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Sustainable management of shellfish resources in Bandon Bay, Gulf of Thailand

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Abstract. Bandon Bay (Surat Thani Province) is one of the most productive coastal areas in southern Thailand. The Tapi River and 18 channels are the main sources of freshwater, nutrients, organic matter and sediment to the bay and the loading of freshwater and nutrients provide essential support for the production of phytoplankton in the estuarine ecosystem. Bandon Bay is important as natural spawning, nursery and feeding grounds for shellfish such as oysters, blood cockles, green mussels, short-necked clams, mud crabs and shrimps, and the estuary also serves as an excellent area for mariculturing of shellfish. In fact, oysters and blood cockles cultured in Bandon Bay are now being exported worldwide. However, Bandon Bay is also a textbook example of overexploitation of coastal resources in the tropics including all the derived changes in the estuarial ecosystem with severe socio-economic consequences. Hence, there is an urgent need for setting up an integrated management plan for a sustainable use of shellfish resources in Bandon Bay. The present study attempts to integrate water quality simulation results, socio-economic data and information on existing shellfish resource use in the process of proposing a set of sustainable management strategies for shellfish resources in Bandon Bay. These strategies involve: (1) using water quality modeling to monitor ecological and environmental changes in shellfish culture beds and their natural habitats in the process of setting up a master plan for management of waste water discharge into Bandon Bay; (2) zoning of shellfish mariculture in the coastal area in order to solve conflicts between resource users; (3) setting up a clear system for taxation of mariculture where the revenue may be used for (4) setting up and managing mangrove strips as filters of pollution and sediment around Bandon Bay; and finally (5) it is suggested to form a committee with members representing all relevant stakeholders plus the local government in order to work on resolving the existing and potential future conflicts over resource usage in Bandon Bay. This methodology may be seen as an important contribution towards a Bandon Bay sustainable management approach, based on the principles of integrated coastal zone management because it is science-based and takes into consideration the needs and perceptions of people involved in coastal resource extraction.

Keywords: Coastal resource management; Integrated coastal zone management; Shellfish culture.

Introduction

General

Bandon Bay, South Thailand, is a textbook example of excessive utilization of coastal resources in the tropics including all derived changes that occur in an estuarial ecosystem. The estuary, with its well-developed mangrove forest, formerly served as an important nursery ground and feeding area for juvenile shellfish (oysters, mussels, crabs and shrimps) of great economic importance (Wattayakorn et al. 1999). However, excessive cutting of the mangrove forest along with uncontrolled massive development of mariculture has led to decreasing water quality and problems with sedimentation (Tookwinas & Youngvanisset 1998).

These problems have already been identified and acknowledged to a great extent by the various stakeholders (Tookwinas & Youngvanisset 1998) ranging from traditional fishermen through businessmen (having invested in mariculture) to authorities and politicians who are responsible for providing a sustainable management plan for the common resources present in the estuary. Regardless of the huge environmental problems, Bandon Bay is still a great source of natural and maricultural shellfish (Anon. 1998b).

In Bandon Bay, the Tapi River and 18 channels are the main sources of dissolved nutrients, organic and inorganic particles, with the latter causing sedimentation problems in the bay (Khaonuna 1994). Nutrient loading from the river and channels results in a huge production of phytoplankton which subsequently supports an extensive production of filtrating shellfish such as oysters, cockles, mussels, short-necked clam (*Paphia undulata*), mudcrab (*Scylla serrata*) and white shrimp (*Penaeus merguiensis*) (Boonyubol 1996). Bandon Bay serves as a very important seedbed for short-necked clams, which are harvested directly from nature and no culture activities are currently present (Chindanonda

1991). In 1992, the total harvest of short-necked clams was 10 858 tons with a total value of 850 000 USD and by 2000 it had increased to 14 400 tons with a total value of 980 000 USD (Anon. 2002). Additionally, artisanal fisheries have long played an important role along the coast making Bandon Bay and the Tapi River highly beneficial to the local residents in terms of food supplies, livelihood and environmental quality.

The commercially important mollusc species currently being cultured are oysters *(Crassostrea lugubris, Saccostrea commercialis* and *Crassostrea belcheri)*, blood cockle (*Anadara granosa*), green mussel (*Perna viridis* sometimes referred to as *Mytilus smaragdinus*). *C. lugubris* is the major aquacultural product of Bandon Bay; it is more valuable than *S. commercialis* and on the domestic market it is in great demand for fresh consumption. In 1992, the culture area of *S. lugubris* was 365 ha with ca. 390 farms and a production of 280 tons. In 2000, the culture area had increased to 567 ha with 562 farms producing 1435 tons with a total value of 1.54 million USD (Anon. 2002).

Problem identification

Over time, a whole set of issues has been identified ranging from environmental problems to socio-economic conflicts and conflicts among the stakeholders. Waste water discharge from households and shrimp farms in particular have caused reduction of shellfish production and decreasing water quality in shellfish culturing grounds (Gannarong et al. 2000). Existing management systems have not taken the temporal and spatial variations in discharge from rivers and channels into consideration and there are often conflicts between parties competing for the natural resources. In Bandon Bay's coastal zone, conflict has arisen between brackish water shrimp farmers and the advocates of mangrove forest conservation because shrimp farmers fell mangrove forest for shrimp pond construction (Tookwinas & Youngvanisset 1998). Other conflicts occur over the coastal area between coastal fishermen and aquaculturists. The problems can be grouped as follows.

1. *Environmental problems*. Water quality deterioration, caused by pollution from land-based activities such as waste water discharge from domestic, industrial, agricultural and aquacultural activities surrounding Bandon Bay, is a major concern (Gannarong et al. 2000; Anon. 1998a). These problems have resulted in oxygen depletion and directly affected mollusc culture and disturbed shellfish and benthic organisms in general. In addition, sediment dispersion during harvesting of blood cockles, negatively affects oyster culture in adjacent areas by increasing water column oxygen consumption and by clogging the oysters' gill filaments. Consequently, there is a need to spatially separate the oyster and cockle production zones when formulating an alternative management plan for shellfish culturing.

2. *Socio-economic conflicts*. Since 1986, the Department of Fisheries has introduced mollusc culture to replace artisanal fishing with a motor push-net (Tookwinas & Yongwanisset 1998) and also provided rights for fishermen to occupy a culturing area in the bay of 8 ha per household. The fishermen have to pay 15 USD per ha per year for this right. Initial interest and uptake of this system was excellent. However, after an implementation phase, mollusc farmers have been faced with a variety of problems such as shellfish infrastructure being damaged by heavy flooding and strong storms inside the bay. This brought hardship for farmers because they could not repay investment loans obtained from private agencies at high monthly interest rates. Consequently, outside investors have taken over their rights and are now operating shellfish culturing as profit oriented big business without any concern for the environment or long-term sustainable development of the bay (Rapid Rural Appraisal interview in this study). Local fishermen still have low incomes and are on the poverty line. The conflicts between shrimp farmers and mollusc farmers are also relevant in terms of socio-economic conflicts, because shrimp farmers traditionally have more economic power.

Bandon Bay needs a strategic management plan in order to achieve sustainable shellfish production in the bay. Unfortunately, an appropriate tool based on integrated coastal zone management (ICZM) principles is unavailable (Anon. 1992). Therefore, this paper attempts to contribute towards a more integrated approach by suggesting a zoning plan for coastal activities in Bandon Bay. The new zoning is science-based, as well as based on the perceptions of the involved stakeholders. A mathematical model served to identify areas of high nutrient loading suitable for filter feeders whereas a mixture of RRA = Rapid Rural Appraisal and PRA = Participatory Rural Appraisal approach, serves to identify interests and conflicts of the stakeholders involved in coastal resource utilization.

Methods

Conceptual framework

This study is based on the conceptual framework outlined in Fig. 1. As part of sustainable management strategies for shellfish resources in Bandon Bay, Gulf of Thailand, a mathematical model called MIKE 21 (Anon. 2000), was used for predicting water quality changes. The model was calibrated with existing monitored data of physical and ecological parameters (see later) and various scenarios were run to simulate freshwater discharge and pollution loading from the Tapi River and surrounding areas into Bandon Bay, on key parameters relevant to shellfish culture and quality. The objective of such simulations was to adjust current regulations if some parameters, for example fecal coliform bacteria, did not meet the standard for safe shellfish production in Bandon Bay. In addition, other parameters such as nitrate and phosphate, could be used to predict areas of local phytoplankton. By linking model simulations with socio-economic data, a more sustainable zoning plan can be developed for the area, taking into consideration the perception of local people and thereby reducing some of the current conflicts over coastal resources.

The study area

Bandon Bay (9°12' N; 99°40' E) is located in the Surat Thani Province, Southern Thailand (Fig. 2). From the Chaiya District in the west to the Don Sak District in the east, it covers an area of ca. 1070 km^2. The bay is exposed to the monsoon weather with northeast winds from November to April; from May to October a southwest wind prevails. There are two pronounced seasons: a dry season, from January to April with less rainfall and high evaporation rates, and a wet season lasting from May to December with higher rainfall and lower evaporation rates. From January to March, surface currents flow counter-clockwise in circular patterns, while from April to December, the surface currents flow southwards (Wattayakorn et al. 1999). The inner bay from the Chaiya District to the Kanchanadit District covers an area of 480 km^2 with 80 km of coastline and only ca. 20 km^2 of mangrove swamps remains in Bandon Bay. The coastal area has a gradual slope and the water is shallow with a mean depth of 2.9 m varying from less than 1 m to 5 m near the bay mouth. The tidal system is a mixed type with principally a semi-diurnal tide. Tidal amplitudes range from ca. 0.7 m at neap tide to ca. 1.9 m at spring tide with an average of 1.0 m. Due to high sedimentation in the bay area, a broad band of mud flats extends along the coast to about 2 km off shore (Wattayakorn et al. 1999).

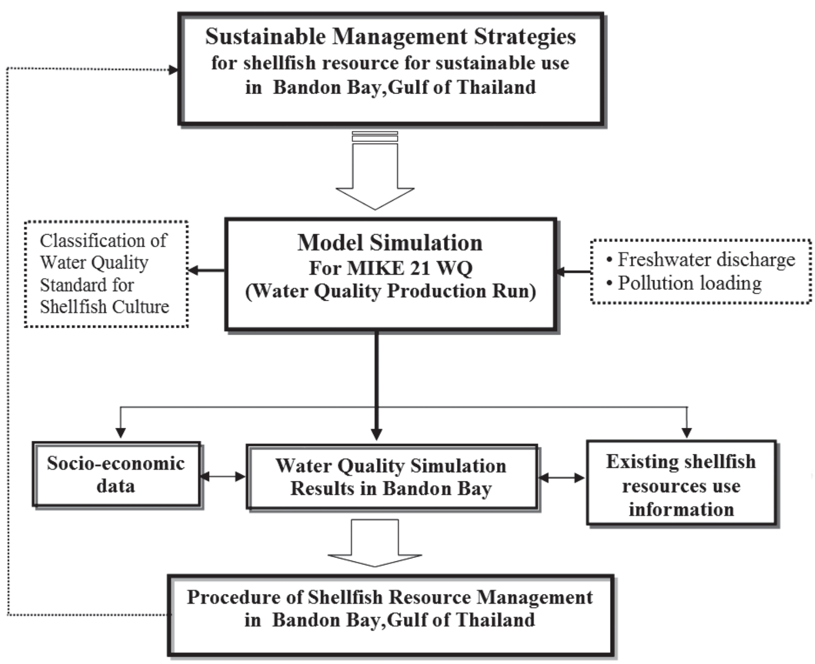

Fig.1. Conceptual framework of this study. The linking of existing physical and ecological data was used to calibrate and validate a mathematical model. By using this model, effects of pollution loading and freshwater discharge into Bandon Bay on key parameters relevant for shellfish culturing and quality were forecasted. Linking this information with socio-economic data and existing shellfish resource use with water quality monitoring should form the basis of an alternative management strategy plan.

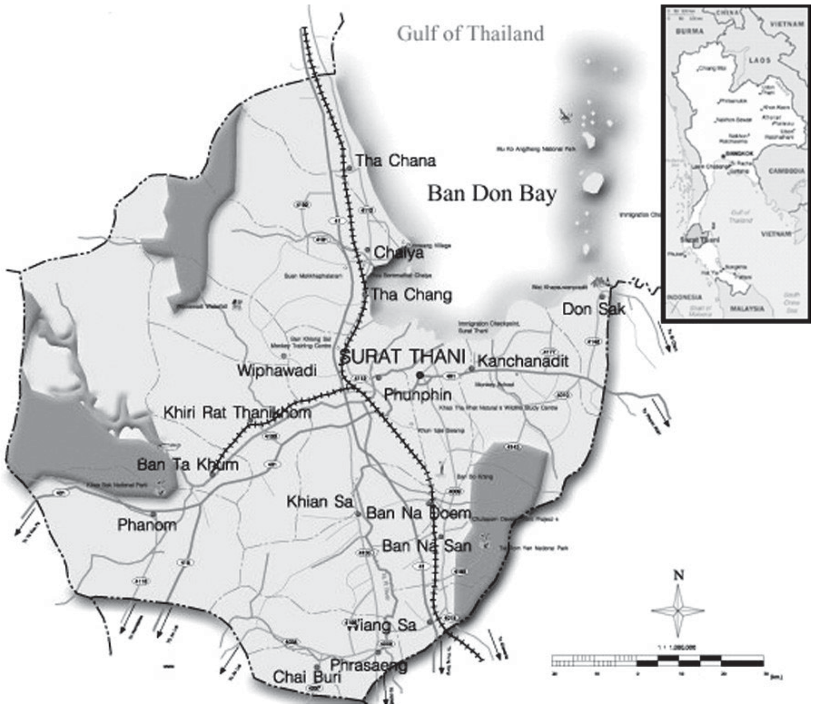

Fig. 2. Map of the coastal zone of Thailand. The coastal zone of Thailand encompasses 2600 km of coastline. The Gulf of Thailand is situated between 5°- 13° N and 99°- 106° E, opening to the South China Sea. Bandon Bay (9°12' N and 99°40' E) is part of the Gulf of Thailand which is in the upper South of Thailand in the Surat Thani Province.

Water quality modeling study

Water quality models were used to investigate environmental problems connected to pollution sources such as domestic and industrial waste water, riverine inputs and agricultural run-off. MIKE 21 is a professional engineering software package containing a comprehensive modeling system for 2D free-surface flows (Anon. 2000), and was selected as a suitable tool for a water quality modeling in Bandon Bay. The model simulates the resulting concentrations of bacteria threatening bathing water and shellfish production quality, oxygen depletion due to the release of material with a high biochemical oxygen demand (BOD), concentrations of nutrients (ammonium, nitrate and phosphate) and various chemical substances of interest to environmental management of Bandon Bay. The included processes, which influence these concentrations, are functions of the environmental conditions e.g. light intensity, water temperature and salinity. The water quality module (WQ Module) solves a system of differential equations describing the physical, chemical, and biological interactions involved in the survival of bacteria, oxygen concentration and levels of nutrients in coastal areas. As a basis for the description of the water quality conditions, the Advection-Dispersion Module (AD Module) calculates the water salinity and temperature. MIKE 21 is also applicable for simulation of hydraulic and related phenomena in estuaries, bays, coastal areas and seas where stratification can be neglected (Anon. 2000). This important criterion is met in Bandon Bay due to the shallow depth of the bay and the wind exposure. The package consists of a number of modules and depending on which water parameter is investigated, the relevant MIKE 21 module(s) may be selected. Generally, for the purpose of water quality modeling, three main modules are required: the Hydrodynamic (HD), the Advection-Dispersion (AD) and the Water Quality (WQ).

The HD Module simulates the water level variations and flows in response to a variety of forcing functions in estuaries and coastal areas. The water levels and flows are resolved on a rectangular grid covering the area of interest when provided with the bathymetry, bed resistance coefficients, wind field and hydrographic boundary conditions. The hydrodynamic input data (water level, bathymetry and wind velocity) used for model calibration were obtained from the Hydrographic Department, Royal Navy of Thailand and Meteorological Department. The bathymetry was established by digitizing navigation map chart No. 227 HD showing depth contours.

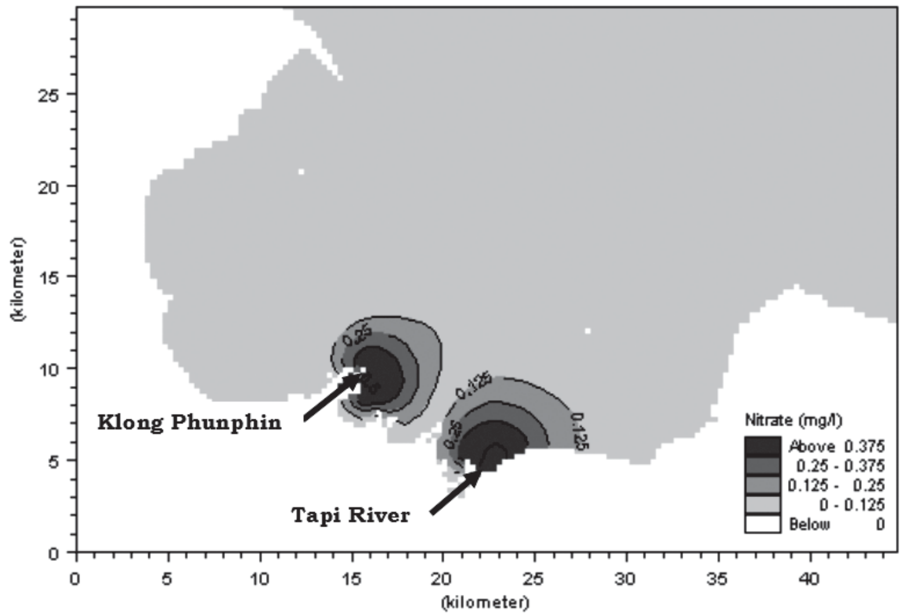

Fig. 3. Nutrient (nitrate, mg/l) load dispersion in the wet season. The figure shows concentrations 200 hr after discharge at arrow points (Tapi river mouth and Klong Phinphin mouth). During the wet season, discharge from Tapi River is very high and the wind direction is from the west. Consequently, nutrient load dispersion moves to the right of the Tapi River mouth in Kanchanadit area. These inputs trigger phytoplankton growth which is responsible for new primary production.

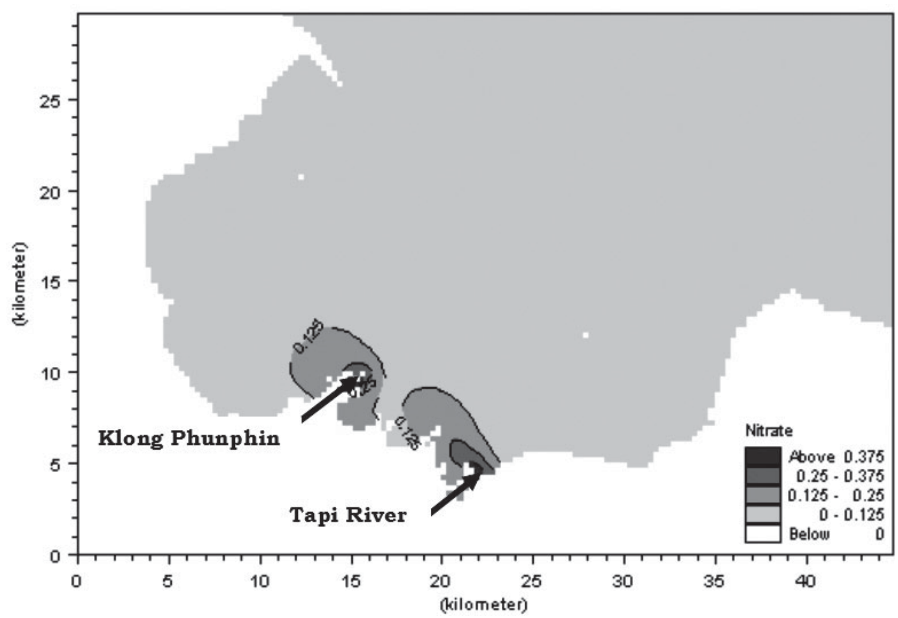

Fig. 4. Nutrient (nitrate, mg/l) load dispersion in the dry season. The figure shows concentrations 200 hr after discharge at arrow points (Tapi River mouth and Klong Phinphin Mouth). During the dry season, discharge from the Tapi river is very low and wind direction is from the east. Consequently, nutrient load dispersion moves to the left of the Tapi River mouth in the Tha Chang area.

With respect to boundary conditions, the model consists of a series of three nested grids from a simulated model by Gansungnoen (2000). The course grid (grid spacing of 9000 m), represents the entire Gulf of Thailand. Results from this grid provide boundary conditions to the medium grid (grid spacing of 1000 m) and results from the medium grid were subsequently applied to a fine grid, which had a grid spacing of 300 m that represents only Bandon Bay. This grid was formatted into the Mike 21 system.

At the model boundaries, the tidal constituents required, were those representing tidal variations in the bay and data were recorded at Ko Prap for model calibration. A time step of 90 seconds was applied to each model grid together with an eddy viscosity of $2\ m^2.s^{-1}$. The Chezy coefficient in the model was $30\ m^{1/2}.s^{-1}$. Several simulations during the calibration procedure suggested that the model boundaries of the Hydrodynamic module should be based on tidal constituents for Bandon Bay only and not the entire Gulf of Thailand.

For the Water Quality module, suitable dispersion coefficients are the most important factors for water quality modeling. In previous studies, dispersion coefficients in the Gulf of Thailand varied from 5 to 40 (Anon. 1998b) and the value of $5\ m^2.s^{-1}$ was used for the dispersion coefficients in both X and Y directions for Bandon Bay. Total coliform, fecal coliform bacteria and relevant nutrient concentrations at the open boundaries and sources were obtained from the Department of Fisheries and used for calibration of the WQ module.

Socio-economic data and perceptions of local people

This study attempts to integrate socio-economic aspects with water quality simulation results, and existing shellfish resource use information in order to create management strategies for shellfish resources in Bandon Bay. The socio-economic data of people affected by freshwater discharge and pollution loading to the Tapi River and Bandon Bay was collected in April and October 2001 representing the dry and wet seasons, respectively. The target groups of the socio-economic study consisted of 14 sub-districts located adjacent to Bandon Bay and the sample size of 398 households was ca. 5 % of the total number of households in each sub-district using an approach similar to that of Gajaseni (2000) and De Ruyck et al. (2001). The two questionnaire surveys were undertaken following interviews with respondents from each household and also a reconnaissance visit to each sub-district and village. Each interview took 30-40 minutes and respondents were asked about their main and additional sources of income. The respondents were also asked to list all problems related to coastal resource utilization in Bandon Bay comparing the wet and dry seasons. The respondents were also asked to explain which factors, in their view, were causing the observed problems. Respondents were asked to address more than one problem and give more than one cause. They were also asked about their perception towards sustainable management of the coastal ecosystem. Data were analysed using SPSS software and non-parametric tests were used because these are compatible with nominal data, ordinal data as well as non-normal distribution of continuous data.

Results

Water quality modeling

Yearly computed simulations showed that the Bandon Bay ecosystem is primarily affected by hydrological and meteorological forces, such as water discharge from the Tapi River and wind field. In particular, wind speed and direction, which change between wet and dry seasons, are important factors. During the wet season, fresh water discharge and hence nutrient loading from the Tapi River is very high. Since the prevailing wind direction is from the west, nutrient dispersion moves eastwards of the Tapi River mouth in the Kanchanadit area as shown in Fig. 3. The nutrient input may trigger phytoplankton production in this area of Bandon Bay and the enhanced availability of high quality food may in turn stimulate the production of filter feeding shellfish. During the dry season, freshwater discharge from the Tapi River is low and with easterly winds, nutrients disperse westwards of the Tapi River mouth into the Tha Chang area as shown in Fig. 4.

In addition to nutrient dispersal, the model was used to forecast maximum coliform bacterial loading in order to compare it with domestic and export-based standard criteria for shellfish. It was found that the maximum simulated allowances for coliform bacteria loading to the Tapi River and Klong Phunphin through Bandon Bay, were 15 000 and 10 000 MPN 100 per ml (MPN = Most Probable Number) for domestic and export purposes, respectively (Table 1). For fecal coliform bacteria, the maximum loading should not exceed 15 000 (domestic) and 10 000 (export) MPN 100 per ml. These bacterial loadings should ensure that standards for the domestic and EU market are met during the dry season when dilution of waste water in flood water is insignificant.

Table 1. Maximum allowance for coliform bacteria loading obtained by using MIKE21. According to this simulation, the maximum acceptable loading of total coliform bacteria into Bandon Bay is 15 000 and 10 000 MPN per 100 ml in order to meet domestic and export criteria, respectively. A loading of 15 000 MPN per 100 ml will result in less 1000 MPN per 100 ml in the bay water, which is sufficient to meet the criteria set by local authorities.

Type of coliform bacteria	Criteria of water quality standard for shellfish culture		Maximum allowance for coliform bacteria loading obtained by using MIKE21 (MPN/100ml)	
	Thai Standard	EEC Standard	Thai Standard	EEC Standard
Total Coliform	1000	500	15 000	10 000
Fecal Coliform	1000	300	15 000	5 000

Socio-economic data and local people's perception

Almost 70% of the population living in the Bandon Bay area is involved in fisheries or aquaculture (Fig. 5; further details can be obtained from the authors). 45% of the population are working in fisheries and of these, 83% are traditional artisanal fishers with only 17% involved in trawler or motor push net fishing. However, practically all households had more than one occupation because (1) the main occupation (fisheries) cannot be carried out during the entire year because of a 'no take' period from 15 February to 15 May following regulations from the Department of Fisheries, or (2) the income from the major occupation is insufficient to support the entire family. Additionally, there are significant differences in household incomes between the wet and dry seasons (χ^2 test, $p < 0.001$). Differences are most pronounced in the majority of families relying on fisheries or aquaculture. In particular, during the flood season, aquaculture and fisheries suffer from impacts of riverine outflow, currents and strong winds. Hence, 70% of the respondents had debts in order to meet basic subsistence needs, whilst only 30% had savings.

The majority of respondents (86.6 %) considered that Bandon Bay and the Tapi River are highly beneficial to their livelihood in terms of food supplies, main income or environmental quality. Waste water discharge into the Tapi River and Bandon Bay from the distillery plant and shrimp farms, was considered to be the main cause of aquatic environmental damage in Bandon Bay (Table 2), whereas overfishing was considered less important. Other important factors such as fishing during the spawning season, mangrove deforestation, sophisticated fishing gear and too many fishermen in a limited area were rated as the most important causes of the current state of Bandon Bay by < 20% of the respondents.

Interestingly, when asked about coastal zone management and mitigation of current problems, the respondents ranked and grouped the alternatives as summarized in Table 3. Under policy and planning issues, the set-up of coastal zone zonation for sustainable livelihood was considered much more important than a strategic plan for mitigation of wast water discharge into Bandon Bay, although the same people considered waste water discharge the main cause of the current problems. However, under legal, institutional and ad-

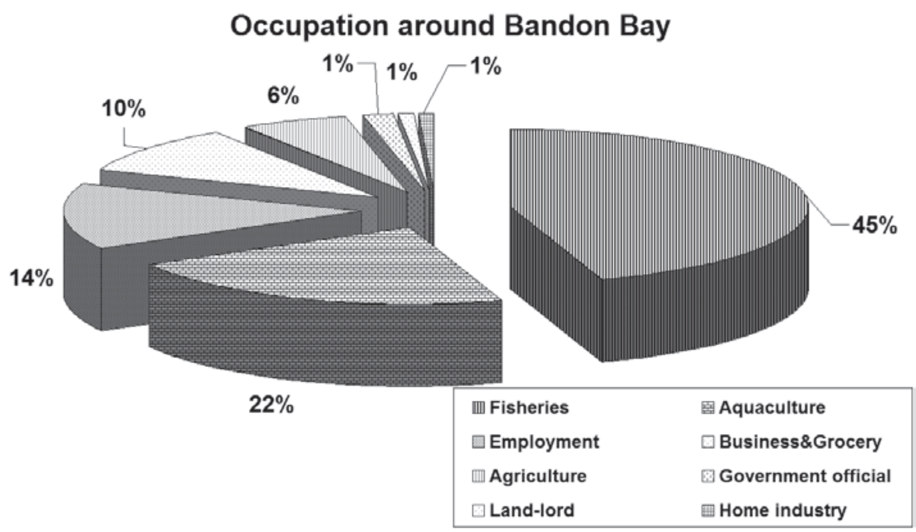

Fig. 5. The main occupation of respondents around Bandon Bay. Fishing and aquaculture are the main occupations for 2/3 of the people in Bandon Bay.

Table 2. The opinions of household respondents concerning the main cause of problems in resource use in Bandon Bay as ranked by 398 household respondents. Results from dry season and flooding season have been pooled. Waste water discharge to the Tapi River and Bandon Bay from domestic households and the distillery plant during flooding time and from shrimp farming all year round were considered to be the main causes of damages to aquatic organisms.

Main cause of problems in resource use in Bandon Bay	% of households
Wastewater discharge to the Tapi River and Bandon Bay	27.7
Overfishing	18.0
Motor push net fishing	14.3
Natural disaster	10.9
Fishing in spawning season	9.4
Mangrove destruction	8.3
Sophisticated fishing gear and using too fine-mesh size nets	7.2
Increasing number of fishers due to increasing of population	2.3
Muro-ami and poison fishing	2.0

ministrative issues, formulation of law and regulations to control wasterwater discharge were considered most important, whereas a monitoring and control program to enforce regulations were considered least important. Finally, under educational and public awareness issues, the encouragement of people to establish cockle farms serving as nursery grounds for aquatic organisms was considered a top priority by respondents.

Sustainable management strategies

This study attempts to integrate water quality simulation results, socio-economic data and information on existing shellfish resource use in order to propose a set of sustainable management strategies for shellfish resources in Bandon Bay. The following should be seen as a response to the fact that most people living around Bandon Bay now realize that an integrated management approach to the economically important shellfish resources is the best option for achieving sustainable development in the area.

Setting up a strategic plan for the management of waste water discharge

One of the major issues in Bandon Bay is pollution of the aquatic environment; in order to guarantee safe shellfish production, the standards of water quality for shellfish culturing must be met. Recently, a master plan for management of waste water treatment in the Surat Thani Province was set up (Anon. 1998a). However, this controls only waste water discharge from industrial plants and not water discharged from domestic households and shrimp farms. Therefore, waste water discharge from these sources must also be included in the master plan for waste water treatment. Furthermore, laws and regulations for control of waste water discharge should be precise and enforcement strengthened. The MIKE 21 model developed in the current study could be an attractive set of tools for the local administration in the process of setting up marginal values for coliform bacteria loading to the Tapi River and Klong Phunphin. The model should guarantee safe shellfish production in Bandon Bay in wet and dry seasons if coliform loading is reduced to the values reported above.

Table 3. Perception of respondents to sustainable management of the coastal ecosystem. When asked about coastal zone management strategies and mitigation, the respondents ranked and grouped them as follows:

Policy and planning issues	Legal, institutional and administrative issues	Education and public awareness	Other issues
1. Set up zonation of coastal zone for sustainable livelihood 2. Set up areas of prohibited fishing for hatching and nursery grounds of coastal animals 3. Set up a master plan for management of wastewater treatment of discharge from shrimp farms 4. Set up a clear system for taxation of mariculture 5. Set up zonation for coastal aquaculture	1. Launch law and regulations to control wastewater discharge 2. Formulate law and regulations to control motor push net fishing 3. Establish coastal zone management organization for local people 4. Formulate a pollution monitoring and control program to enforce regulations for factories	1. Encourage people to establish cockle farms to serve as nursery ground for aquatic organisms 2. Educate and train local people in order to develop a sense of ownership in the coastal zone 3. Provide knowledge and alternative sources of income for fishermen and local people 4. Provide additional occupational training to local people in closed-fishing period for their alternative sources of income	1. Provide financial aid for mollusc-culture farmers when experiencing disaster from storm, flooding or an other natural event

Setting up mangrove strips as pollution and sediment filters

Almost all mangrove forest surrounding Bandon Bay has been cleared for shrimp pond construction (Tookwinas & Youngvanisset 1998) and waste water from shrimp farms, discharges directly into the bay without prior treatment. Mangroves are known to effectively trap both suspended particles and dissolved nutrients (Hogarth 1999) and mangrove forests and waterways have long been used as convenient sites for disposal of sewage and waste water in tropical countries (Boto 1992). Therefore, setting up mangrove strips as primary filters of pollution and sediment is an urgent approach for managing shellfish resources in Bandon Bay. It is proposed that the National Agreement of the Cabinet passed in 1987 entitled 'Mangrove forest classification of Thailand' (Charuppat 1998), mentioning that a conservation zone of mangrove forest must be at least 75 m wide measured from the coastline, be followed. In order to maximize the sustainability of the mangrove strip, local people should be involved in the planning process, and implementation/monitoring and evaluation as outlined in the 1997 Constitution of the Kingdom of Thailand. Since the mangrove strip is also likely to serve as general nursery ground for oysters, cockles, mud crabs and fishes, an organized group of people relying on these natural resources as their major source of income, may prove sufficiently strong to conserve and maintain the mangrove.

Setting up a clear system for taxation of mariculture Collection of taxes to grant the right for exploitation and use and enjoyment of coastal resources for mariculture around the coastal area must be regulated by laws or regulations to ensure equal access. Currently, the rate of tax payment has been set at 15 USD per ha per year for shellfish culturing in Bandon Bay (Kanchanadit District Fisheries Offices, personal communication) but it is not clear how the revenue has been distributed. Transparency in the distribution of these taxes is definitely required in order to maintain the incentive for paying such fees. Currently, many mariculture farmers are not paying the required fees, but the incentive would probably increase if the revenue was channelled back into the coastal area and used for establishing and managing the mangrove strips mentioned above.

Resolving stakeholders conflicts and overlaps

In order to resolve problems related to conflicts and overlaps in responsibilities and to reduce the gaps among stakeholders in accordance with the principles of integrated coastal zone management (Olsen et al. 1999), it is necessary to establish cooperation among relevant organizations in both government and non-government agencies. A committee should be formed and members should include representatives from all relevant stakeholders plus the local government in Bandon Bay. This committee should carry out the tasks required to manage the shellfish resources in a sustainable way. The process of planning through implementation, monitoring, and evaluating should be clear when this committee raises the issue of stakeholders analysis and responsibilities analysis. Regarding decentralization, the local government must be the principle instigator in pursuing and carrying out tasks since it is the lowest administrative organization in Bandon Bay. The local government should also act as a link between local stakeholder organizations and the central government to ensure smooth running of policy implementation.

Zoning of aquaculture

In order to set up a successful zoning plan for shellfish culture, it is necessary to use relevant information on the ecology of the cultured species and link this to the physical and social environment of Bandon Bay. Tookwinas et al. (1985b) suggested that the coastal region of Thailand could be zoned for mollusc culture purposes as follows:

1. Suitable areas for oyster culture should be near river mouths. The area must be protected from strong winds and wave action during storms and the water must contain adequate nourishment to sustain a sufficient plankton production acting as food for the oysters. Water depth should be between 1 and 2 m;
2. Suitable areas for cockle culturing should be near the mouths of channels or along the coastlines with salinity around 13 ‰. In addition, it should be shallow (1 to 2 m) and wind-sheltered bays with a river or channel in order to support the cockles with sufficient organic particles to feed on;
3. Green mussels should be cultured near the coastline or river mouths where phytoplankton production is high with suitable species. The water depth is less critical and could be anything between 1 and 4 m.

By integrating the literature information on existing resource utilization and previous and current zoning (Chindanonda 1991) with the findings of this study, the authors propose a zoning plan for aquaculture in the Bandon Bay area as shown in Fig. 6. In essence it is suggested to set up three different zones of shellfish culturing; oyster culturing areas, blood cockle culturing areas and green mussel culturing areas. A relatively large area in front of the mouths of the Tapi River and Klong Phunphin should be kept free from mariculture activities because this area is subject to heavy sedimentation, strong currents and wave action. Boat traffic is also heavy in the area and oil spills common. This area receives ca. 1.3 million tons of sediment per year from the Tapi river basin and in addition, the existing navigation channel, subjected to a sediment deposition of 100 000 tons per year, is usually dredged every five years (Vongvisessomjai et al. 1975). In addition, the 10 km wide area allocated for traffic purposes serves to alleviate the ongoing conflicts between blood cockle farmers and oyster farmers in particular. The latter group claims to suffer from re-suspended sediment particles in the water column during cockle harvesting and the hydrodynamic model developed in this paper shows that the suggested buffer zone between the two principally different mariculture activities is sufficiently wide to protect oyster farmers from re-suspended sediment.

It is suggested that the huge area (more than 50 km^2) west of Kong Phun Phin, be utilised for blood cockle production. This area is subject to high natural sedimentation and the substrate is muddy and rich in organic particles making it very suitable for cockle production. This area may also support traditional artisanal fishing activities on, for instance, swimming crabs, short-necked clamp and sea catfish.

The area northwest of the Tapi River mouth, could be allocated for green mussel production purposes. As indicated in Fig. 3, the developed model predicts that this zone receives much of the nutrients delivered by the Tapi River and this area should be able to support a significant plankton production, to act as suitable food for green mussels. The area is primarily delimited by the forecasted plankton production but exposure to wave action and wind is also considered. The latter is the reason why the area allocated for green mussel culture does not extend to the 4 m contour line as suggested by Tookwinas et al. (1985), since the sea is too rough for

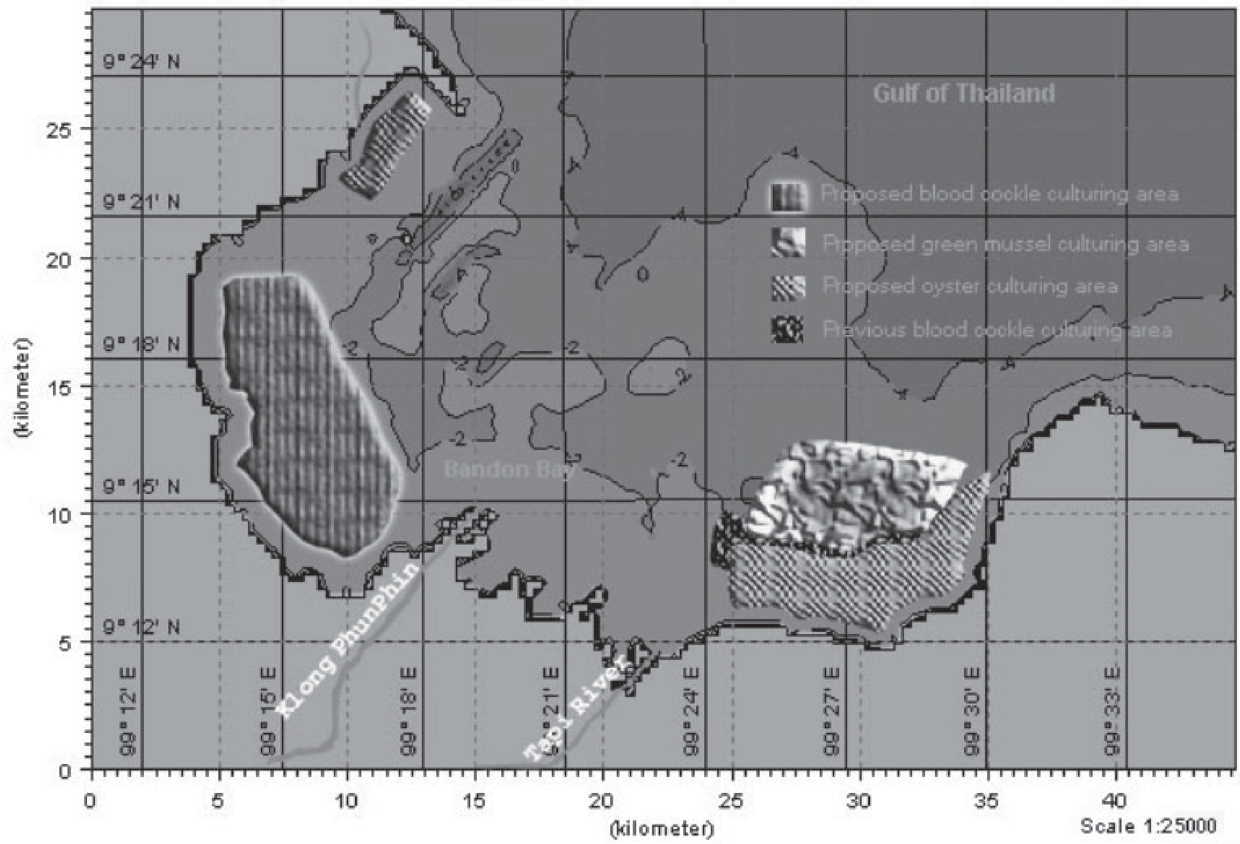

Fig. 6. Proposed coastal zoning for shellfish culture areas in Bandon Bay based on the hydrography of Bandon Bay, predictions of the MIKE21 model, the socio-economic survey, and current usage of the area. The area north-east of the Tapi River mouth in Kanchanadit district is presently used to culture oyster and blood cockle together without any zoning. This has caused conflicts during blood cockle harvesting due to re-suspension of sediment, which disturbs the oysters.

mariculture activities beyond the 4 m contour line.

Finally, it is suggested allocating the area just south of the green mussel culture area for oyster production. This area is within the 2 m contour line but still receives a significant amount of nutrients from the Tapi River which should be able to support the necessary plankton and bacteria production acting as food for the oysters.

Conclusions

An Integrated management approach for shellfish resources in Bandon Bay is needed in order to guarantee a source of income for local people and to allow long term sustainable exploitation of natural shellfish resources. The high quality and the unique taste, which have made shellfish of Bandon Bay famous, provide high incomes from the export market which must be taken into consideration. This paper has integrated various scenarios of water quality simulation, socio-economic data and existing shellfish resource use information, in order to propose sustainable management strategies. These strategies involve: (1) using water quality modeling to monitor ecological and environmental changes in shellfish culture beds and their natural habitats in the process of setting up a master plan for management of waste water discharge into Bandon Bay, (2) zoning of shellfish mariculture in the coastal area in order to resolve conflicts between resource users, (3) setting up a clear system for taxation of mariculture where the revenue may be used for (4) setting up and managing mangrove strips as filters of pollution and sediment around Bandon Bay, and finally (5) a committee should be formed with members representing all relevant stakeholders plus the local government in order to work on resolving the existing and potential future conflicts over resource use. Applying these strategies, encouraging stakeholder participation and raising awareness of coastal resource issues will ensure sustainable development in Bandon Bay.

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