# Contribution of mollusc culture to control eutrophication in the coastal bay: a case study of Bandon Bay, Surat Thani, Thailand

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## ABSTRACT

An ecological survey using measurements of water quality parameters was conducted monthly from January to December 1999 at 29 sampling stations in the river mouth, mollusc culture beds, and open bay areas of Bandon Bay. Information on water level, water discharge, wind, nutrients and Chlorophyll *a* (Chl-*a*) concentration in Bandon Bay were used to simulate Chl-*a* concentration and distribution around the mollusc culture area using hydrodynamic and water quality modules of MIKE21 model. The results showed that low concentration of Chl-*a* can occur in mollusc culture areas. The difference between simulated and observed values was used to evaluate Chl-*a* content reduced by molluscs in the culture area. It was found that MIKE21 model can be successfully used to determine Chl-*a* distribution in relation to nutrient loading, water discharge and wind conditions in Bandon Bay. The modeling results showed that the simulated Chl-*a* concentrations in November in the mollusc culture area ranged from 11.5 – 37.5 $\mu g\ l^{-1}$ probably due to relatively higher water discharge from river and shrimp farm effluents. The modeling results also showed that Chl-*a* concentration was approximately 72% lower in the mollusc culture area than in non-mollusc culture areas. These simulated and observed results indicated that mollusc farming can be effectively used to recycle the nutrients discharged from the river and shrimp farms and to control eutrophication in Bandon Bay.

**Keywords:** Mollusc culture, shrimp culture, eutrophication, water quality modeling, Chlorophyll *a*

## INTRODUCTION

Coastal bays are commonly characterized by high biological productivity due to nutrient inputs from both freshwater and other nutrient sources. These nutrients promote the growth of phytoplankton leading to potential occurrence of phytoplankton blooms (Jørgensen and Richardson, 1996; Strain and Yeats, 1999; Cloern, 2001; Fisheries and Oceans Canada, 2003; Hartnett and Nash, 2004). Chlorophyll *a* (Chl-*a*) normally represents the value of phytoplankton blooms (Bricker *et al*., 2003). This occurrence could be accelerated by external sources of nutrients, such as intensive aquaculture farm effluents which promote eutrophic conditions (Hartnett and Nash, 2004).

Intensive shrimp culture is an important aquaculture activity which is widely operated and is a potential nutrient source along the coastal bay. Intensive shrimp culture primarily depends on protein rich pelleted feeds. (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 excess would be released to the coastal bay through water exchange and drainage.

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These nutrients enrich the natural environment in coastal waters and enhance plankton blooms (Macintosh and Phillips, 1992a; Lin *et al*., 1993; Sataporvanit, 1993; Songsangjinda and Tunvilai, 1993; Tunvilai et al., 1993; Tookwinas *et al*., 1994; Lin 1995; Funge-Smith and Briggs, 1998). Shrimp culture effluents can accelerate phytoplankton blooms while molluscs are efficient filter feeders and capable of depleting phytoplankton in the water column (Soto and Mena, 1999). Therefore, mollusc culture is considered a beneficial activity that can be used as a biological treatment for polluted water due to its uptake capability (Shpigel and Blaylock, 1991; Tookwinas and Youngvanitsset, 1998; Jones *et al*., 2001) and can increase coastal aquaculture profitability, producing seed (Jara-Jara *et al*., 1997) and edible biomass in coastal areas (Mazzola and Sarà, 2001).

In principle, the concentration of nutrients and phytoplankton in the connecting water column of the circulated coastal water should be evenly distributed or should be gradually changed. When molluscs are cultured in coastal areas receiving shrimp farm effluents, it is possible that phytoplankton in terms of Chl-*a* concentration in the mollusc culture area is lower than that in outside area. However, concentration and distribution of Chl-*a* in estuarine areas are not only dependent on biological and chemical functions, but also reliant on many other factors involving hydrodynamics, such as amount of river runoff, tidal and wind force. Thus, to investigate the fluctuation and distribution of Chl-*a* in a certain coastal bay, all possible factors should be involved. As generally known, the study of nutrient concentrations and Chl-*a* in estuarine systems is a complex issue and requires various supporting data (Bricker *et al*., 2003). Therefore, models can be useful tools to specify, describe, organize and communicate knowledge about the complex phenomena (Chapra, 1997). Several different modeling approaches can be selected and used to study coastal area situations. Many models are reported in literature, ranging from simple statistical approaches to complex 2D and 3D dynamic simulations (Gourbesville and Thomassin, 2000; Bricker et al., 2003). These models relate nutrient concentrations to phytoplankton blooms.

MIKE21, which is a comprehensive modeling system for the simulation of hydraulics and hydraulic-related phenomena in estuaries, coastal waters and seas, has been widely used for simulating the hydrodynamics, transport of pollutants, thermal plumes and water quality parameters in coastal waters (Babu *et al*., 2006). This study aims to use MIKE21 as a tool to investigate fluctuation and distribution of Chl-*a* in Bandon Bay, a coastal bay in Thailand that has been utilized mainly for shrimp and mollusc culture for decades. The information gathered from simulated results will represent Chl-*a* in Bandon Bay excluding mollusc culture. In comparsion, the observed value of Chl-*a* in Bandon Bay includes mollusc culture. Therefore, the different amounts between simulated and observed values can be used to evaluate the contribution of mollusc culture in controlling eutrophication in the study area. In addition, availability of phytoplankton as indicated by Chl-*a* distribution in Bandon Bay was used to evaluate the potential expansion areas for mollusc culture. Recommendations for the employment of mollusc culture to control eutrophication in Bandon Bay are also discussed.

## MATERIALS AND METHODS

### Study area

Bandon Bay is located in Surat Thani Province ($9^{o}$ 12' N; $99^{o}$ 40' E) in southern Thailand (Fig. 1) covering approximately an area of 1,070 $km^2$. The bay is exposed to two monsoonal winds a year: northeast monsoonal winds from November to April and southwest monsoonal winds from May to October. The dry season, with less rainfall and high evaporation rates, occurs from January to April (Wattayakorn *et al*., 1999). The inner bay extends 80 km from Chaiya District to Kanchanadit District, where mollusc culture covers an area of 480 $km^2$. The gradually sloped intertidal zone has a mean water depth of 2.9 m with respect to mean sea level. A large band of mudflats extends to about 2 km of off shore area along the coast (Wattayakorn *et al*., 1999).

Bandon Bay's coastal belt has been utilized mainly for shrimp and mollusc culture for decades (Office of Environmental Policy and Planning, 1995). Shrimp farms are located in Dondak, Kanchanadit, Muang, Punpin, Thachang, Chaiya and Thachana districts along the Bandon bay coast line (Fig. 1). In 1999, 3, 584 ha was utilized for intensive shrimp farming and nearly 57% (2,050 ha) shrimp farms were located in Kanchanadit district. The rest were located in Thachang, Punpin, Chaiya, Thachana, Donsak and Muang districts which accounted for 15.2, 13.1, 4.9, 4.7, 2.9, and 2.1% of total shrimp culture area, respectively. The inner bay, where most mollusc culture areas are located, extends from Chaiya District to Kanchanadit District covering 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 7°58.2' N to 9° 31.0' N, longitude 97° 28.4'E to 99° 46.0'E). The runoff flows through Tapi and Phumduang rivers which join at Phunphin district (30 km west of Surat Thani), and then flows into the Bandon at Muang District. Moreover, there are many canals scattered in Bandon Bay's coastal areas and flow through the districts, where shrimp farms are present. Those rivers and canals receive effluents from shrimp farms and discharge into Bandon Bay.

**Observed water quality data**

The study area is classified into three areas in this study: (1) river mouth, (2) mollusc culture beds, and (3) open bay. Water samples from 29 sampling stations (Fig. 1) were collected monthly for 12 months (January to December, 1999). There were 9 stations (B1-B9) in the open bay area, approximately 3-15 km offshore, 11 (R1-R11) at the river mouth receiving shrimp farming effluents, and 9 (M1-M9) in the mollusc culture area. Water samples were analyzed using methods described in standard methods (APHA, AWWA and WPCF, 1980) and Strickland and Parsons (1972). Phenol-hypochlorite method was used for ammonia-nitrogen. Colorimetric method and cadmium reduction method were used for nitrite-nitrogen and nitrate-nitrogen analysis, respectively. Ascorbic acid method was used for soluble reactive phosphorus (Strickland and Parsons, 1972) and Trichromatic method was used for Chl-*a* (APHA, AWWA and WPCF, 1980)

**Chl-*a* modeling**

MIKE21, a professional engineering software package containing a comprehensive modeling system for 2D free-surface flow, was used to simulate Chl-*a* concentration in Bandon Bay. To simulate Chl-*a* concentration, basic parameters, hydrodynamic model (HD) and water quality model (WQ) of MIKE21 were set up with the following details.

***Basic parameters***

The model boundary with grid spacing of 300 m was specified to cover the study area. Bathymetry was set up using depth information of topographic data shown on the navigation map survey chart (no. 227) of the Hydrographic Department, Royal Thai Navy. The model's boundary conditions were set up by adopting results from a previous study on tide and tidal current in the Gulf of Thailand (Gansungnoen, 2000). Tidal data of Ko Prap located in Bandon Bay were used for tidal level in the model.

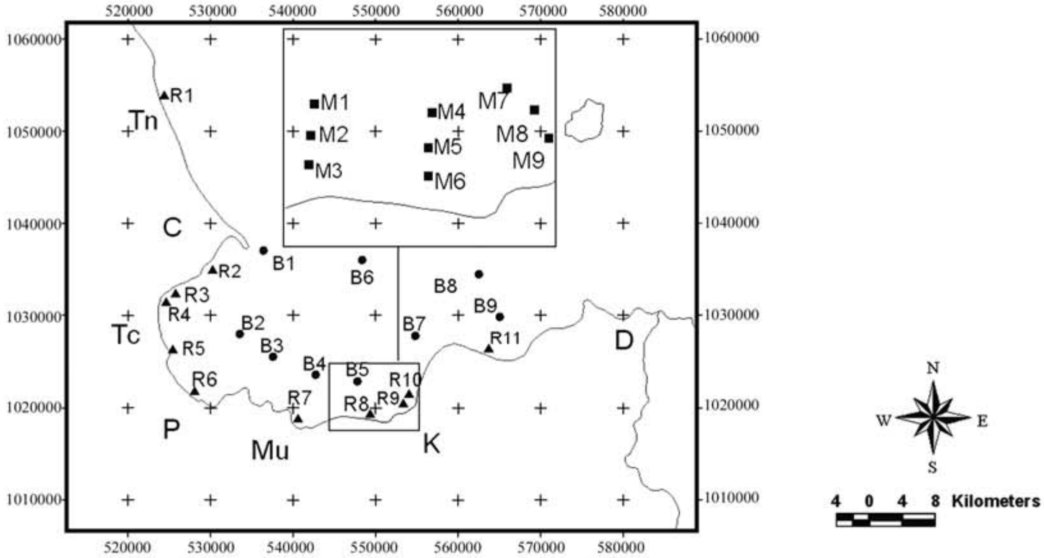


Fig.1 Sampling stations in Bandon Bay, Surat Thani province. (■ = mollusc culture area, ● = open bay area, ▲ = river mouth area, D = Dondak district, K = Kanchanadit district, Mu = Muang district, P = Phunphin district, Tc = Thachang district, C = Chaiya district and Tn = Thachana district).

Two periods of simulation were performed with time intervals of 90 seconds (s): first, during the months when most shrimp farmers did not discharge the effluents (Feb and August, 1999) and second, during the months when most shrimp farmers discharged their effluents (May and November, 1999). Each simulation period covered the first to the last date of the particular month. The courant number of 2.38442, which expresses the number of grid points the information or the given matter moves in one time step in model simulation, was set to simulate reliable hydrodynamic conditions. In this study, drying depth and flooding depth was set to be 0.02 m and 0.03 m, respectively.

***Hydrodynamic model (HD)***

In this study, HD model was set up according to hydrodynamic model validation results of Jarernpornnipat (2004). The initial surface elevation was set to be 0.65 m. Eddy viscosity of 2 $m^2 s^{-1}$ was applied to each model grid simulation. Meanwhile, Chezy Coefficient of 30 $m^{1/2} s^{-1}$, suitable for shallow and deep water in the Bandon Bay, was applied for bed resistance according to Jarernpornnipat (2004). Data extracted from the results of a study on tide and tidal current in the Gulf of Thailand (Gansungnoen, 2000) were used for tide and tidal current at model boundaries. Wind and direction data obtained from Meteorological Department (meteorological station (551202), Surat Thani Airport) were inputted for wind conditions in the HD model. Since the effects of rivers, intakes and outlets from external sources are included in a simulation, these sources and sink were included in both the hydrodynamic and the water quality models. In this study, the water discharge records of river and canals, which flowed into Bandon Bay in 1999 at specified grid points, Tapi river (R7) and Thathong canal (R10), were gathered from the Office of Hydrology and Water Management, and Surat Thani Irrigation office, Royal Irrigation Department and were set as source and sink of HD model.

***Water quality model (WQ)***

The model's default concentrations of dissolved BOD (0.5 mg $l^{-1}$), dissolved oxygen (4 mg $l^{-1}$), ammonia (0.05 mg $l^{-1}$), nitrite (0.05 mg $l^{-1}$), nitrate (0.05 mg $l^{-1}$), phosphorus (0.06 mg $l^{-1}$), Chl-*a* (0.005 mg $l^{-1}$), salinity (30 ppt) and temperature (30$^{\circ}$C) were set as initial concentrations. Meanwhile, these parameters were gathered from water sample analysis at open bay stations (B6, B8 and B9) located near the model boundary and were used for boundary concentrations. The concentrations of these parameters at river mouth stations (R7 and R10) were used for source and sink concentrations in the model. Dispersion coefficient of 5 $m^2$ $s^{-1}$ was applied to x and y directions, and specific thermal of sea water and surface heat exchange of 4.2 MJ $m^{-3}.^{\circ}C$ and 30 watt $m^{-2}.^{\circ}C$ were used for WQ model simulation, respectively. Mass balance for the parameters involved BOD, oxygen, ammonia, nitrate, phosphorus and Chl-*a* processes were calculated for all grid points at all time step using Runge-Kutta method according to MIKE21 system. When WQ model simulation was done, Chl-*a* concentration of a specific area or grid point was retrieved and plotted.

***Model calibration and verification***

The simulated models were calibrated and verified by adjusting parameters according to seasonal changes (Jarernpornnipat, 2004) in WQ module processes. The parameters of the dry season were applied to February and May, and parameters of the wet season were applied to August and November. Simulated data were tested against observed data in Bandon Bay. Two stations in the open bay area (B3 and B7) located close to the mollusc culture area were selected to compare Chl-*a* concentrations between simulated and observed values.

## RESULTS

**Observed water quality data**

Concentrations of Chl-*a* in river mouth stations ranged from 8.1 to 45.4 µg $l^{-1}$. Open bay and mollusc culture areas had relatively low Chl-*a* concentrations at 4.0 - 10.2 and 2.6 – 4.5 µg $l^{-1}$, respectively. The data indicated that high Chl-*a* concentrations were found in Tapi river mouth and in Klong Thathong; however, low concentration was observed in mollusc culture area. Chl-*a* concentration in sampling stations such as Klong Thathong (R10) where most of shrimp farms were located was significantly higher ($p<0.05$) than in areas where relatively few shrimp farms were located, e.g. Klong Thapoon (R4), Klong Haohao (R3), and Klong Pumreang (R2).

**Chl-*a* concentrations simulation**

Results showed that MIKE21 model could be effectively used to evaluate Chl-*a* concentration in relation to nutrient loading, water discharge and wind conditions in Bandon bay (Table 1). The percent of difference between observed and simulated values of Chl-*a* concentrations in May, August and November ranged from 8.7–27.5%. However, due to strong winds in February, Chl-*a* data could not be collected. Therefore, in Table 1 the observed Chl-*a* in February was not available for comparison. Figure 2 shows the relationship between observed and simulated values of Chl-*a* concentrations.

In November, when shrimp pond effluent discharge was high, average Chl-*a* concentration at station B3 was 9.69 µg $l^{-1}$ with a range of 3.32 – 19.84 µg $l^{-1}$. Meanwhile, station B7 had Chl-*a* concentration of 6.60 µg $l^{-1}$ with a range of 3.35 – 14.58 µg $l^{-1}$. It was observed that the simulated Chl-*a* concentration in November was greater than those in February, May and August when the average concentration ranged from 1.89 – 3.78 µg $l^{-1}$ (Table 1). These extracted values could be compared with observed values.

According to the above results, the distribution of Chl-*a* in a specified area and time could be plotted. The results indicated that distribution of simulated Chl-*a* during spring and neap tides in Bandon Bay, especially at the river mouth area where most of shrimp farms were located, varied during different months. Figures 3 to 10 show the distribution of simulated Chl-*a* during spring and neap tides at 6.00 am in Tapi (R7 in Fig. 1) and Thathong (R10 in Fig. 1) river mouth areas. The figures show that Chl-*a* concentration reached 20 $\mu g\ l^{-1}$ in Tapi and Thathong river mouth areas. During spring tide, there was high Chl-*a* concentration (>20 $\mu g\ l^{-1}$) in the seaward area. For example, in November, the Chl-*a* concentration was high at nearly 10 km offshore from Tapi river during spring tide (Fig. 9) and about 7 km during neap tide (Fig. 10). Meanwhile, in February, May and August, high Chl-*a* concentrations (>20 $\mu g\ l^{-1}$) were found only within 5 km of offshore (Fig. 3 - 8). It should be noted that Chl-*a* concentrations shown in Figures 3 to 10 are different from the Chl-*a* concentration of observed data, especially in the mollusc culture area. This is because Chl-*a* concentrations shown in Figures 3 to 10 were simulated with the assumed condition that there were no mollusc culture present.

Table 1. Simulated and observed Chl-*a* concentrations in area outside of the mollusc culture area.

| **Mouth** | **Station** | **Simulated Chl-*a* ($\mu g\ l^{-1}$)** | | | | **Observed Chl-*a* ($\mu g\ l^{-1}$)** | **Different (%)** |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Mean | SD | | |
| February | B3 | 0.58 | 3.98 | 2.13 | 0.77 | NA* | - |
| | B7 | 0.00009 | 4.39 | 2.10 | 1.22 | NA* | - |
| May | B3 | 0.44 | 4.01 | 1.88 | 0.74 | 2.36 | 20.3 |
| | B7 | 3.17 | 5.23 | 3.73 | 0.43 | 4.73 | 21.1 |
| August | B3 | 0.35 | 6.71 | 1.89 | 1.27 | 2.61 | 27.5 |
| | B7 | 1.84 | 5.88 | 3.13 | 0.94 | 4.22 | 25.8 |
| November | B3 | 3.32 | 19.84 | 9.69 | 3.86 | 8.86 | 9.4 |
| | B7 | 3.35 | 14.58 | 6.60 | 2.76 | 7.23 | 8.7 |

* NA = Data not available

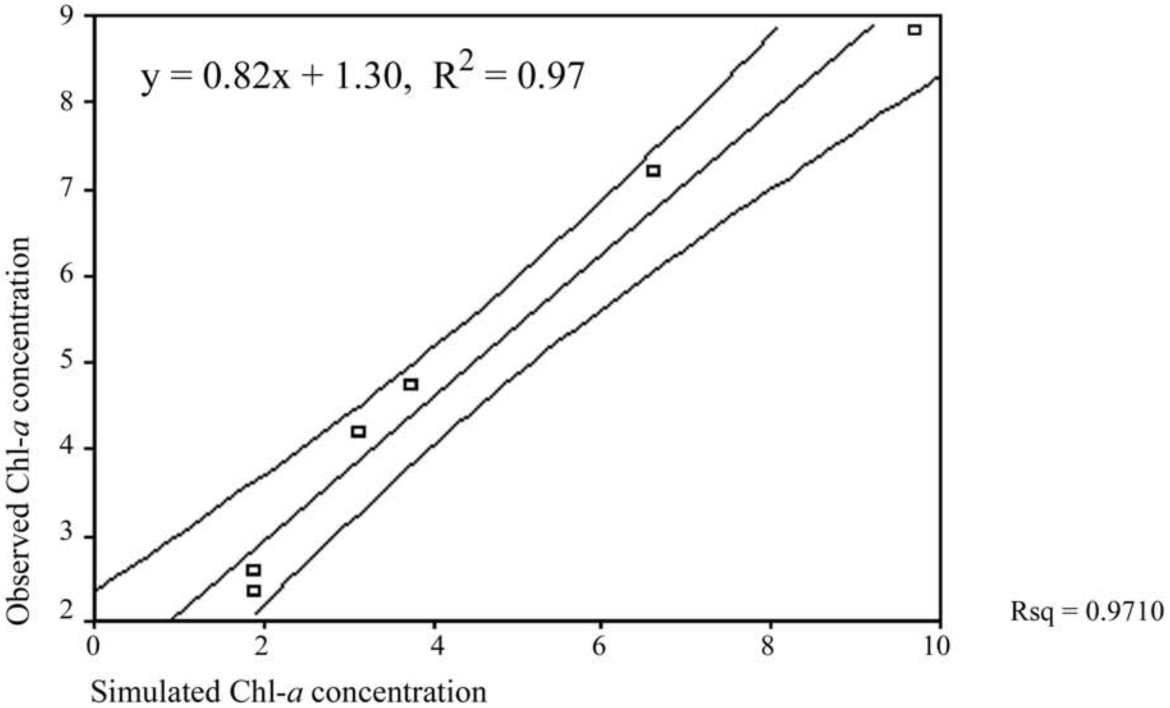


Figure 2. Regression lines and respective 95% confidence limits between mean simulated and observed values of Chl-*a* concentrations.

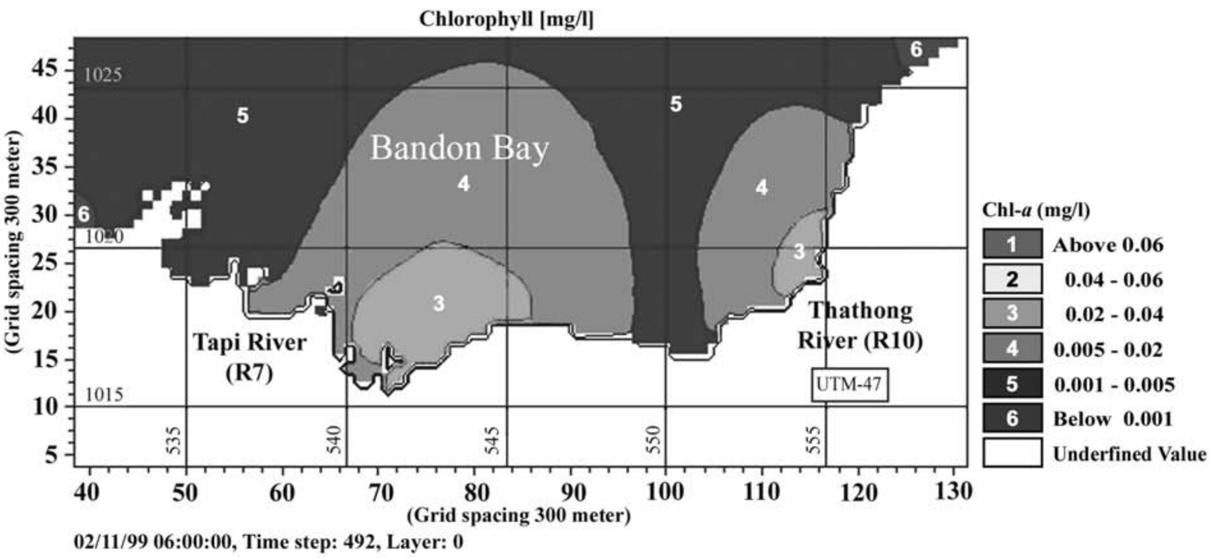


Figure 3. Simulated Chl-*a* distribution during spring tide, February 1999

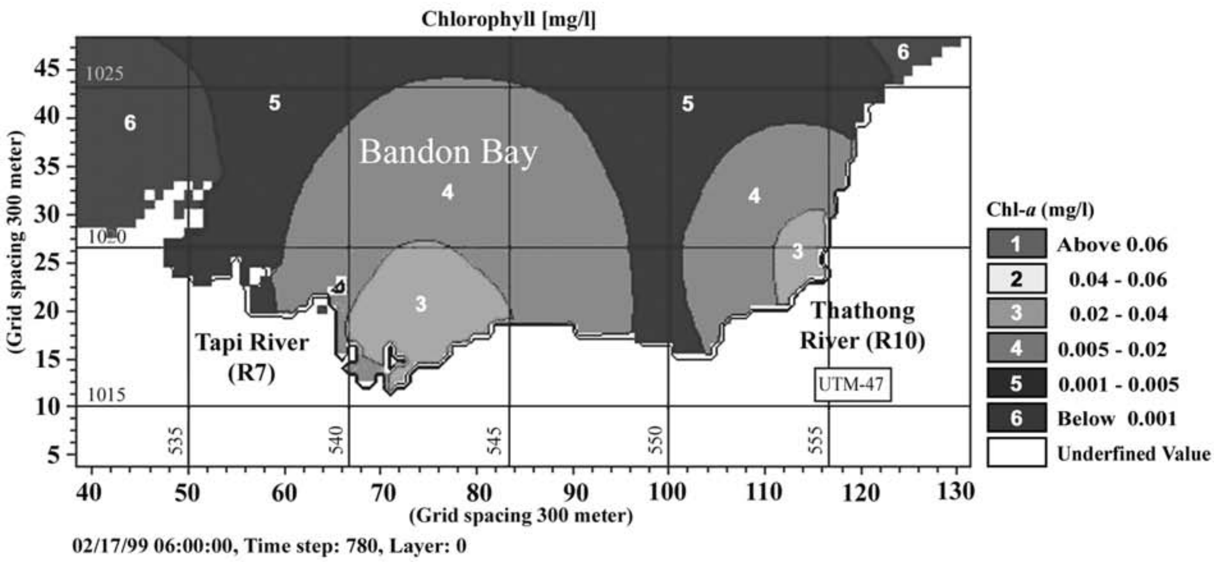


Figure 4. Simulated Chl-*a* distribution during neap tide, February 1999

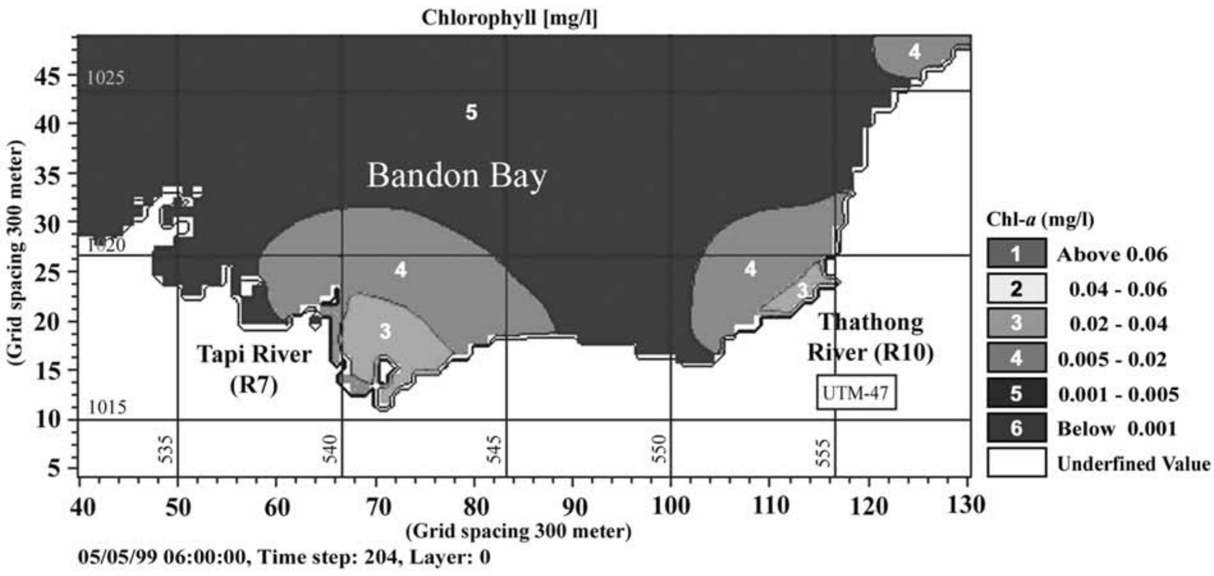


Figure 5. Simulated Chl-*a* distribution during spring tide, May 1999

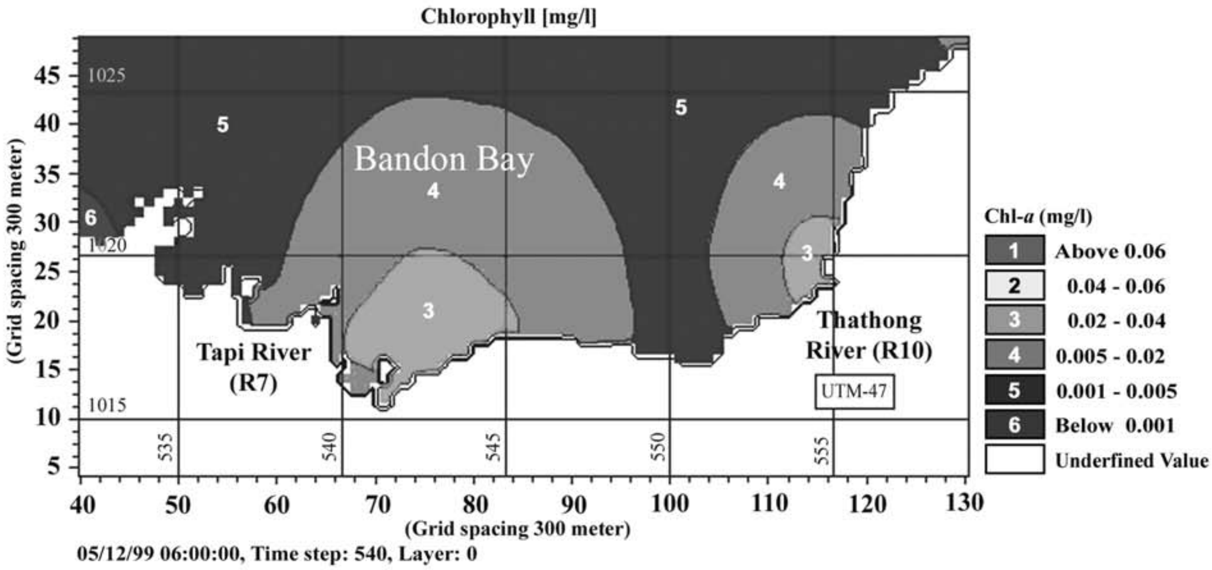


Figure 6. Simulated Chl-*a* distribution during neap tide, May 1999

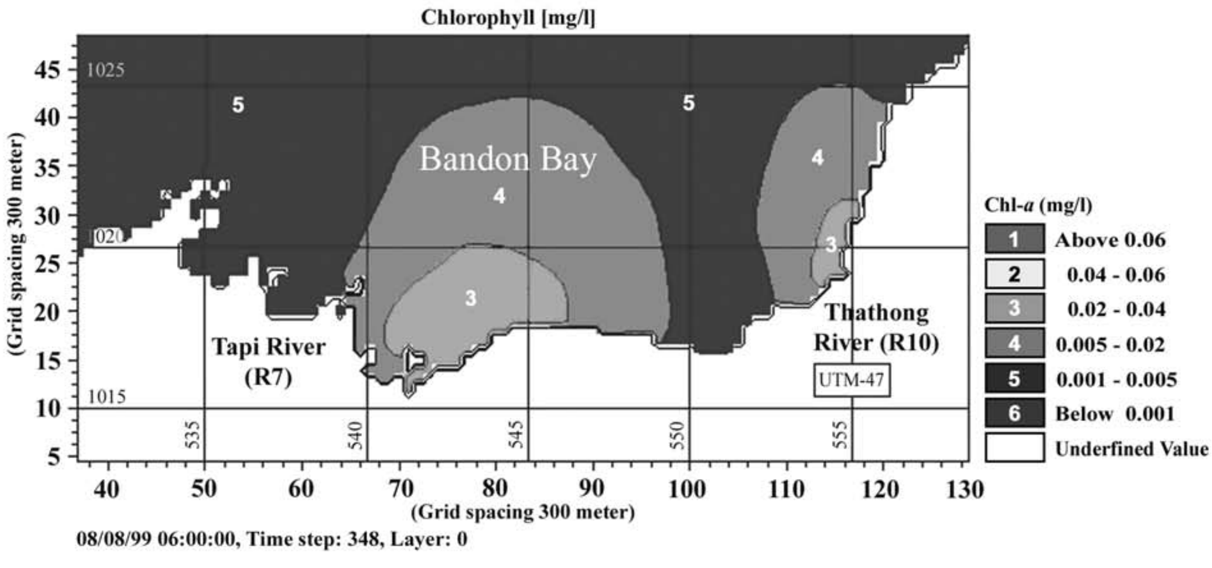


Figure 7. Simulated Chl-*a* distribution during spring tide, August 1999

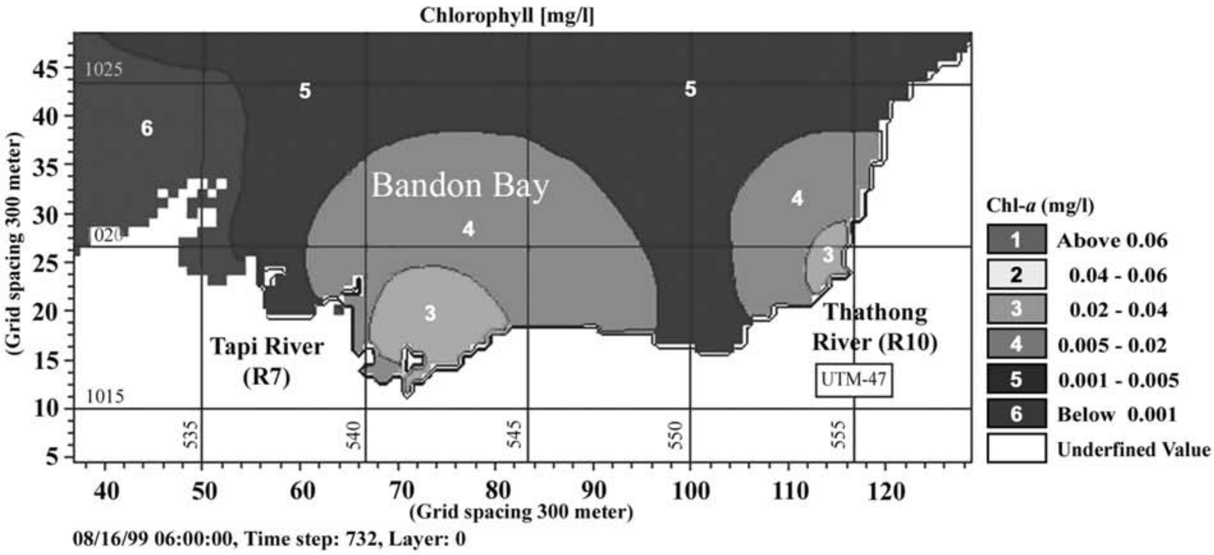


Figure 8. Simulated Chl-*a* distribution during neap tide, August 1999.

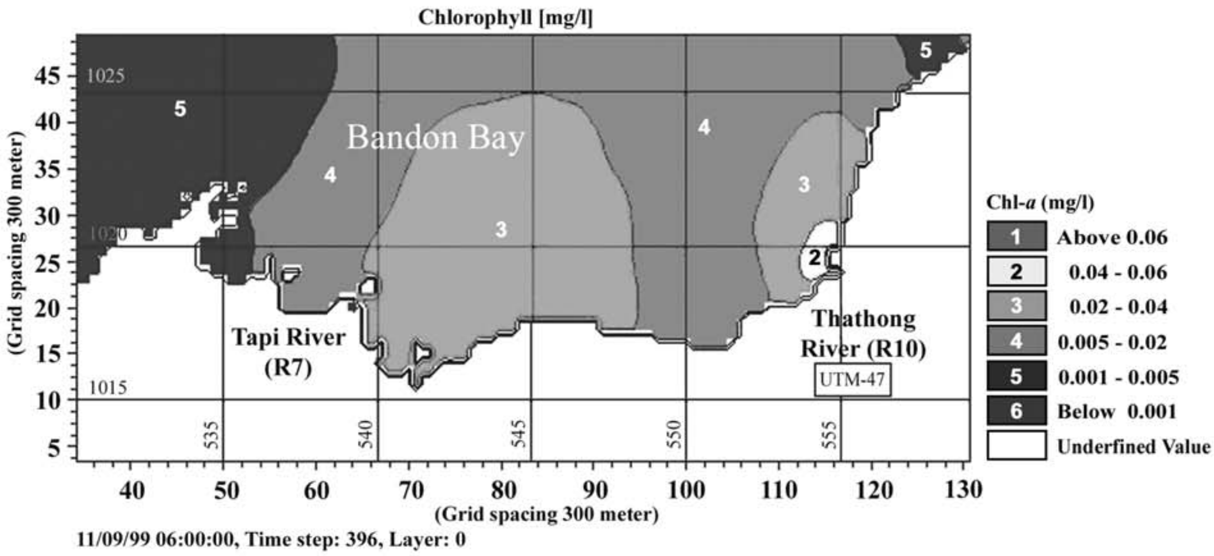


Figure 9. Simulated Chl-*a* distribution during spring tide, November 1999.

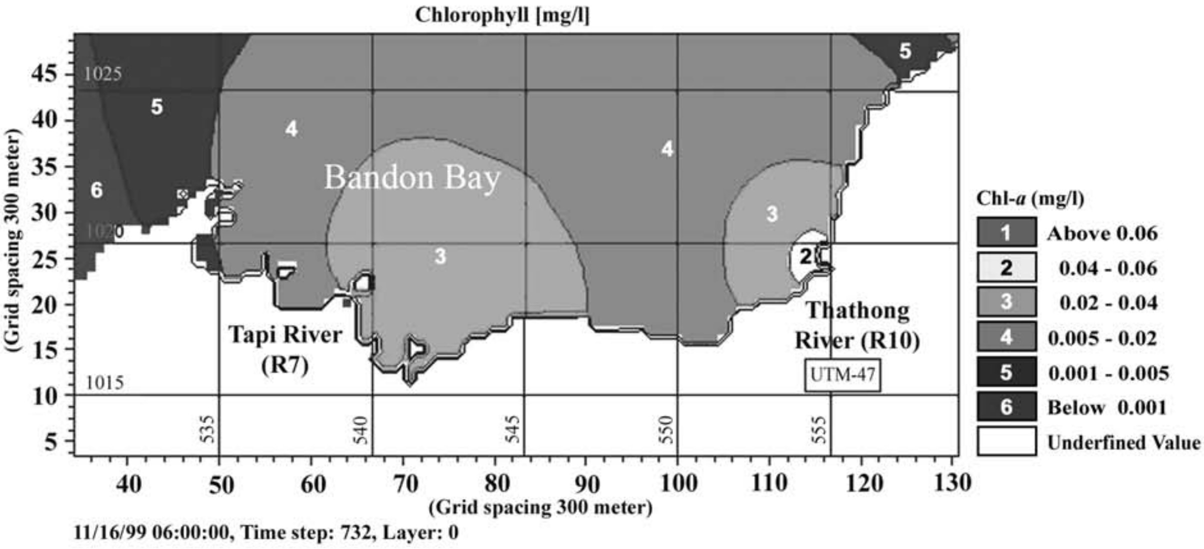


Figure 10. Simulated Chl-*a* distribution during neap tide, November 1999.

## Chl-*a* concentration reduction in mollusc culture area

Since the observed data of Chl-*a* concentration inside the mollusc culture area were relatively low compared to the outside area, the difference between simulated and observed values was used to evaluate Chl-*a* content reduced by molluscs in the culture area as shown in the following equation.

Where

$\text{Chl-}a_{red} = \text{Chl-}a_{sim} - \text{Chl-}a_{obs}$

$\text{Chl-}a_{red}$ = Reduced Chl-*a* concentration

$\text{Chl-}a_{sim}$ = Simulated Chl-*a* concentration

$\text{Chl-}a_{obs}$ = Observed Chl-*a* concentration

Chl-*a* concentration in Bandon Bay and the mollusc culture area were simulated to evaluate its concentration and distribution during the time when shrimp farming effluents were discharged to Bandon Bay. The modeling results showed that the simulated Chl-*a* concentration in November ranged from 11.5 – 37.5 $\mu g\ l^{-1}$ (Table 2). The simulated Chl-*a* concentration in stations near the river mouth (M1, M2, M3, M7, M8 and M9) were higher than in stations located distantly from the river mouth (M4, M5 and M6). Results indicated that the observed values of Chl-*a* concentrations in mollusc culture area, ranging from 2.59 - 4.51 $\mu g\ l^{-1}$, were on the average 72% lower than the simulated values of every sampling station (Table 2). This implies that, assuming the bay water is well-mixed, 72 % of Chl-*a* concentration was reduced by mollusc culture.

Table 2. Simulated concentration and reduction of Chl-*a* in mollusc culture areas during November.

| Mouth | Station | Locations | Chl-$a_{sim}$ ($\mu g\ l^{-1}$) | Chl-$a_{obs}$ ($\mu g\ l^{-1}$) | Chl-$a_{red}$ ($\mu g\ l^{-1}$) | Reduction (%) |
|---|---|---|---|---|---|---|
| November | M1 | River mouth | 22.83 | 2.61 | 20.22 | 88.6 |
| | M2 | River mouth | 24.28 | 2.59 | 21.69 | 89.3 |
| | M3 | River mouth | 25.85 | 3.30 | 22.55 | 87.2 |
| | M7 | River mouth | 21.06 | 3.61 | 17.45 | 82.9 |
| | M8 | River mouth | 30.26 | 3.09 | 27.17 | 89.8 |
| | M9 | River mouth | 37.50 | 3.03 | 34.47 | 91.9 |
| | M4 | Between river mouth | 11.9 | 3.38 | 8.52 | 71.6 |
| | M5 | Between river mouth | 11.59 | 3.02 | 8.57 | 73.9 |
| | M6 | Between river mouth | 11.71 | 4.51 | 7.20 | 61.5 |
| | Avg. | | | | | 71.7 |

Note: Chl-$a_{sim}$ is the simulated Chl-*a* concentration
Chl-$a_{obs}$ is the observed Chl-*a* concentration
Chl-$a_{red}$ is the reduced Chl-*a* concentration

## DISCUSSION

The results showed that MIKE21 model could be effectively used to simulate hydrodynamic and water quality parameters in Bandon Bay. Hydrology module could be used to indicate water level and current of Bandon Bay and the water quality module could be used to determine Chl-*a* distribution in relation to nutrient loading, water discharge and wind conditions in Bandon Bay. The result indicated that the difference between observed and simulated values of Chl-*a* concentration in May, August and November ranged from 8.7 – 27.5 % (Table 1). This is probably due to the fact that only two main canals located at R7 and R10 (Fig. 1) were used for model simulation although there are other small canals scattered around Bandon Bay's coastal area and flowing into the bay. Nevertheless, these differences are acceptable according to Donigian (2000) who pointed out that a difference between simulated and observed values within the range of 15-30% could be classified as the range of good agreement for water quality and nutrient simulation. The main factor that affects the distribution pattern of Chl-*a* in Bandon Bay is nutrient loading from the river and mollusc culture. This result is in agreement with Wattayakorn *et al*. (1999) and Jarernpornnipat *et. al*., (2004).

The results of model simulation in this study indicated that about 72% of Chl-*a* concentration was reduced by molluscs in the culture area. Use of molluscs as a biological filter to remove excessive suspended particles has been studied and evaluated in fish ponds (Shpigel and Blaylock, 1991; Shpigel *et al.* 1993) and shrimp ponds (Wang, 1990; Macintosh and Phillips, 1992b; Jones and Preston, 1996; 1999;

Jones *et al*., 2001; 2002). It is recognized that oyster biofiltration accounted for most of the decreases in turbidity, Chl-*a*, total suspended solids (TSS) and settleable solids (Kinne *et al*., 2001). Due to the high ability of molluscs to filter phytoplankton, therefore it is possible to find that approximately 72% of Chl-*a* concentration in mollusc culture in Bandon Bay was reduced. A similar value was also found by Jones *et al*. (2002) who reported that about 61% of Chl-*a* concentration in effluent of a commercial *Penaeus japonicus* (Bate) shrimp farm was reduced by oysters (*Saccostrea commercialis*, Iredale and Roughley). According to modeling results, the average Chl-*a* concentration in mollusc culture area was 21.89 $\mu g\ l^{-1}$ and about 72% (15.76 $\mu g\ l^{-1}$) was reduced by mollusc culture

The results reflect 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. However, as filter feeders also consume bacteria and other detritus particles apart from plankton, it would be difficult to demonstrate direct correlation between qualitative and quantitative characteristics of phytoplankton and somatic production of molluscs (Sarà and Mazzola, 1997). Mollusc culture plays a significant role in nutrient cycling in coastal systems, as nutrients stored in the cultured biomass are removed by farmers. It has a large capacity to filter water, directly altering concentrations of the seston in the surrounding water (Bayne *et al*., 1989; Dame, 1993; 1996; Jørgenson, 1996; Smaal *et al*., 1997). It has often been suggested that dense mollusc populations exert a strong long-term influence on energy flow at the scale of whole estuaries, bays and coastal systems by controlling phytoplankton and seston concentrations through their filter-feeding activity (Cloern, 1982; Officer *et al*., 1982; Nichols, 1985; Hily, 1991; Smaal and Prins, 1993; Dame, 1996; Dame and Prins, 1998; Prins *et al*., 1998). The trophic conditions in coastal areas could affect mollusc growth (Sarà and Mazzola, 1997). Meanwhile shrimp effluents can accelerate phytoplankton production.

The results of this study imply that nutrient loading from river runoff and shrimp farming has a positive impact on mollusc culture in Bandon Bay. Mollusc culture can be used to control eutrophication in Bandon Bay effectively since it has a shallow depth and stratification has not occurred due to the water in the bay is well mixed. On the other hand, removal of phytoplankton or nutrients from the system through mollusc harvest may help to alleviate some of the eutrophication problem. The results of this study confirm that mollusc culture is a good coastal aquaculture activity which can be used as a biological treatment to treat polluted water due to the mollusc's capability to filter phytoplankton and detritus (Shpigel and Blaylock, 1991, Tookwinas *et al*., 1998, Jones *et al*., 2001). This could also increase coastal aquaculture profitability, producing seed (Jara-Jara *et al*., 1997) and edible biomass (Mazzola and Sarà, 2001). However when mollusc culture is applied to control eutrophication in waterbodies, water stratification and mixing of water column should be considered (Pomeroy *et al*., 2006). In addition, although molluscs are efficient in removing planktons, the bulk of nutrients and biomass are returned to the adjacent water in dissolved forms and fecal material (Cloern, 1982; Cranford and Hill, 1999; Tanyaros, 2001) therefore stocking of molluscs should be carefully planned. Intensive mollusc culture can lead to large-scale growth reduction and high mortalities of molluscs in the Bay. For example, reduction in growth and high mortality were observed in Mutsu Bay, Japan when large biomass of scallops was cultured (Aoyama, 1989).

The Thai Department of Fisheries reported in 1999 that the main mollusc culture area was located only in Kanchanadit district. It implies that, during this study period, shrimp -mollusc integration might have occurred only in Kanchanadit district. According to observed data, beside Tapi river mouth (R7) and Klong Thathong (R10) where Chl-*a* concentration was high, it was also found that phytoplankton was available at the river mouth areas of Thachang (R5) and Phunphin (R6) district. However, there was no report indicating whether molluscs were cultured in Thachang and Phunphin districts in 1999. Therefore, these areas could be considered as the potential expansion area for mollusc culture to control eutrophication in the bay. The results agree with the report of Jarernpornnipat *et al*., (2004) who studied sustainable management options of shellfish culture in Bandon Bay.

The results indicate that Phunphin district is a new area that may be utilized for mollusc culture due to availability of phytoplankton. However, since it is located close to Tapi river where freshwater runoff could affect mollusc growth, promoting mollusc culture in Phunphin district is not recommended. Meanwhile, although there was low concentration of Chl-*a* at R2 compared to R5 and R6, and the shrimp culture areas in Chaiya district (R1, R2) were still low there is high potential that shrimp culture area can be expanded. Hence, to maximize shrimp and mollusc culture production in Bandon Bay, Chaiya district is another potential area to expand mollusc culture in Bandon Bay when more shrimp culture area is expanded. This conclusion agrees with the information on mollusc culture in Bandon Bay in 2005 which revealed that the main mollusc culture area in Bandon Bay was not only located in Kanchanadit district as in 1999, but also spread to Thachang and Chaiya district where the area was about 2,639 ha and 1,473 ha, respectively.

## CONCLUSIONS

The simulated and observed results indicated that mollusc farming can be effectively used to recycle the nutrients discharged from rivers and shrimp farms to control eutrophication in Bandon Bay. Modeling can be successfully used to determine Chl-*a* distribution in relation to nutrient loading, water discharge and wind conditions in Bandon Bay. The modeling results showed that Chl-*a* concentration was approximately 72% lower in the mollusc culture area than non-mollusc cultured areas.

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