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Shrimp and Mollusc Culture at the Bandon Bay in Thailand: A Situation Analysis

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Abstract

A socio-economic and ecological survey was conducted using farmer interviews and SWOT analysis, and monitoring of water quality parameters in Bandon Bay, Surat Thani, Thailand from January to December 1999. Monthly water samples from 29 sampling stations in the river mouth, mollusc culture and open bay areas were collected for 12 months and analyzed for ammonia-nitrogen (NH_3-N), nitrite-nitrogen (NO_2^--N), nitrate-nitrogen (NO_3^--N), soluble reactive phosphorus (PO_4^{3-}), and chlorophyll-*a* (Chl-*a*). Secondary information on phytoplankton abundance and shrimp culture area was collected from local research institutions. The results revealed that both oyster and cockle cultures provided net returns of USD 4,905 and 1,257 ha^{-1} $year^{-1}$, respectively. Nutrient concentrations in the river mouth and shrimp culture areas were significantly higher ($P<0.05$) than the open bay area and Chl-*a* in mollusc culture areas was significantly lower ($P<0.05$) than the river mouth and shrimp culture areas. There was a significant positive relationship ($P<0.05$) between shrimp culture area and Chl-*a* concentration and a significantly positive relationship ($P<0.05$) between shrimp and oyster yields. Effluent discharging period of shrimp farms coincided with Chl-*a* peaks in the bay. Efficient integration of mollusc and shrimp cultures in a mutually beneficial way, i.e. to use shrimp farming effluents to attain a controlled eutrophication in the mollusc culture area and mollusc farming to recycle the waste nutrient discharged by shrimp farmers, is probably the best option for achieving sustainable development of aquaculture in the Bandon Bay. It is suggested that intensive shrimp culture areas be taken as a variable when developing zonal plans for Bandon Bay.

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Introduction

Bandon Bay located at Surat Thani province of southern Thailand is one of the most productive coastal areas in the country. More than 80 km of coastal belt is utilized mainly for shrimp and mollusc culture (Office of Environmental Policy and Planning 1995). Molluscs, especially oyster, *Crassostrea belcheri* (Sowerby) and cockle, *Anadara granosa* (Linnaeus), have been cultured at the Bandon Bay for more than 20 years. In 1998, mollusc farms occupied about 3,000 ha of intertidal mud flat of the shore area. These farms produced 7,800 and 20,000 t of oysters and cockles, respectively, which contributed 42 % of the total mollusc production in Thailand worth USD 17.3 million (DOF 2000a). Aside from mollusc culture in the bay, intensive shrimp culture is also practiced along the coast. The number of shrimp farms has increased from 234 (953.76 ha) in 1989 to 1,015 farms (4,485.12 ha) in 1994. In 1998, a total of 13,797 tons of shrimp was produced by 1,165 farms which occupied 6,083.09 ha of land (DOF 2000b). The current production is about 15,000 t from 1,635 intensive shrimp farms with areas of 6,400 ha (DOF 2004).

Intensive shrimp culture which primarily depends on high-protein pelleted feeds is practiced around the bay (Kompiang 1990; Fast and Lannan 1992; Lin 1995). Only 20-25 % of nitrogen and 10-15 % phosphorous from feeds are retained in the biomass and the rest are exported to the bay during water exchange and drainage. Exported nutrients from shrimp culture to the natural environment enrich coastal waters and enhance plankton blooms (Macintosh and Phillips 1992; Lin et al. 1993; Sataporn-vanit 1993; Songsangjinda and Tunvilai 1993; Tunvilai et al. 1993; Tookwinas et al. 1994; Lin 1995; Funge-Smith and Briggs 1998). It is known that molluscs are efficient filter feeders capable of depleting phytoplankton in the water column (Soto and Mena 1999). Hence, it is possible that eutrophication process in this coastal area from shrimp farming effluents could probably enhance mollusc production. Enhanced mollusc production might be potentially beneficial to mitigate the negative environmental impacts of shrimp culture. This research study, therefore, is conducted to investigate the current situation in mollusc culture at the Bandon Bay in terms of culture practices and socio-economics, and to identify constraints and prospects. Furthermore, it was also investigated whether shrimp culture activities pose any positive or negative impact on mollusc production. Finally, the potential for integrating mollusc and shrimp cultures to enhance mutual benefits for the farmers in coastal areas and ways to minimize coastal eutrophication are likewise discussed in this paper.

Materials and Methods

Study area

Bandon Bay located in Surat Thani province (9°12' N; 99°40' E), southern Thailand (Fig. 1a) covers approximately 1,070 km^2. The bay is exposed to two monsoonal winds during the wet season; northeast monsoonal winds from November to April and southwest monsoonal winds from May to October. The dry season with less rainfall and high evaporation rate occurs from January to April (Wattanakorn et al. 1999). The inner bay that extends for 80 km coast from Chaiya District to Kanchanadit District, where most mollusc culture areas are located, covers an area of 480 km^2. Gradually sloping intertidal zone of the coast has a mean water depth of 2.9 m with respect to mean sea level. A large band of mudflats extends along the coast to about 2 km of off shore area (Wattanakorn et al. 1999).

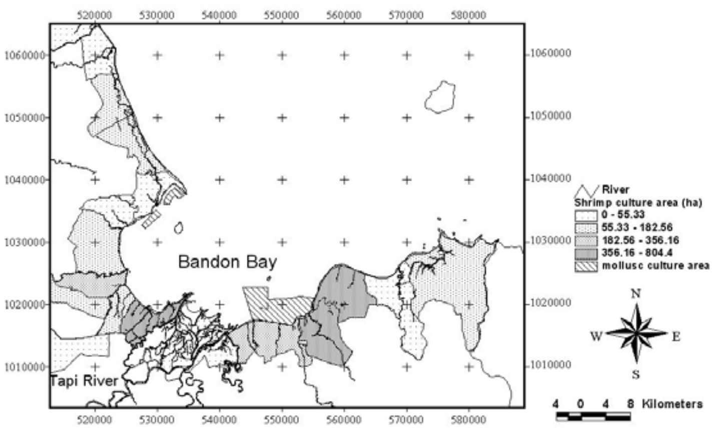

Fig. 1a. A map showing the study area, shrimp culture area and mollusc culture area at the Bandon Bay, Surat Thani province.

Shrimp farms are located in the Chaiya, Donsak, Kanchanadit, Muang, Punpin, Thachang and Thachana districts along the Bandon Bay coast line (Fig. 1a). In 1999, about 3,584 ha were utilized for intensive shrimp farming and nearly 57 % (2,050 ha) of the shrimp farms were located in the Kachanadit district. The rest were located in the Thachang, Punpin, Chaiya, Thachana, Donsak and Muang districts that accounted for 15.2, 13.1, 4.9, 4.7, 2.9, and 2.1 % of the total shrimp culture areas, respectively. The inner bay, where most mollusc culture areas are located, extends from Chaiya district to Kanchanadit district which covers an area of 480 km^2 with a 80 km coast line.

Bandon Bay receives most of the surface freshwater runoff from the Tapi-Phumduang river watershed (latitude 7º58.2'N to 9º31.0'N, longitude 97º28.4'E to 99º46.0'E). The runoff flows through the Tapi and Phumduang rivers which join at Phunphin district (30 km west of Surat Thani), and then flows into Bandon Bay at Muang District (Fig. 1a). Moreover, there are many canals scattered at the Bandon Bay coastal area and flow through the districts where shrimp farms are operated. Those rivers and canals receive effluents from shrimp farms which are then discharged into the Bandon Bay.

Survey methods

The survey on mollusc farms at the Bandon Bay was conducted to investigate the current situation in mollusc culture. Seventy-three mollusc farmers and farmer leaders in Chaiya, Kanchanadit and Thachang districts were interviewed using a structured questionnaire. Information on fixed and variable costs were used to calculate gross return, net return and break event point of mollusc culture. Participatory SWOT analysis was conducted with three groups of farmers (consisting of 5 – 10 farmers per group) to identify the strengths, weaknesses, constraints and prospects of mollusc farming. Secondary information on shrimp culture practices and production statistics were obtained from local agencies such as the Surat Thani Coastal Fishery Development Center, provincial and district fishery offices, and the Surat Thani Coastal Aquaculture Cooperative Ltd.

The study areas at the Bandon Bay were classified into 3 areas in this study: (1) river mouth, (2) mollusc culture, and, (3) open bay areas. Monthly water samples from 29 sampling stations (Fig. 1b) were collected for 12 months (January to December 1999). There were nine stations (OP1-OP9) in the open bay area approximately about 3-15 km offshore, 11 stations (R1-R11) in the river mouth that received shrimp farming effluents, and nine stations (M1-M9) in the mollusc culture area of Kanchanadit district. Water samples were analyzed for ammonia-nitrogen (NH_3-N), nitrite-nitrogen (NO_2^--N), nitrate-nitrogen (NO_3^--N) and soluble reactive phosphorus (PO_4^{3-}), and chlorophyll-*a* (Chl-*a*) using methods described in APHA et al. (1980) and Strickland and Parsons (1972). Secondary data on phytoplankton abundance and species composition at the Bandon Bay for the year 1999 were collected from the Department of Fisheries (DoF), Thailand. The data were analyzed to determine whether shrimp culture activities have enhanced the natural feed supply and whether shrimp culture has posed any positive or negative impacts on mollusc production. Water quality parameters were analyzed using a one way analysis of variance (ANOVA) using SPSS (version 11.0) statistical software package (SPSS Inc. Chicago, USA). All data were subjected to Kolmogorov-Smirnov test for goodness of fit of a normal distribution. If the data were found to be not normal, Kruskal Wallis Test was used to determine significant ($p<0.05$) differences among means (Steele and Torrie 1980).

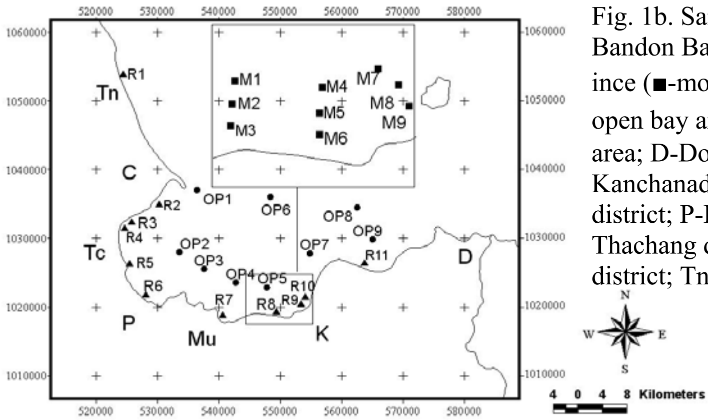

Fig. 1b. Sampling stations at the Bandon Bay, Surat Thani province (■-mollusc culture area; ●-open bay area; ▲-river mouth area; D-Donsak district; K-Kanchanadit district; Mu-Muang district; P-Punpin district; Tc-Thachang district; C-Chaiya district; Tn-Thachana district)

Results

Situation analysis

Mollusc farming systems and culture practices

The oysters are cultured in mud flat areas of Chaiya and Kanchanadit districts and cockles are cultured in Chaiya, Kanchanadit and Thachang districts of Bandon Bay. The survey results indicated that 57.5 and 15.1 % of farmers culture oyster and cockle, respectively. About 27.4 % of the farmers culture both species. The average area of oyster and cockle farms were 1.42 ha (ranging from 0.16 to 6.4 ha) and 15.37 ha (ranging from 0.32 to 192 ha), respectively.

The most common oyster species cultured at the Bandon Bay was *Crassostrea belcheri* (Sowerby). The majority of farmers collect oyster spat from the bay twice a year (February to March and September to October). Only about 1.6 % of the farmers purchased 2.5 to 9 cm size spat from other farmers at a cost of USD 0.03 – 0.1 seed^{-1}. Spats are collected using cultches made of cement tubes (CT), cement blocks (CB; 45-50 cm diameter and 50-80 cm height) or cement poles (CP; 150 x 10 x 10 cm length x width x depth) but some farmers used bamboo poles for collecting spat at the beginning and then transfer oysters onto CT, CB or CP for growing-out. A typical CT comprise of a bamboo pole with a length of 120 cm and 3.2 cm diameter that inserted into a cylindrical cement tube with a length of 44 cm and diameter of 15 cm. The bamboo pole was then inserted into the mud flat. Some farmers use polyvinyl chloride pipes to encase the bamboo stick to prolong its usage. The survey result showed that 85, 42 and 41 % of the oyster farmers used CT, CB and CP, respectively. Farmers, who purchased spat use cement to attach them onto CT or CB and after the cement dried, place cultches in the culture area (12-20 hr). The average density of CT and CB used in the culture area was 6,746 (ranging from 313 to 25,000) and 738 pieces ha^{-1}, respectively. The density of CP is about 3 times higher than CB.

Farmers usually take care of the day to day culture operations without hiring additional workers. Each farmer has a boat for transportation, guardhouse to avoid poaching and bamboo fence to demarcate the farm area. Extra workers were hired by some farmers to plant and maintain cultches in the mud flats and during harvesting period. Oysters are normally harvested during the dry season (January to July) when there are no monsoonal winds. Farmers harvest oysters with a length of 8-10 cm after 12-14 months of culture period for spat collected from the bay. If farmers prefer to harvest bigger sized (> 12 cm) oysters, they extend the culture period for 4 more months. A relatively shorter (8-10 months) culture period is used for seed purchased from outside. Oyster culture was operated in permitted area by individual farmers. Since cockle culture requires more mud flat areas than those of oysters, farmers combine the allocated mud flat area to culture cockles.

The most common cockle species cultured at the Bandon Bay is *Anadara granosa* (Linnaeus). Natural cockle seed is scarce in the Bandon Bay area. Farmers who culture cockles in Donsak district at the east of

Bandon Bay produce about 500 t cockles a year (1,387 ha) using natural cockle seed. However, trawl and push net fisheries are said to have affected this seed bed negatively. Hence, most of the farmers at the Bandon Bay obtained cockle seed from other areas by collaborating with the Surat Thani Coastal Aquaculture Cooperative Ltd. About 95% of cockle seed used at the Bandon Bay was imported from Malaysia and the rest was purchased from Satun province in Thailand located near the Malaysian border. Once the suitable size of seed is available, cockle seeds are spread out in the culture area using an iron container from January to March. Various sizes of seeds (180 - 3,000 cockles kg^{-1}) were stocked at a rate of 0.26 - 12.50 t ha^{-1}. The mean seed size and stocking density were 1,500 cockles kg^{-1} and 3.81 t ha^{-1}, respectively. The average culture period was about 16 months but it can vary from 12 to 24 months depending on the initial size at stocking and the required marketable size. At the end of the culture period, cockles are harvested by dragging a sled made of iron rods at the bottom of the cockle beds. Either total or partial harvesting methods are employed taking farm size and market demand into account. Total harvest is usually done when there is a good yield of uniform-size cockles. Harvesting period usually lasts for 5-20 days but in some farms the harvesting period lasts for 2-3 months. Culture management operations are undertaken by the farmer group who has combined their permitted culture areas. A typical farmer group consists of around 15 persons. Similar to oyster culture, extra workers are hired during the stocking and harvesting periods.

Production of oyster for each cultch varies from 0 to 20 individual animals. The average production of oysters from one CT and CB were 3 and 9 animals per cultch, respectively. The average production of oyster was 22,220 oysters ha^{-1} per crop (Table 1). The farm-gate price of a 12 cm long oyster was 0.26 USD. The survey results showed that cockle was harvested at a size of 70 - 100 cockles kg^{-1}. The farm-gate price of cockle was USD 0.36 kg^{-1}. The average production of cockle was 11,808.8 kg ha^{-1}. All oysters and most of the cockles produced at the Bandon Bay were sold to local markets in Petchaburi, Samut Sakorn and Surat Thani provinces of Thailand and some cockles are exported to other markets in Asia.

Cost-benefit analysis showed that the gross returns of oyster and cockle cultures were USD 5,813 and 4,210 ha^{-1} $year^{-1}$, respectively, and net returns from oyster and cockle cultures were USD 4,905 and 1,257 ha^{-1} $year^{-1}$, respectively. Since the spat are collected from the wild, there is a relatively higher net return from oyster culture. Nearly 84 % of the operational cost of cockle culture originated from the seed cost. While the major fixed cost in oyster culture was the investment for the grow-out substrate (65 %), the cost of fuel and gasoline dominates the variable cost. Break-even productions for oyster and cockle culture were 3,008 and 8,938 kg ha^{-1} year^{-1}, respectively (Table 1).

Table 1. Cost-benefit analysis for oyster and cockle culture at Bandon Bay

Items	Average ± SD	
	Cockle (n=31)	Oyster (n=62)
1. Fixed cost (USD ha^{-1} year^{-1})		
1.1 Boat and Engine	105.52 ± 31.10	96.50 ± 41.14
1.2 Grow-out materials	-	389.14 ± 305.56
1.3 Guard-house	93.51 ± 53.66	74.22 ± 41.85
1.4 Bamboo fence	57.79 ± 49.31	21.92 ± 11.29
1.5 Others (iron rods sled)	17.24 ± 8.52	-
1.6 Tax	13.16 ± 0	13.16 ± 0
Sub total	211.22 ± 129.24	518.10 ± 30.29
2. Variable cost (USD ha^{-1} year^{-1})		
2.1 Seed	2,541.25 ± 1,057.74	-
2.2 Fuel and gasoline	135.31 ± 56.75	124.51 ± 59.75
2.3 Labor (stocking and harvesting)	284.21 ± 187.13	49.63 ± 16.79
2.4 Guard	67.54 ± 58.13	-
Sub total	2,938.11 ± 963.27	142.16 ± 68.21
3. Maintenance cost (USD ha^{-1} year^{-1})	16.38 ± 13.20	191.54 ± 176.19
Total cost	**3,197.56 ± 884.62**	**775.13 ± 533.88**
Production (cockle kg ha^{-1} and number of oysters ha^{-1})	11,808.87 ± 4,664.69	22,220.24 ± 13,694.09
Price (USD kg^{-1} cockle and USD oyster^{-1})	0.36 ± 0.1	0.26 ± 0.01
Gross return (USD ha^{-1} year^{-1})	42,09.56 ± 1,561.12	5,813.14 ± 3,379.80
Net return (USD ha^{-1} year^{-1})	1,257.30 ± 1,050.74	4,905.11 ± 3,298.88
Break even point (Cockle kg ha^{-1} and number of oysters ha^{-1})	8,937.92 ± 2,517.54	3,008.35 ± 1,232.23

Shrimp farming

Shrimp farming areas were mainly located around Bandon Bay in the Kanchanadit and Thachang districts. In 1999, intensive shrimp culture that used similar culture practices spread over approximately 3,584 ha produced 16,197 t of shrimp. Shrimp farms adjacent to Klong Thathong (R10), Klong Thanchang (R5), Klong Cha-nger (R8) and Klong Leeled (R6) canals located in the river mouth area produced approximately 3213, 2457, 2399 and 2115 t, respectively.

There were two crops of shrimps per annum. The first crop was cultured during February and April and harvested during May and June, and the second crop was cultured during August and September and harvested during November and December. Approximately, 94 % of shrimp farms in Surat Thani discharged their effluents into the Bandon Bay through rivers and canals scattered around the bay. About 21.1, 16.2, 15.8, 13.9, 13.0 and 10.3 % farms discharged effluents to Klong Thathong (R10), Klong Thanchang (R5), Klong Cha-nger (R8), Klong Leeled (R6), Klong Ram (R9) canals and to Tapi River (R7), respectively (Figs. 1a and 1b).

Nutrients and phytoplankton concentrations in relation to shrimp farming and mollusc production

The results showed that nutrient concentrations in river mouth areas were significantly higher ($P < 0.05$) than those of the mollusc culture and open bay areas. It was also found that Klong Thathong (R10), Klong Ram (R9), and Klong Cha-nger (R8) sampling stations, where most of shrimp farms were located, had high concentrations of NO_3^--N, NO_2^--N and NH_3-N (Table 2). However, PO_4^{3-} concentrations in these stations were significantly lower than the other areas.

Table 2. Mean nitrate, nitrite, ammonia, soluble reactive phosphate and chlorophyll-*a* concentrations of sampling stations in the river mouth area

Station	NO_3^--N (mg l^{-1})		NO_2^-N (mg l^{-1})		NH_3-N (mg l^{-1})		PO_4^{3-} (mg l^{-1})		Chl-*a* (µg l^{-1})	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
R1	0.1159	0.0215	0.0098	0.0016	0.0127	0.0041	0.0975	0.0514	13.46	2.71
R2	0.1315	0.0202	0.0086	0.0035	0.0090	0.0034	0.0427	0.0343	8.13	2.01
R3	0.1675	0.0324	0.0186	0.0052	0.0100	0.0025	0.0580	0.0406	11.35	2.29
R4	0.2390	0.0410	0.0171	0.0048	0.0124	0.0025	0.0610	0.0441	12.31	2.53
R5	0.2103	0.0369	0.0118	0.0029	0.0164	0.0048	0.0540	0.0327	15.75	3.19
R6	0.2411	0.0330	0.0129	0.0021	0.0104	0.0026	0.0371	0.0126	11.06	2.72
R7	0.2709	0.0516	0.0115	0.0021	0.0191	0.0052	0.0315	0.0104	29.39	2.16
R8	0.2009	0.0408	0.0172	0.0032	0.0130	0.0029	0.0661	0.0170	24.58	6.49
R9	0.2682	0.0412	0.0372	0.0177	0.0116	0.0020	0.0305	0.0059	19.35	4.57
R10	0.2039	0.0439	0.0138	0.0026	0.0059	0.0009	0.0325	0.0137	45.41	3.48
R11	0.0939	0.0220	0.0112	0.0032	0.0102	0.0027	0.0200	0.0041	13.11	2.26

R1 – R11 were sampling stations in the river mouth areas located at river or canal mouths that received shrimp farming effluents: R1-R4 (Chaiya district), R5-R6 (Thachang district), R7 (Muang district), R8-R10 (Kanchanadit district), R11 (Donsak district); SE = Standard error.

Concentration of Chl-*a* in river mouth stations ranged from 8.1 – 45.4 µg l^{-1} (Table 2). Open bay and mollusc culture areas had relatively low Chl-*a* concentrations that amounted to 4.0 – 10.2 µg l^{-1} and 2.6 – 4.5 µg l^{-1}, respectively (Tables 3 and 4). The Chl-*a* concentration in sampling stations such as Klong Thathong (R10) where most of the shrimp farms were located was significantly higher ($p<0.05$) than the areas where relatively few shrimp farms were located e.g. Klong Thapoon (R4), Klong Haohao (R3), and Klong Pumreang (R2) (Table 2). There were no significant differences in Chl-*a* concentrations among the sampling stations located in the mollusc culture area (Table 4). Annual fluctuation in Chl-*a* station in mollusc culture areas are shown in figure 2. There were two peak concentrations during May – June and November – December which coincided with the two shrimp harvesting periods. The positive relationship between the shrimp culture area and Chl-*a* concentration in sampling stations located in the river mouth area is shown in figure 3.

Table 3. Mean nitrate, nitrite, ammonia, soluble reactive phosphate and chlorophyll-*a* concentrations of sampling stations in the open bay area

Station	NO_3^-N (mg l^{-1})		NO_2^-N (mg l^{-1})		NH_3-N (mg l^{-1})		PO_4^{3-} (mg l^{-1})		Chl-*a* (µg l^{-1})	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
OP1	0.0712	0.0254	0.0045	0.0016	0.0019	0.0005	0.0103	0.0036	8.79	3.00
OP2	0.0783	0.0312	0.0023	0.0008	0.0008	0.0002	0.0268	0.0162	8.11	3.80
OP3	0.1014	0.0424	0.0025	0.0008	0.0010	0.0003	0.0318	0.0212	9.32	3.09
OP4	0.0847	0.0392	0.0029	0.0013	0.0010	0.0003	0.0175	0.0109	9.31	3.06
OP5	0.1177	0.0606	0.0012	0.0003	0.0014	0.0006	0.0276	0.0238	7.83	2.89
OP6	0.0856	0.0381	0.0032	0.0007	0.0083	0.0048	0.0406	0.0309	10.29	2.94
OP7	0.0775	0.0351	0.0024	0.0007	0.0015	0.0004	0.0334	0.0268	7.01	1.50
OP8	0.0549	0.0150	0.0015	0.0007	0.0051	0.0022	0.0322	0.0296	5.04	0.79
OP9	0.0484	0.0138	0.0008	0.0004	0.0046	0.0018	0.0292	0.0280	4.05	0.74

OP - OP9 were sampling stations in the open bay that are approximately 3-15 km offshore; SE = Standard error

Table 4. Mean nitrate, nitrite, ammonia, soluble reactive phosphate and chlorophyll-*a* concentrations of sampling stations in mollusc culture area

Station	NO_3^-N (mg l^{-1})		NO_2^-N (mg l^{-1})		NH_3-N (mg l^{-1})		PO_4^{3-} (mg l^{-1})		Chl-*a* (µg l^{-1})	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
M1	0.0528	0.0229	0.0039	0.0016	0.0137	0.0077	0.0108	0.0035	2.61	0.61
M2	0.0574	0.0375	0.0117	0.0073	0.0107	0.0072	0.0333	0.0238	2.59	0.65
M3	0.0834	0.0340	0.0059	0.0015	0.0126	0.0078	0.0236	0.0158	3.30	0.75
M4	0.0450	0.0219	0.0041	0.0013	0.0187	0.0125	0.0113	0.0023	3.38	0.59
M5	0.0501	0.0241	0.0064	0.0030	0.0205	0.0180	0.0183	0.0093	3.02	0.52
M6	0.0443	0.0250	0.0097	0.0042	0.0184	0.0105	0.0136	0.0042	4.51	0.68
M7	0.0520	0.0235	0.0055	0.0026	0.0147	0.0121	0.0123	0.0041	3.61	0.85
M8	0.0707	0.0294	0.0042	0.0014	0.0121	0.0074	0.0243	0.0157	3.09	0.59
M9	0.0595	0.0334	0.0050	0.0025	0.0116	0.0077	0.0345	0.0239	3.03	0.73

M1-M13 were sampling stations in the mollusc culture area of Kanchanadit district; M1, M4 and M7 located approx. 3 km offshore; M2, M5 and M8 located approx. 2 km offshore; M3, M6 and M9 located approx. 1 km offshore; SE = Standard error.

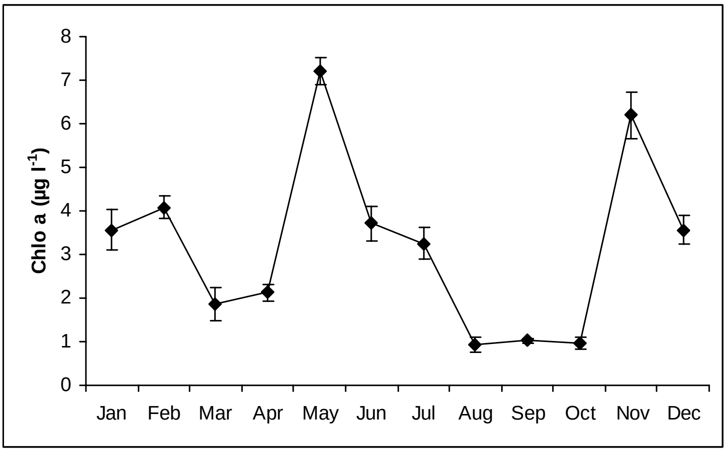

Fig. 2. Fluctuations of average concentration of Chlorophyll *a* in mollusc culture area (error bars show standard error).

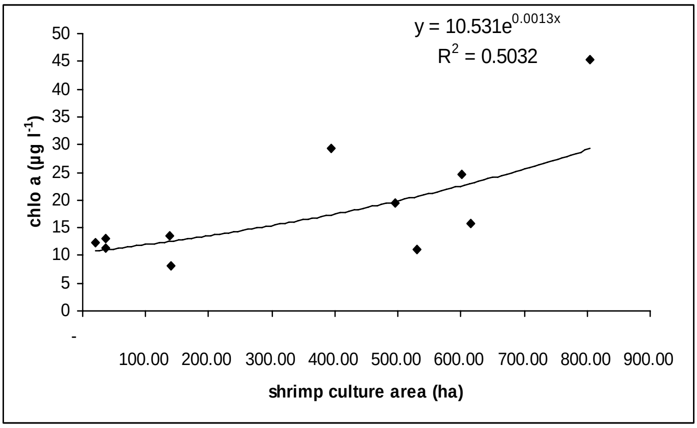

Fig. 3. The relationship between adjacent shrimp culture area and concentrations of chlorophyll *a* in sampling stations in the river mouth area receiving shrimp farm effluents.

Diatoms and dinoflagellates such as *Bacteriastrum* sp., *Ceratium* sp., *Chaetoceros* sp., *Coscinodiscus* sp., *Dinophysis* sp., *Gyrosigma* sp., *Nitzschia* sp., *Noctiluca* sp., *Peridinium* sp., *Rhizosolenia* sp., *Thalassionema* sp. and *Thalassiothrix* sp. dominated the phytoplankton community in the bay. Relatively few blue green and green algae species were found in the bay. The average phytoplankton concentrations in the inner bay area stations such as OP1, OP2, OP3, OP4, OP5 and OP7 (Fig. 1b) that ranged from 5,379 to 9,336 cells l^{-1} were significantly higher ($p < 0.01$) than the more seaward stations (OP6, OP8, OP9 which ranged from 1,642 to 3,966 cells l^{-1}). Phytoplankton density in sampling station OP5 located close to the shrimp farming area was significantly higher ($p<0.05$) in May and November when most shrimp farms discharge effluents, and it ranged from 7,488 to 18,560 cells l^{-1}.

The results indicated that mollusc production in the river mouth area is higher than in other culture areas. It was found that the average oyster production at Kanchanadit district was about 3.2 animals CT^{-1} while at Chaiya district it was about 3.0 animals CT^{-1}. There was no statistical difference between these two areas. The mollusc yield in relation to shrimp production in a time series is shown in figure 4. Oyster production per unit area increased with the increase in shrimp yields after 1992 (Fig. 4). However, cockle production per unit area initially decreased for some unknown reasons but there was an increasing trend of cockle production per unit area after 1997. The positive relationship (r^2 = 0.66) between oyster and shrimp yields per unit area is shown in figure 5.

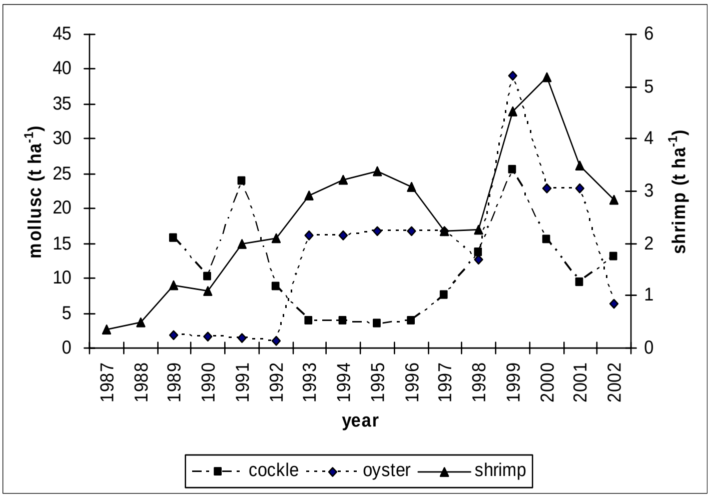

Fig. 4. Time series analysis of oyster, cockle and shrimp yields at the Bandon Bay area during 1987 -2002

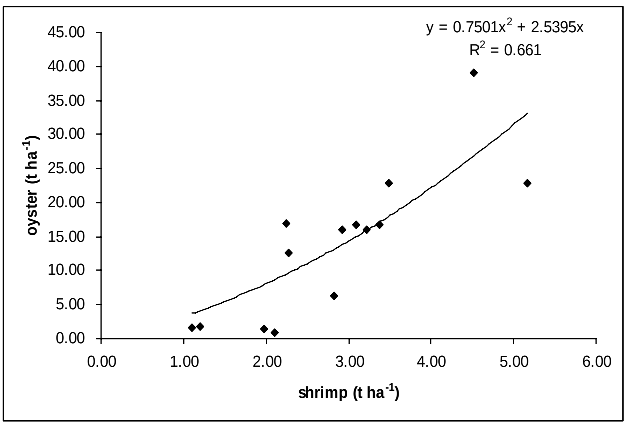

Fig. 5. The relationship between shrimp and oyster yields during 1989 – 2002

Mollusc culture constraints and prospects

Opinions of mollusc farmers on their culture practices and constraints are shown in table 5. The farmer survey results showed that majority of the farmers (63 %) were of the opinion that effluent from shrimp farms benefit the mollusc culture by enhancing its natural feed supply but only 20 % of the interviewed farmers mentioned that shrimp effluents did not negatively affect mollusc culture. Marketing of cultured products is identified as a major constraint (35 %). This is mainly due to the fact that farmers do not have the power to influence the farm gate price as the middlemen totally control the price. The slow growth rate of molluscs, freshwater runoff during the rainy season and pollution at the river mouth area ranked as the next set of constraints. Around 11 % of the interviewed farmers considered chemicals used in shrimp farms as a threat. Relatively few farmers worried about user area conflicts between farmers and small-scale fishermen. In addition to individual farmer survey, the SWOT analysis with farmer groups showed the following strengths, weaknesses, opportunities and threats to mollusc farming at Bandon Bay.

Table 5. Views of farmers on mollusc culture practices at Bandon Bay

Problem	% of farmer
Effluents from shrimp farms benefit mollusc culture by enhancing natural feed availability in the bay (n=46)	63.01
Farmers cannot influence farm gate price of molluscs as middlemen control the price (n=26)	35.62
Effluents from shrimp farms do not negatively affect mollusc culture (n=14)	19.18
Growth rate of oysters is slow (n=13)	17.81
Fresh water runoff negatively affects mollusc culture (n=12)	16.44
Water quality problems/pollution in the river mouth area affect mollusc farming (n=12)	16.44
Chemicals use in shrimp farms negatively affect mollusc culture (n=8)	10.96
Growth rate of cockle is slow (n=5)	6.85
Conflicts between mollusc farmers and small-scale fishermen on fishing/aquaculture area used by the two groups (n=4)	5.48

Strength

A large band of mudflats that extend along the coast to about 2 km off shore (Wattanakorn et al. 1999) makes Bandon Bay an ideal area for culturing molluscs. Availability of natural oyster seed provides opportunity for farmers to utilize these natural resources for farming activities. The survey results showed that farmers have extensive experience and skills in mollusc culture practices.

Weakness

Farmer groups identified their inability to influence farm gate price of molluscs (Table 5) and the unavailability of local cockle seeds as the two major constraints in mollusc farming at the Bandon Bay. Farmers also faced marketing difficulties when the harvest size did not reach the marketable size.

Opportunity

Shrimp farming located along the coast of Bandon Bay and discharge from shrimp farm to accentuate nutrients in the bay and enhance plankton productivity provide a good opportunity for farmers to enhance mollusc production. However, shrimp farming should be sustainable and should not pollute the bay excessively to pluck its secondary benefits to the mollusc farmers. The Department of Fisheries of Thailand has now implemented a Code of Conduct (COC) to enhance the sustainability of shrimp farming. This provides a good opportunity to integrate shrimp and mollusc farming in a mutually beneficial way to both farmer groups. Implementation of various pollution treatments is considered to be a necessary strategy to conserve and improve coastal environment. Mollusc culture is now recognized as an efficient biological treatment for water polluted by other aquaculture and human activities. Since the Surat Thani Coastal Aquaculture Research and Development Center and Surat Thani Aquaculture Co-operative Ltd. are closely assisting mollusc farmers, they can use this opportunity to make both shrimp and mollusc cultures sustainable.

The high market demand for oysters, which are mostly considered as a luxury food in the domestic market, and the demand for cockles in both domestic and export markets, can be further exploited. Domestic market demand for cockle was about 30,000 - 40,000 t year^{-1} in 1999, but farmers could produce only 10,000 - 20,000 t (Faculty of Economics 1999) The Customs Department of Thailand reported that a high volume of cockle (over 5,100 t in 2003) was exported to Hong Kong (Customs Department of Thailand 2005).

Threat

The bay receives a runoff of more than 10 billion m^3 from the Tapi-Phumduang river system annually (Wattanakorn et al. 1999). Decrease in salinity level is a major problem due to the influx of large volumes of freshwater from rivers in the rainy season (NACA 1988). The relatively low production in 1997 was said to have resulted from the excessive freshwater influx in 1996 (DOF 2000a). Aside from salinity, the relatively slow growth rate due to variability in temperature and sediment accumulation on mud flat that causes the shallow culture areas in the intertidal zone could also negatively affect mollusc culture (Faculty of Economics 1999). Moreover, social conflicts between mollusc farmers and small-scale fishermen for common property uses such as restrictions in fishing area and navigation in the mollusc culture area is a foreseeable threat at Bandon Bay (Jarernpornnipat et al. 2004).

Furthermore, disease outbreaks can also be a possible threat to mollusc culture (Mialle et al. 1995; Renault and Novoa 2004). Although this was not specifically mentioned by the stakeholders, there is a possibility that the culture areas will be contaminated with faecal and chemical residues in domestic and sewage wastes originating from urban and industrial areas. Gannarong et al. (2000) and Gannarong and Sopakul (2000) reported the presence of coliforms, fecal coliforms, *Escherichia coli* and *Vibrio parahaemolyticus* in oysters harvested from the Bandon Bay.

Discussion

Chlorophyll-*a* contents ranging from 0 – 5, 5 – 20, 20 – 60 and > 60 µg l^{-1} in estuarine waters are considered as low, medium and high Chl-*a* contents and hyper-eutrophic condition, respectively (Bricker et al. 2003). Relatively high Chl-*a* concentrations (>20, ≤ 45 µg l^{-1}), NO_2^-N, NO_3^-N and NH_3 were observed in the river mouth and shrimp culture areas (R7 – R10 in Fig. 1b; Table 2). Both open bay and mollusc farming areas had medium content of Chl-*a* (>2, ≤ 12 µg l^{-1}). Relatively few shrimp farms located in the river mouth area (R5 – R6) also had medium concentrations of Chl-*a* (Fig. 1b; Tables 2 and 3). Relatively less volume of water is exchanged in intensive shrimp culture during grow-out period and water is completely discharged during harvesting period (Funge-Smith and Briggs 1998). Two peak concentrations of Chl-*a* were observed during May – June and November – December which coincided with the two shrimp harvesting periods (Fig. 2). A similar trend in Chl-*a* fluctuation at Bandon Bay was observed by La-Ongsiriwong et al. (1997) and Wattanakorn et al. (1999). Ogilvie et al. (2000) showed that availability of phytoplankton in mollusc culture area in Beatrix Bay, New Zealand, was dependent on water discharge pattern from adjacent rivers that is enriched with nutrients. These observations indicated that the bay might have received nutrients from both the freshwater runoff from the Tapi-Phumduang river watershed and shrimp farm effluents.

Intensive shrimp culture is mainly dependent on high protein feed and only 20-25 % of nitrogen and 10-15 % of phosphorus in feed is retained by shrimp (Kompiang 1990; Fast and Lannan 1992; Lin 1995). Shrimp farmers usually discharge untreated effluents to the canals connected to the bay. Wattanakorn et al. (1999) showed that the discharged nutrients from river-runoff and shrimp farm effluents were trapped in the river and estuarine sections not in the open bay. These exported nitrogen and phosphorus from shrimp culture might have enhanced plankton blooms at the Bandon Bay (Macintosh and Phillips 1992; Lin et al. 1993; Satapornvanit 1993; Songsangjinda and Tunvilai 1993; Tunvilai et al. 1993; Tookwinas et al. 1994; Lin 1995; Funge-Smith and Briggs 1998).

Analyses of dietary composition of molluscs showed that these animals prefer to consume diatoms and dinoflagellates (Coastal Aquaculture Division 1990). There was a positive curvilinear relationship of shrimp culture area and Chl-*a* concentration (Fig. 3). There was a positive relationship between shrimp and mollusc yield per unit area (Fig. 5). Time series analysis showed that oyster yield increased after the introduction of shrimp culture at the Bandon Bay (Fig. 4). These observations suggested that shrimp farming has considerable influence on the primary productivity of Bandon Bay and as a result it might have a positive impact on mollusc culture via enhanced food availability to the latter. However, as filter feeders also consume bacteria and other detritus particles apart from plankton, it would be rather difficult to demonstrate the direct correlation between qualitative and quantitative characteristics of phytoplankton and somatic production of molluscs (Sarà and Mazzola 1997).

The Chl-*a* in mollusc culture areas was significantly ($P<0.05$) lower than in the river mouth areas. Similar results were shown by Youngvanitset et al. (1999) who analyzed water quality parameters in oyster culture area at the Bandon Bay. These observations indicated that mollusc culture might have positively contributed to the Bandon Bay ecosystem by controlling excessive eutrophication and improve livelihood of farmers by converting waste nutrient from shrimp farms and river-runoff to a marketable product.

Cost-benefit analysis showed that both oyster and cockle culture provided average net returns of 4,905 and 1,257 USD ha^{-1} yr^{-1}. Moreover, oyster and cockle production at the Bandon Bay are favored by consumers due to the quality and unique taste (Jarernpornnipat et al. 2004). The relatively high demand in local luxury market makes oyster culture more profitable than cockle culture. However time series analysis showed that the cockle production pattern was quite different from the trends in oyster production (Fig. 4). The oyster production per unit area was increased after 1992 (Fig. 4) and cockle production started to increase after 1997. This is mainly due to the provision of extension services that started only after 1997 at the Bandon Bay (Surat Thani Coastal Aquaculture Cooperative Co. Ltd, pers. comm.) which resulted in the intensification of cockle culture. Marketing of molluscs are done through middlemen and every middleman receives products from a relatively large number of farmers. This provides an opportunity for middlemen to maintain a low market price (Faculty of Economics 1999). Since local seed supply is inadequate, farmers have to buy imported seeds. Both factors lower farmer profits (Faculty of Economics 1999).

Mollusc culture is recognized as one of the most suitable activities for small-scale aquaculture as it can be practiced using either traditional or semi-traditional methods and without any feed supplementation. Moreover, mollusc culture is also considered as a good human intervention to treat polluted water (Shpigel and Blaylock 1991; Tookvinas and Youngvanitset 1998; Jones et al. 2001), and a profitable livelihood option for seed collectors (Jara-Jara et al. 1997) and commercial farmers in coastal areas (Mazzola and Sarà 2001). The SWOT analysis reflected that Bandon Bay has high potential for mollusc culture. The mud flat area in the bay where natural seed and feed is abundant can be utilized for mollusc culture. Majority of farmers (63.0 %) interviewed in this study agreed that shrimp farms are beneficial for their mollusc culture as shrimp effluents provide nutrient source for phytoplankton growth at the Bandon Bay (Table 5). However farmers mentioned that they were worried that the excessive effluent discharge of shrimp farming would have a negative impact on the sustainability of mollusc culture. Jarernpornnipat et al. (2004) who studied sustainable management options of shellfish culture at the Bandon Bay proposed to set up a mangrove strip as primary filters to reduce nutrient discharge by shrimp farmers. They also proposed to set up three zoning areas for cockle, oyster and green muscle culture e.g. use of over 50 km^2 area at the west of Klong Phun Phin (between R6–R7 in Fig. 1b) for cockle culture as high sedimentation rates. The muddy substrate rich in organic particles makes this river mouth area ideal for cockle production. Jarernpornnipat et al. (2004) suggested to utilize the southern northwest area of

Tapi river mouth (R8 – R9 area) for oyster and green muscle culture where a significant amount of nutrient inputs from Tapi river and shrimp farms are received.

Cost-benefit analysis showed that both oyster and cockle culture provided adequate net returns. The relationships between shrimp culture area around the Bandon Bay and chlorophyll *a* concentration are shown in figure 3 and shrimp farms effluent discharge and Chl-*a* dynamics are shown in figure 2. A positive regression between shrimp and oyster yields is shown in figure 5. Authors, therefore, suggest that intensive shrimp culture areas should be taken as a variable when developing zonal plans for Bandon Bay to take advantage of these mutually beneficial relationships. The best option for achieving sustainable development of aquaculture at the Bandon Bay is probably to integrate mollusc and shrimp culture efficiently i.e. the use of shrimp farming effluents to generate a controlled eutrophication in the mollusc culture area and to use mollusc farming to recycle the waste nutrient discharged by shrimp farmers. Further research on the quantity of nutrient release from shrimp farms in relation to primary productivity of the bay is urgently needed to develop sustainable resource use plans for Bandon Bay.

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