\displaystyle\sum_{i=1}^{n} \dfrac{Aj(M^2)Vj(m/s)3600(s/h)Cj(mg/l)}{1000\ g\cdot kg^{-1}}$

j	=	low tide level at, 1st to n^{th} hour
Aj	=	cross section area of KKB's mouth at j hour(m^2)
Vj	=	current at j hour (m/s)
Cj	=	ammonia-nitrogen concentration at j hour (mg/l)

ammonia inflow (AI) = $\displaystyle\sum_{i=1}^{n} \dfrac{Ai(m^2)Vi(m/s)3600(s/n)Ci(mg/l)}{1000\ g/kg}$

i	=	high tide level at 1st to n^{th} hour.
Ai	=	cross section area of KKB's mouth at i hour (m^2)
Vi	=	current at i hour (m/s)
Ci	=	ammonia-nitrogen concentration at i hour (mg/L)

maximum ammonia inflow (MAI) = $\displaystyle\sum_{i_m=1}^{n} \dfrac{Ai_m(m^2)Vi_m(m/s)3000(s/h)Ci_m(mg/L)}{1000\ g/kg}$

i_m	=	high tide level at 1st to n^{th} hour
Ai_m	=	Ai
Vi_m	=	Vi
Ci_m	=	Total ammonia-nitrogen concentration at optimum safe level
	=	0.1 mg/L (Chien 1992; Liu 1989; Tookwinas 1985).

Results

Water quality

Water quality in shrimp ponds, supply canals, drainage canals, Kung Krabaen Bay and its mouth, and along the coast are shown in Table 1 and Figs. 2, 3, 4, 5, 6, 7, 8, 9 and 10. Transparency was 0.425 m±0.024 in shrimp ponds, 0.680 m±0.012 in the supply canals, 1.008 m±0.110 in the bay, 1.454 m±0.23 at the mouth of the bay and 1.635 m±0.530 along the coast. Dissolved oxygen above 6.0 mg/l was present in every survey station. pH was around seven to eight in every survey station. Total ammonia-nitrogen was in normal condition, except in the drainage canals, which was at a very high 0.401 mg/l±0.002.

Biochemical oxygen demand was 2.447 mg/l±0.890 in the supply canals, 2.029 mg/l±0.730 in the bay, 1.895 mg/l±0.550 at the mouth of the bay, 1.800 mg/l±0.430 along the coast and 1.797 mg/l±0.850 in drainage canals. Total bacterial plate count was 12,890 CFU/ml in the water supply canals, 19,003 CFU/ml±15.4 in the bay , 19,789 CFU/ml±17.2 at the mouth of the bay, 18,527 CFU/ml±18.1 along the coast and 13,801 CFU/ml±17.33 in the drainage canals.

Carrying Capacity Estimation

The depth of Kung Krabaen Bay's mouth, the quantity of ammonia nitrogen and the water current were measured every hour for 24 hours. The width of the bay's mouth was calculated following Sasaki and Inoue (1985). Accordingly, the area of Kung Krabaen Bay's mouth was calculated (Table 3). The concept of carrying capacity estimation is done by mass balance model using total ammonia-nitrogen at the optimum safe level of 0.1 $mg \cdot l^{-1}$ (Chien 1992; Liu 1989; Tookwinas 1985). Ammonia outflow during low tide and ammonia inflow during high tide are calculated in Tables 4 and 5.

Total ammonia outflow = 746.27 $kg \cdot day^{-1}$.
Total ammonia inflow = 256.17 $kg \cdot day^{-1}$.
Removing rate (R) = $\dfrac{\text{Ammonia outflow}}{\text{Ammonia inflow}}$
= $\dfrac{746.27}{256.17}$

The optimum safe concentration for total ammonia-nitrogen in receiving water is set as 0.1 mg/l. Maximum total ammonia inflow is calculated. The result is presented in Table 6.

Maximum total ammonia inflow = 739.53 $kg \cdot day^{-1}$
Then
Maximum total ammonia outflow = R x maximum total ammonia inflow
= $2.9132 \cdot 739.53$
= 2154.40 $kg \cdot day^{-1}$.

Table 1 Average value of water quality at marine shrimp farming area and Kung Krabaen Bay during 1989 to 1994 (P<0.05)

Station / Parameters	Shrimp ponds st0	Water supply st1	KKB st2	Mouth of KKB st3	Coastal water st4	Drainage canals st5
Transparency (m)	$0.425^a \pm 0.024$	$0.680^{ab} \pm 0.012$	$1.008^{bc} \pm 0.110$	$1.454^d \pm 0.23$	$1.635^d \pm 0.530$	-
Salinity (ppt)	$29.50^a \pm 3.04$	$29.99^a \pm 2.21$	$31.34^a \pm 3.11$	$31.59^a \pm 2.75$	$30.86^a \pm 2.66$	$25.12^b \pm 3.11$
DO (mg/l)	-	$6.04^a \pm 0.800$	$6.21^a \pm 0.750$	$6.29^a \pm 0.770$	$6.25^a \pm 0.890$	$6.55^a \pm 0.390$
pH	$7.93^{ab} \pm 0.99$	$7.98^{ab} \pm 0.720$	$8.08^{ab} \pm 0.532$	$8.11^a \pm 0.456$	$8.12^a \pm 0.110$	$8.02^{ab} \pm 0.250$
NO2-N (mg/l)	$0.042^a \pm 0.00$	$0.010^b \pm 0.001$	$0.004^b \pm 0.002$	$0.004^b \pm 0.002$	$0.004^b \pm 0.003$	$0.014^b \pm 0.005$
NH3-N (mg/l)	$0.120^a \pm 0.00$	$0.032^a \pm 0.002$	$0.017^a \pm 0.001$	$0.018^a \pm 0.006$	$0.012^a \pm 0.001$	$0.401^b \pm 0.002$
Si (mg/l)	$0.391^a \pm 0.00$	$0.593^a \pm 0.003$	$0.514^a \pm 0.029$	$0.466^a \pm 0.033$	$0.460^a \pm 0.028$	$0.206^a \pm 0.015$
PO-34 (mg/l)	$0.325^a \pm 0.02$	$0.099^b \pm 0.002$	$0.041^c \pm 0.003$	$0.039^c \pm 0.002$	$0.039^c \pm 0.002$	$0.006^c \pm 0.004$
Total bacterial plate count (CFU/ml)	-	$12890^a \pm 10.3$	$19003^a \pm 15.4$	$19789^a \pm 17.2$	$18527^a \pm 18.1$	$23801^a \pm 17.33$
Vibrio count bacterial (CFU/ ml)	-	$283^a \pm 5.37$	$557^a \pm 6.23$	$442^a \pm 3.45$	$214^a \pm 2.77$	$659^a \pm 4.56$
Total alkalinity (mg/l)	-	$120.09^a \pm 11.23$	$19.233^a \pm 12.5$	$19.632^a \pm 14.78$	$118.348^a \pm 15.63$	$116.400^a \pm 17.23$
BOD (mg/l)	-	$2.447^a \pm 0.890$	$2.029^a \pm 0.730$	$1.895^a \pm 0.550$	$1.800^a \pm 0.430$	$1.797^a \pm 0.850$

Remark : 1 - = no data
2   Values a row that have the same superscript are not significantly different (P<0.05)
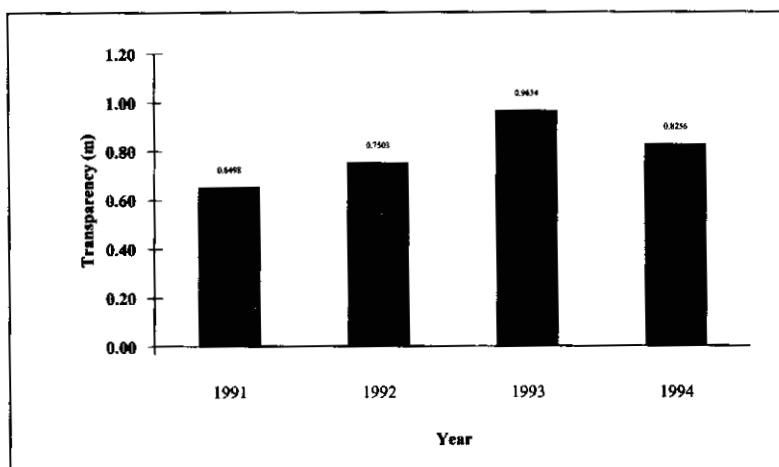
Fig. 2. Average transparency of marine shrimp ponds at Kung Krabaen Bay from 1991-1994.
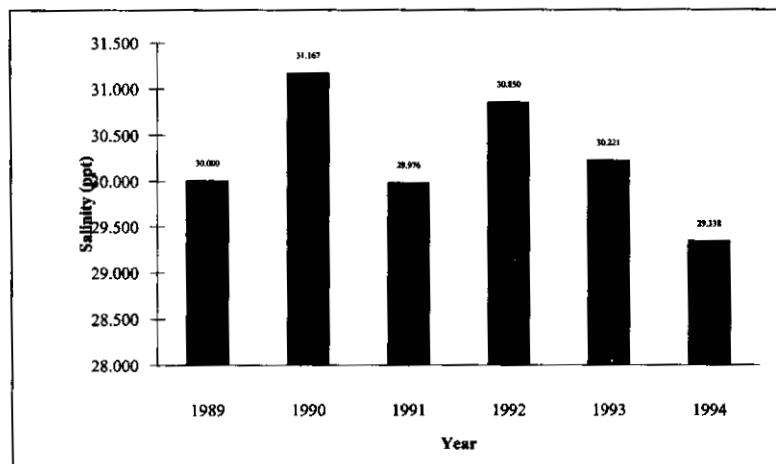

Fig. 3. Average salinity from marine shrimp ponds at Kung Krabaen Bay from 1991-1994.
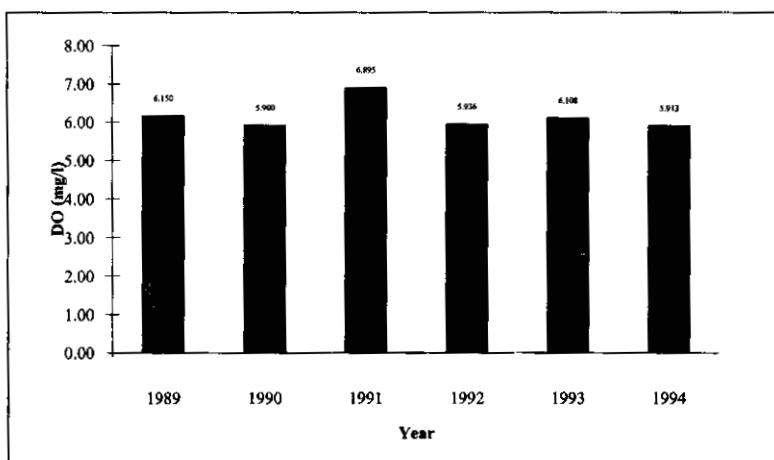

Fig. 4. Average dissolved oxygen from marine shrimp ponds and Lung Krabaen Bay from 1991-1994.
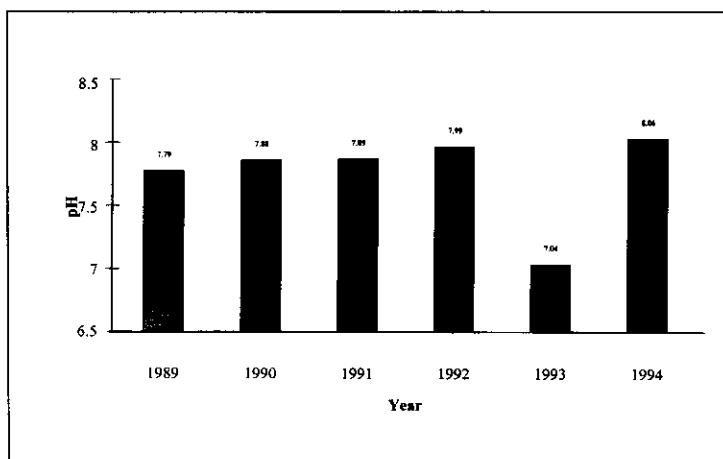
Fig. 5. Average pH from marine shrimp ponds and Kung Krabaen Bay from 1991-1994.
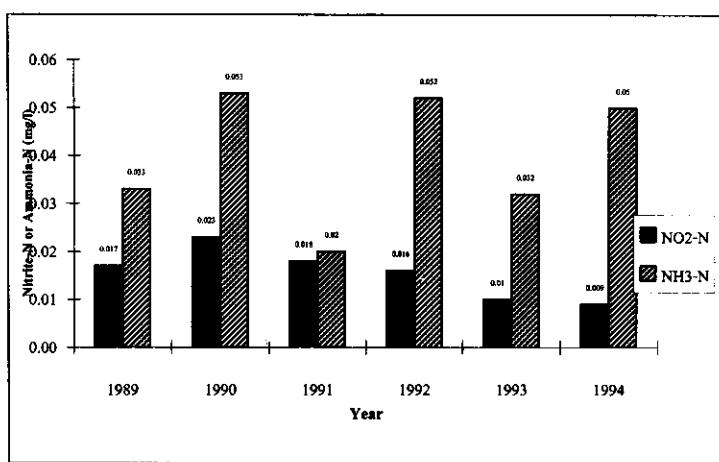

Fig. 6. Average nitrite-N and ammonia-N from marine shrimp ponds and Kung Krabaen Bay from 1989-1994.

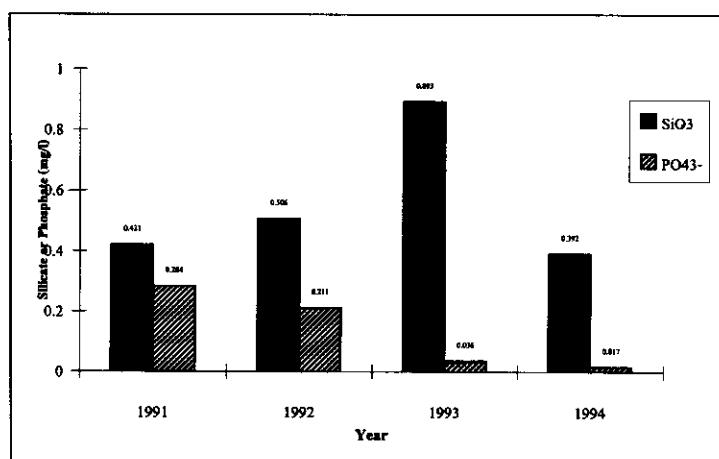Fig. 7. Average silicate and phosphate from marine shrimp ponds and Kung Krabaen Bay from 1991-1994.
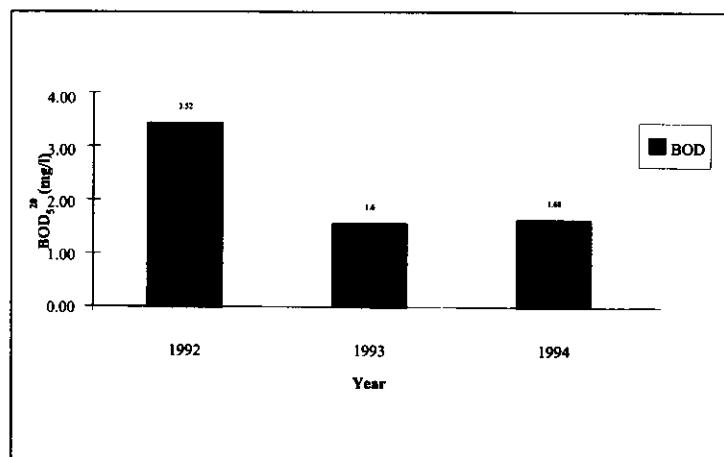
Fig. 8. Average BOD from marine shrimp ponds and Kung Krabaen Bay from 1991-1994.
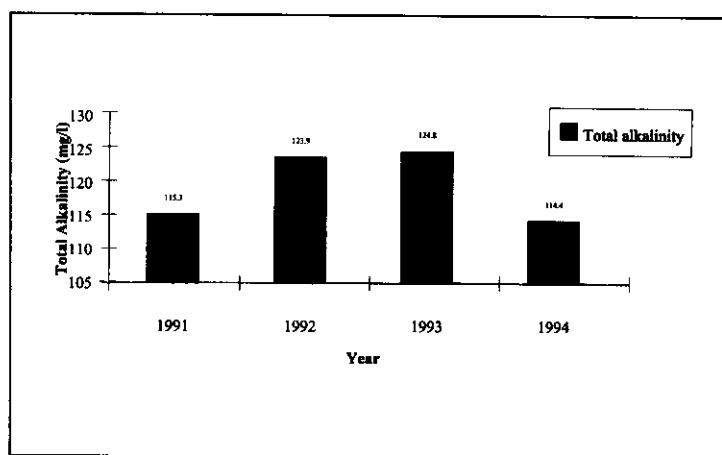

Fig. 9. Average alkalinity from marine shrimp ponds and Kung Krabaen Bay from 1991-1994.
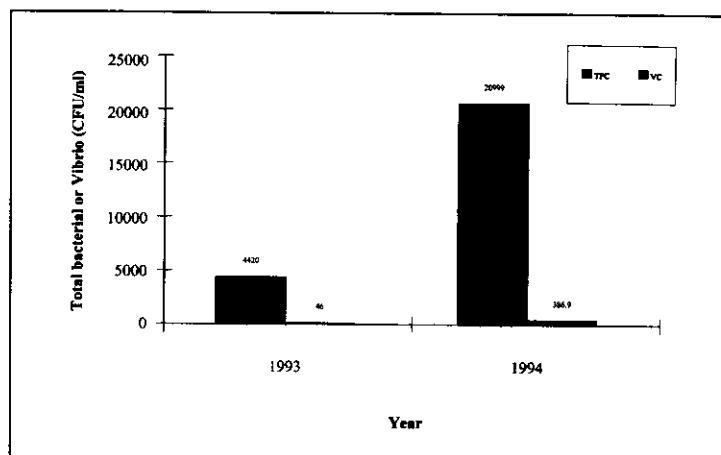

Fig. 10. Average total bacteria plate count and vibrio bacteria from marine shrimp ponds and Kung Krabaen Bay from 1993-1994.

Table 2. Total ammonia outflow in one day at the mouth of Kung Krabaen Bay.

Time	Ao (m^2)	Vo (m/s)	NH3-N(mg/l) Co (mg/l)	3.6 (CoAoVo)	AOVO
2100	1178.45	0.225	0.033	31.4999685	265.1513
2200	1147.2	0.161	0.015	9.9737568	184.6992
2300	1123.375	0.19	0.054	41.492979	213.4413
2400	1076.475	0.19	0.034	25.0345026	204.5303
100	952.45	0.271	0.041	38.09761902	258.114
200	876	0.322	0.037	37.5719904	282.0272
300	781.2	0.315	0.031	27.4623048	246.078
400	749	0.29	0.064	50.045184	217.21
500	719.1	0.271	0.04	28.0621584	194.8761
600	700.15	0.261	0.518	340.7719669	182.7392
700	681.45	0.241	0.08	47.2980816	164.2295
800	619.5	0.161	0.07	25.134354	99.7395
900	491.6	0.152	0.06	19.4234112	89.9232
1000	564.2	0.145	0.055	16.198182	81.809
1100	527.35	0.12	0.036	8.20113472	63.282
Ammonia outflow (AO)	=746.2678064		2747.894		

Table 3. Total ammonia inflow in one day at the mouth of Kung Krabaen Bay.

Time	Ai (m^2)	Vi (m/s)	Ci mg/l	3.6* (CIAIVI)	AIVI (m^3)
1200	491.25	0.22	0.055	21.39885	108.075
1300	619.5	0.344	0.019	14.5765872	213.108
1400	725.9	0.25	0.025	16.33275	181.475
1500	906	0.255	0.044	36.595152	231.03
1600	1041.75	0.254	0.056	53.3442672	264.6045
1700	1207.5	0.234	0.062	63.066276	282.565
1800	1282.35	0.215	0.024	23.8209336	275.7053
1900	1307.8	0.175	0.012	9.886968	228.865
2000	1359.45	0.219	0.016	17.14864608	297.7196
Ammonia inflow = 256.17 2083.137					

Table 4. Maximum total ammonia inflow in one day at the mouth of Kung Krabaen Bay.

Time	Aim (m^2)	Vim (m/s)	Cim (mg/l)	CimAimVim
1200	491.25	0.22	0.1	38.907
1300	619.5	0.344	0.1	95.2576
1400	725.9	0.25	0.1	65.331
1500	906	0.255	0.1	83.1708
1600	1041.75	0.254	0.1	95.25762
1700	1207.5	0.234	0.1	101.7198
1800	1282.35	0.215	0.1	99.25389
1900	1332.95	0.175	0.1	83.97585
2000	1207.5	0.219	0.1	95.1993
Maximum ammonia inflow	= 739.53414			

Shrimp farm area = 142.76 ha (Leeraksakiat 1995).

Total ammonia loading (AL) = $\dfrac{AO\text{-}AI}{SA}$

where AO = total ammonia outflow
$\quad\quad$ AI = total ammonia inflow
$\quad\quad$ SA = Shrimp farm area

AL $\quad= \dfrac{746.27 - 256.17}{142.76}$

$\quad\quad = 3.4330 \ \ kg \cdot ha^{-1} \cdot day^{-1}$

Carrying capacity (C) = $\dfrac{MAO - AO}{AL}$

where MAO = Maximum ammonia outflow;

C = $\dfrac{2154.40 - 746.27}{3.433}$

$\quad\quad = 410.17 \ \ ha$

Therefore, at the present shrimp farming area around Kung Krabaen Bay of 142.76 ha, the maximum potential farming area is estimated at around 552.93 ha (410.17+142.76).

Discussion

The Environmental Impact

Water quality is a critical factor for the survival and optimal growth of shrimp in cultured ponds. The maintenance of good water quality is essential in cultured shrimp production (Chiu 1988). In the present study, average water transparency remarkably decreased from 1991 to 1993, from which it can be concluded that more suspended solids accumulated in the KKB complex at that time. These solids might have resulted from shrimp ponds, which were the major source of loading in the complex. Total ammonia-nitrogen concentrations in the same period were high in drainage canals and shrimp ponds, even higher than the optimum safe concentration of $0.1 \ mg \cdot L^{-1}$. However, ammonia concentraton declined in the bay and the surrounding coastal waters and was even in the optimum safe concentration. It is doubtful that the concentration of amomonia might have decreased as it passed the canal before reaching the bay. However, this needs to be explored further in future studies.

At the present scale of shrimp farm operations in the area, most of the shrimp farms discharge their effluents directly along drainage canals. This means that suspended solids and other waste materials are transported along the canals where some might reach the bay and adversely affect its water quality. Therefore, it is recommended that sludge disposal areas or ponds be constructed to keep suspended solids from settling at the bottom. This would mimimize the impact of effluents on the Bay's waters.

Stapornvanit (1993) estimated the concentration changes of each parameter in the bay by the flushing time (Beveridge 1987; NCC 1989). It was assumed that all the shrimp ponds produced shrimp. Aerial photography and ground surveys indicated that the total area under shrimp culture around Kung Krabaen Bay in 1993 was 170.62 ha, with all effluents b ing discharged into the bay. Concentrations of total nitrogen, total phosphorus and total organic carbon were shown to be clearly highest during harvesting.

It is clear from the present study that the water quality of the bay and its environs significantly deteriorated due to loading from shrimp culture, particulaly during harvest time. Although Kung Krabaen Bay has nine canals connecting to the shrimp culture areas, during the ebb tide, loading of discharge water into the bay almost stops completely. Under this scenario, there is a likelihood that certain amounts of nutrients and polluted materials will not reach the bay. In other words, the bay will not receive all of the discharge from the shrimp farms. In this regard, it can be presumed that most of the shrimp ponds' sludge would be left in the drainage canals. This supports Stapornvanit's theory that shrimp ponds do not pollute the Bay's waters. However, this requires further study.

Carrying capacity

Rosenthal, as cited in Stapornvanit (1993), defines the term 'carrying capacity' as the maximal potential production that a species or population is able to maintain with respect to the food resources available in an area. A related term, which is particularly used when referring to environmental problems, is 'sustainable aquaculture.' The principle of sustainable development, as defined by FAO (1988), and cited by Stapornvanit (1993), means "the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable."

Barg (1992), in coming up with his methods for estimating the carrying capacity of areas used for oyster and mussel farming (reviewed by Heral in 1991 and cited by Stapornvanit in 1993), concluded that carrying capacity can be assessed by evaluating historical records of bivalve culture, by measuring the availability of phytoplankton biomass or by undertaking more detailed studies, e.g., of carbon and nitrogen flows through a bivalue culture unit interacting with the food web (Rodhouse et al. 1985, as cited by Stapornvanit 1993). Beveridge (1987) explained that the major consideration in the site selection process should be the carrying capacity of the site, i.e., the maximum level of production that a site might be expected to sustain without any environmental problems.

The carrying capacity of Kung Krabaen Bay was estimated at 552.93 ha. From this, it is possible to conclude that expanding the farmed area to around

401.17 ha will not have an impact on the environment. This means that the expansion area is about three times the present farming area and that if the farming area is expanded to 540 ha, it would not have any effect on the bay's water quality. This study showed that the water quality in the KKB complex is very poor, particularly in the drainage canals and shrimp ponds. On the other hand, water quality in the bay and coastal waters still fall under the acceptable limit. (Chien 1992; Liu 1989; Tookwinas 1985). It can be presumed that a certain amount of waste materials would settle down in the drainage canals. Thus, drainage canals may act as treatment areas for shrimp farm effluents. This agrees with Stapornvanit's result. However, this requires further in-depth study.

At present, many shrimp farmers in the KKB complex complain that :

(I) there is not enough supply of seawater for shrimp farming;

(ii) water quality in water supply canals is poor; and

iii) the survival rate of shrimp in the ponds is low.

These problems have been investigated by the concerned government agencies. In response, the Department of Fisheries issued a plan and allocated a budget for a seawater irrigation project at the KKB complex in 1995 (DOF 1994). The project proposes to improve the seawater supply pumping unit and effluent treatment facility areas. However, some shrimp ponds will need reconstruction and improvement to ensure the project's success. It is hoped that this project will make shrimp farming at the KKB complex sustainable and environment-friendly.

Conclusion

Average water transparency in Kung Krabaen Bay remarkably decreased from 1991 to 1993, probably due to the presence of drainage canals running from shrimp farms to the bay's mouth. At the same time, water quality parameters, especially ammonia-nitrogen, was in the acceptable levels for aquatic organisms.

Carrying capacity of Kung Krabaen Bay is estimated at around 553 ha. The present shrimp farm area is 143 ha. The cultured area can be expanded to around 410 ha. However, further investigation is needed to assess the environmental impact of an increase in the shrimp culture area.

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