Integration of fed and extractive aquaculture

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INTEGRATION OF FED AND EXTRACTIVE AQUACULTURE

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INTRODUCTION

Integration of the fed and extractive components is an approach to aquaculture that seeks balance to protection of the environment and increasing total production. Our human tendency is focus only on high value and high production aquaculture. When an innovative aquaculture succeeds everyone adopts that system and concentrates aquaculture in areas were it was successfully. Aquaculturalists then strive to increase production by intensifying the system. This usually evolves into high-density monoculture systems. Such an approach to aquaculture leads to deterioration of environmental quality. Disease outbreaks made more virulent by the high density of organisms and by stressful environmental conditions. In pond aquaculture, the aquaculturist monitors and is responsible for balancing production with environmental conditions. When aquaculture moves to the public waters, such as Jiaozhou Bay or Xincun Bay, the aquaculturist does not control the situation and the primary responsibility of maintaining a balance between the environment quality and aquaculture production usually shifts to a government resource management agency. In bays aquaculture is rarely the only user of the resource, and management agencies are faced with competing demands. Integrating the resource uses in not an easy task. Managers must use an approach of integrated coastal management (ICM) and must have the scientific tools to understand the impacts of various resource uses. The 3-dimensional models offer such a tool for integrating the impacts of human activity and natural environmental processes on an embayment.

In this paper we will focus on how fed and extractive aquaculture can be integrated to reduce the impacts of aquaculture.

The first step in integrating aquaculture is to determine a body of water's capacity to sustain aquaculture. Carrying capacity is the interaction of physical, chemical and biological factors. Eutrophication becomes a problem when the input of organic matter and inorganic nutrients beyond moderate levels. In some situations moderately eutrophic conditions improve the basic productivity; however, humans rarely can determine the optimum conditions or stop the process of eutrophication. As organic matter and nutrient inputs increase, the capacity to support water-related activities is reduced. First, eutrophication resulting from pollution that adds to natural nutrient transport processes. In excessive amounts, nutrients become a serious threat to coastal waters. The growing number of toxic algal blooms and oxygen hypoxia events are often the result of eutrophication, but these environmental catastrophes are only symptoms of a more serious problem. Aquaculture's future success depends on abundant and clean water; thus, the industry is more threatened by extreme eutrophic conditions than any other water use. Second, extractive aquaculture (bivalve mollusk and seaweeds) that removes plankton and nutrients from surrounding waters can have a significant positive impact on moderately eutrophic waters. In fact, these species require moderate nutrient levels from natural (Blanton *et al.* 1987) to maintain planktonic productivity from which they secure their food and inorganic nutrients for their growth. Without moderate levels and appropriate types of nutrients and plankton species, the extractive aquaculture species cannot thrive. Third, fed aquacultures (shrimp and finfish) that depend on supplemental feeding to grow out their products contribute to eutrophication and should be balanced with extractive aquaculture species. The question is how can carrying capacity of an abayment be managed to create a balance between extracting aquaculture, fed aquaculture systems and other human nutrient inputs (Rawson *et al.* in press).

In this paper , we will use a two joint Sino-US Living Marine Resources Panel approved studies of Jiaozhou Bay and of Xincun Bay to explore how integrated aquaculture could benefit water quality and total production.

Jiaozhou Bay Study

Jiaozhou Bay is a shallow semi-closed bay adjacent to the Yellow Sea (YS) in the northeastern Province of Shandong, People's Republic of China. The bay's area is ~400 km^2 with an average depth of 7 m and maximum depth over 50 m in the strait to the YS. The bay has an extensive intertidal zone in its northwest quadrant. Tidal amplitude ranges from ~120 cm at the entrance to ~130 cm near the northeast shoreline. Average tidal current is >15 cm s^{-1} with a maximum of 150 cm s^{-1} at the bay's entrance. The bay is dominated by a southerly or southeasterly wind in the spring and summer and by a northerly or northwesterly wind in the fall and winter (Figure 1). Average wind velocity is ~5 m s^{-1} in summer and ~7 m s^{-1} in winter (Zhao *et al.* 1995). Freshwater input is primarily from six major rivers whose total maximum discharge is 135 m^3 s^{-1}. The largest river, the Dagu River, accounts for >80% of the freshwater flow and is located on the west side of the bay (Chen *et al.* 1999).

The ecology of Jiaozhou Bay has changed dramatically over the last three decades as a result of increased industries, aquaculture, agriculture and domestic sewage (Liu 1992). Annual average concentrations of total inorganic nitrogen and phosphates increased from 1.2 and 0.14 mmol L^{-1}, respectively, in 1962-63 to 10.4 and 0.45 mmol L^{-1} in 1992. During the same period, the ratio of total inorganic nitrogen to phosphates shifted from ~10 to 24.2 in 1992. Nitrogen, that was the limiting factor in growth of phytoplankton, has given way to a phosphorus-limited ecosystem (Shen 1995). Light intensity, water temperature, turbidity and the continuing input of nutrients from rivers also contribute to phytoplankton productivity that reaches a peak in summer with chlorophyll *a* readings of 0.37 to 9.5 mg m^{-3}. The highest levels are in the northwestern bay, where the Dagu River is located, and the lowest is at the entrance to the bay. Similarly, total primary productivity ranges from 33.60 to 2145.45 mg C m^{-2} d^{-1} with the highest values near the northern coast during summer.

During the study, aquaculture of two scallop species (Chlamys farreri and Argopecten irradians) in suspended nets was the dominant production system along with bottom-cultured clams. These areas occupied 50 km^3, about 1/8 of the bay (Collaudin 1996). The annual production of aquaculture scallops during the study period was ~40,000 tons (fresh total weight). The major clam species, Ruditapes philippinarum, cultured in the intertidal and subtidal northern part of the bay, produces ~ 70,000 tons (fresh total weight) annually (Chen et al. 1999).

The pronounced increase in nutrients in Jiaozhou Bay has caused serious environmental problems. The frequent occurrence of harmful algal blooms and the increased mortality rates and decreased rates of growth of natural and cultured organisms is evidence of the seriousness of the ecological problem. A 3-dimensional model allows us to simulate the physical and biological processes and predict where eutrophication may become a problem or where aquaculture could have positive or negative impacts on the environment. The coupled biological model simulates simple nutrients (N), phytoplankton (P), and zooplankton (Z) using a modified model developed by Franks and Chen (1986). The biological parameters varied widely in time and space. The model was run with an initial set of parameters. Sensitivity analyses were then run over the parameter range. The stock density of shellfish was calculated directly from measurements taken in Jiaozhou Bay in 1996 (Collaudin 1996). The scallop rafts consist of vertical lines of lantern nets. Simulation experiments were made with two scallop stocking densities of 12 individuals m^{-3} (0.012 individuals L^{-1}) in the first case, and 24 individuals m^{-3} in the second case. In both cases, scallop grazing dramatically decreased concentrations of phytoplankton in the culture area (Figure 2). The experiments suggested that the scallops would sharply reduce the concentration of phytoplankton 0.99 μg Chl *a* L^{-1}in A1, 0.52 μg Chl *a* L^{-1}in A2 and 1.0 μg Chl *a* L^{-1}in A3, about 31.8%, 33.3% and 37.3% lower than those in the case without shellfish (Figure 1). The response of phytoplankton to increased shellfish stocking densities was not linear. When the stocking density was doubled to 24 individuals m^{-3} the concentrations decreased to 0.71μg Chl *a* L^{-1}in A1, 0.38 μg Chl *a* L^{-1}in A2 and 0.67μg Chl *a*L^{-1}in A3. These concentrations were ~51.1%, 50.8% and 55.6% lower than the case without shellfish, but only 19%, 18% and 22% lower than the first case with shellfish (Chen *et al.* 1999).

The impact of scallop culture on the concentration of nutrients was very small, even at the higher stocking density. This is in contrast to previous studies which indicated that shellfish have an important role in nutrient cycling and distribution (Dame 1993). One explanation is that the model did not consider the impact of the biodeposition process of shellfish. The biodeposition process could result in shellfish taking up small particulate organic matter and producing feces and pseudo-feces that decompose into inorganic nutrients. Our model did include shellfish excretion, which was directly converted to phosphates. If the above explanation is correct, there should be significant modification of nutrient concentrations when the excretion rate or stocking density is increased. However, that was not the case in simulation experiments. Another possible explanation is that most of the phosphates in Jiaozhou Bay were the result of loading from the land and rivers. The recycling of nutrients by shellfish may directly influence the concentration of nitrogen but not phosphates, or the nutrient regeneration rate may be orders of magnitude smaller than the nutrient loading rate from other sources.

The model results revealed that physical processes had a direct impact on temporal and spatial distributions of nutrients and phytoplankton as well as on shellfish aquaculture. Tidal mixing caused physical and biological variables to be well mixed vertically. The concentrations of nutrients and phytoplankton were high near the northwestern and northern coast near river sources but decreased from the inner bay to the outer bay. The model results suggested that prevailing river discharges and tidal mixing, and the southeasterly wind in the summer might cause unusual nutrient accumulation and lead to phytoplankton blooms in the innermost bay. The fact that a phytoplankton bloom can occur under a condition of southeasterly wind implies that physical processes may have a direct impact on the occurrence of "red tide" along the northern coast of Jiaozhou Bay. The overloading of nutrients from inland shrimp aquaculture, industries and other urban human activities caused a high nutrient concentration in the inner bay that provided favorable conditions for eutrophication. Accumulation of nutrients due to the southeasterly wind speeds up the eutrophication processes and contributes to the likelihood of "red tide".

The estimation of nutrient and phytoplankton fluxes in the five identified sites suggested that physical processes controlled the nutrients, while the phytoplankton was controlled predominantly by biological processes. The loss of phytoplankton in shellfish aquaculture sites was compensated by nutrients that advected and diffused from surrounding waters. High levels of phytoplankton consumption also caused a net flux of phytoplankton into the bay from the YS, even though nutrients were advected out of the bay. In addition to eutrophication caused by human activities, high densities of suspended feeding shellfish altered the lower trophic food web by grazing phytoplankton, excretion and biodeposition. Aquaculture populations of bivalves tended to transfer large quantities of materials from the water column to the sediment, which can dramatically change the content of the organic matter in the benthic layer (Kautsky and Evans 1987; Kasper *et al.*, 1985). The benthic processes, in turn, may alter nutrient cycling in the bay (Barg 1992, Dame 1993, and Jorgensen 1990). It also should be noted that this model did not include the extensive intertidal zone. The direct impact of the intertidal process remains unclear, but a large quantity of nutrients potentially can be advected back to the bay during ebb tide. The impact of intertidal process will be the focus of the next phase of this cooperative research program.

Xincun Bay Study

Xincun Bay is a lagoon located on the southeast coast in Lingshui County, Hainan Island (110°E, 18°25'N). Xincun Bay has a gourd-shaped basin 6 km long and 4 km wide, covering an area of 21.97 km^2. Maximum depth is 10.6 m, and the bay is connected to the open sea by a single tidal inlet about 120 m wide. People began to cultivate pearl oysters in the bay in the 1970s, and aquaculture has continued to grow in importance. At present fish, shrimp, molluscan shellfish and the macroalga, *Kappaphycus* sp., are cultured over an area of 160 hectares (ha) in the bay. In 1997, the total income of aquaculture was about $7 million in Lingshui County, which is an important mariculture center in the South China Sea fishery region (Marine and Fishery Department of Hainan 1998).

The aquaculture industry in Xincun Bay is dominated by the fish-cage culture systems that are located near the bay's entrance and adjacent to the navigation channel. There are approximately 450 floating cage units consisting of 3 m x 3 m net cages generally configured in a square with three cages per side. Each unit also includes a house with a family (4 – 5 people) and one or two laborers. Several species are grown in the pen from fingerlings, including cobia, local grouper and pompano. The fish are fed 2 to 5% of their body weight/day of ground whole fish from the trawl fishery and nearshore light-net fisheries.

The culture of the macroalga *Kappaphycus* sp. is a relatively new culture system in Xincun Bay. *Kappaphycus* is cultured on suspended lines seasonally from October to April. These rakes occupy a significant portion of the middle area of the bay and are often mixed with pearl oyster culture rafts. *Kappaphycus* sp. segments are tied onto long ropes suspended horizontally within a meter of the surface. This culture system is used extensively in the Lian Lagoon, which is adjacent but not connected to Xincun Bay. In Xincun Bay, production of *Kappaphycus* sp. is increasing and in the 1998-1999 and 1999-2000 season's production was 1,500 and 2,000 tons, respectively.

Shrimp are cultured in 85 ha and production was about 4,500 kg yr^{-1} in 1999, and some of the aquaculture ponds were at the expense of the coastal forest. To date, the major species produced was the Chinese shrimp, *Fenneropenaeus chinenis* (Osbeck 1765), but initial success with the Pacific white shrimp, *Litopenaeus vannamei* (Boone 1931), has prompted a shift to the latter species. Food conversions of 1.5 kg of feed to 1 kg of shrimp as compared to a 1.8:1 conversion ratio for the other species and disease outbreaks have prompted the change in species.

Pearl oysters are cultured, but the primary bivalve molluscan production is clams. They are harvested from the intertidal zone out to 3 m depth in the middle portion of the bay. The other major biological components are the beds of seagrass, *Enhalus acoroides*, located in the middle and upper portions of the bay, and mangroves in the upper most region (Marine and Fishery Dept. of Hainan, Pers. Comm. 2000).

The history of aquaculture in Xincun Bay is one of boom and bust. Rapid expansion of the fish cage aquaculture industry in the 1990s exceeded the assimilative capacity to maintain the water quality in the bay. In 1997, water quality problems became very serious, and as a result the cultured species began to grow slowly and the mortality rate increased dramatically. Fish cage culture declined form 200 and 230 ha in 1995 and 1996 to 20 ha after the 1997 disaster. It increased to 33 ha in 1999. The number of hectares and fish cages are reduced and they are concentrated near the mouth where tidal *exchange is greatest. Shrimp production also collapsed in 1997 from 100 ha in 1996 to 10 ha in 1997 and remained low (5 ha) through 1999. The shrimp ponds are in the extreme interior of the bay. Although environmental factors played a role in the mortalities in the shrimp ponds, diseases that ravaged shrimp production throughout China also may have been a major factor in the disastrous decline in production. After the two major aquaculture industries - fish and shrimp - collapsed, production of other aquaculture species increased and emerged as important economic and environmental factors. Pearl oyster culture expanded dramatically in 1998 then declined to 85 ha in 1999. Seaweed culture also grew from 52 ha in 1998 to 133 ha in 1999 and increased to 160 ha in 2000.*

To determine the severity of the existing environmental problems, two field surveys of Xincun Bay were carried out. From July 31 to August 6, 2000, two continuous stations and nine area stations were sampled. At the continuous stations, the physical parameters monitored included temperature, salinity, DO, DO%, pH, current speed and direction, turbidity and tidal level. Primary productivity, basic water quality and nutrients, Chl *a*, ATP, Chl a/ATP ratio, MPN total coliform organisms, MPN *E. coli* organisms, chemical oxygen demand (COD), suspend solids (SS), pH, turbidity, ortho-phosphate, nitrogen (NO_2, NO_3, NH_4), DO, temperature, salinity and bacterial communities were measured at the area stations (Figure 3). During the survey, pollutant sources were evaluated to understand the sewage discharge and its impact on water quality.

A three dimensional conventional water quality simulation model, which was originally developed by Ambrose et al. in 1993 (known as WASP5), was modified and used to study the dissolved oxygen in the Xincun Bay. The equations solved by WASP5 are based upon the key principle of conservation of mass. The equations include three major components, the advection and dispersion of transport, the kinetic interaction and transformation, and external loading. WASP5 eutrophication water quality model considered eight water quality state variables include DO, PHYT, CBOD, NH_3, NO_3, ON, OPO_4 and OP, and used the kinetic framework developed by Di Tore et al. (1971). In our water quality model, we only consider DO, NH3, NO3 and their major kinetic interactions. This is based on an evidence that low DO is the major problem of eutrophication, and the nitrate and ammonium concentration are relative large within the fish cages region in Xincun Bay.

The dissolved oxygen concentration (DO) is an important indicator of water quality. Although it is difficult to determine the DO production and consumption mechanisms precisely, the basic trend can be understood by monitoring the degree to which the water is being polluted. The vertical distribution of DO is particularly important in order to determine the extent to which an area is polluted. DO are lower than 6 mg/L at stations 2 to 6 in all layers (Figure 4). At area stations 2, 4, 5, and 6, the DO is less than 5 mg/L, and the average value is only 4.8 mg/L. Vertically, DO decline sharply and reach a minimum 2 to 3 m under the surface in the fish cage culture region. On the other hand, vertical DO distribution is different at station 1 outside the bay; DO becomes larger from surface to depth. DO at the surface is 5.04 mg/L, very similar to that in stations 2 to 6. At station 1 DO is 6 mg/L at depths of 2 m. We speculate that this phenomena is the result of the surface water out flowed from the bay. At station 7, where there are no fish cages, water quality is better. DO is 6 mg/L at surface, but at depths >3 m, the DO value is below 5 mg/L. The distribution of DO at all stations is not desirable for fish cage culture. The fish cages used in Xincun Bay are 3 m × 3 m, and are submerged to a depth of 1 to 4 m. Also, where fish are cultured at a high density, respiratory difficulties for fish may result when DO is low, particularly early in the morning. A clear distribution of DO can be seen along the survey profile. Dissolved oxygen concentrations were high outside the bay and in the inner bay regions. In the navigational channel region, dissolved oxygen concentrations were low at greater depths. This is the region where fish cage culture is concentrated.

The spatial and temporal distributions of nutrients are reflected by the dissolved oxygen distribution in the water column. These biochemical characteristics are associated with the aquaculture activities in the Xincun bay. Within the fish cage area, substantial quantities of organic matter accumulate in the sediment due to uneaten food and fish excrement. Sediment oxygen consumption increases as a result of chemical oxidation. activity of benthic organism and bacterial decomposition of organic matter. The oxygen in the water column above the sediments can then become depleted, leading to anoxic conditions. When oxygen above the sediments is depleted, nitrogen and phosphorus may be released in the water column more readily. Phosphorus is released under anoxic, reducing conditions, whereas it normally complexes with oxidized iron and becomes immobilized. Previous research has examined these relationships between nutrients, dissolved oxygen and sediments oxygen consumption in aquatic systems (Stumn 1970, Frevert 1980, Nixon 1982).

The results showed that the water column in the Xincun Bay aquaculture region was heavily polluted by organic material and, according to sediment sample analysis, was also high in silicate contents. Except for dissolved oxygen, sampled chemical parameters and nutrients did not exceed the national water quality standards Class I. The data were also evaluated according to Criteria for Surface Water Quality Classifications, Class II (Florida EPA). Although the water generally met standards, the environmental health of the fish cage culture and navigation channel region has declined considerably as evidenced by the mortality of cultured fish and low DO.

Two kinds of pollutants affect water quality and sediment quality in Xincun Bay. One source is the pollutants produced by four factories, four restaurants and 7 gasoline stations, and an estimated 481 tons of COD from the sewage discharging. The other pollutant is a by-product of fish cage operations, which results in an estimated 5,000 tons of organic pollutants annually. The results of water quality samples indicate that DO is lower than the value of national water quality standards in fish culture areas. The assessment results show the main source of pollution is the fish cages. When feeding fish, large amounts of uneaten food and feces descend to the bottom. The sediment release NH_3 H_2S and other pollutants by degradation of the organic matter by bacteria. This chemical reaction requires large quantities of oxygen and reduces the dissolved oxygen substantially in the sediment and water column. The results of DO concentration modeling show that average DO concentration will by decrease about 10% when fish cages are doubled in the model, this may be the effect of the capacity of strong tidal current mixing and transport near the mouth of the bay. Macroalgal culture enhances the DO concentration within its culture area.

Macroalgal and seagrass samples were taken from up to 4 stations in the Bay. In order to evaluate their role as nutrient sinks in the ecosystem, the tissue carbon, nitrogen and phosphorus contents were analyzed with a Perkin-Elmer CHN elemental analyzer and by the method of Murphy and Riley (1962). The initial sampling was made in May and August for the macroalgae and seagrasses, respectively, along with the water sampling described above and another sampling was carried out in November 2000 for both the macroalgae and seagrasses.

The macroalgal *Kappaphycus alvarezii* samples in May and November presenting the higher tissue nitrogen and carbon contents were those collected in the areas close to the fish cage pens. These areas had an average nitrogen content of 1.6% DW and 30% DW for carbon, compared to the lower values of these two nutrients in the specimens from Station IV at the head of the Bay. On the other hand, internal phosphorus content follows the inverse pattern, since plants at Station IV were enriched in this nutrient (0.22% DW). These results reveal that seaweeds are active nutrient scrubbers, which also has an impact on their biomass quality. Considering the average seaweed production between 1999-2000 of 2000 mT, the calculated potential nutrient removal by these primary producers would be 28.8 mT for nitrogen and 3.66 mT for phosphorus for the November sampling period of time; however, if we based our estimations on the May collections, then the amount of nutrient removal for nitrogen would be 53.8 mT and 2.24 mT for phosphorus. Obviously, the nutrient removal capacity of *Kappaphycus* is quite substantial, but does appear to vary seasonally. Other reports have documented how other red seaweed species can act as biofilters removing nutrients efficiently from fish aquaculture farms effluents: Kautsky *et al.* (1996) integrated the culture of *Gracilaria* to salmon aquaculture in Chile, reducing the ecological footprint for nitrogen and phosphorus assimilation by 56% and 94%, respectively; likewise Chopin *et al.* (1999) reported high values of phosphorus and nitrogen in *Porphyra* grown close to salmon cages in the Cobscook Bay, Maine, USA.

Nutrient contents in seagrass tissue were also determined (leaves, roots and rhizome) when material was available. The different pattern of tissue nitrogen content indicated different strategies of nitrogen storage and subsequent use, which has been demonstrated in other seagrasses (Kraemer and Mazzella 1999). Leaf samples collected in August showed higher nitrogen content than those collected in November, but lower carbon and phosphorus levels, coinciding with the peak of fish production in the Bay. It is noteworthy that *Enhalus acoroides* presented in November high values of nitrogen in leaves and rhizome tissues, even higher than those found in *K. alvarezii* in the same area, as well as higher phosphorus contents in leaves and rhizome, and higher carbon contents in all three parts. Previous studies showed that the nitrogen uptake and assimilation by leaves could be more important than acquisition by roots (Hemminga *et al.* 1991; Kraemer and Mazzella 1996). Therefore, leaves and rhizome appear to have a nutrient (mainly nitrogen) storage functions and may have a significant role in the ecosystem as a sink/source of nutrients, which must be recognized in any modeling effort.

The assessment of nutrient state shows that inorganic phosphorus is low relative to other nutrients in Xincun Bay, which are generally at a low level, except in the fish cage region of the Bay. This is beneficial for most aquaculture. As *Kappaphycus* is usually cultured in oligotrophic tropical or sub-tropical regions, it productivity is limited by nutrient replete waters. Moreover, nutrient requirements vary greatly between species. The point is that with integrated aquaculture, moving commercially important seaweeds species closer to the source of nutrients alleviates potential nutrient limitations for seaweed production. Also, from looking at the internal nitrogen and phosphorus tissue contents in seaweeds and seagrasses in the Bay, our data suggests that these primary producers can act as key nutrient scrubbers from the water column and sediments. These organisms may play a key competitive role in the ecosystem by reducing the risk of other less desirable, potentially harmful, micro-algal blooms.

CONCLUSIONS

Integrating fed and extractive aquaculture to maintain a balanced ecosystem is not a new idea. It is "common sense". Scientists in China and the Western countries are now pointing out the benefits of an integrated approach to aquaculture. This approach to aquaculture allows nutrient bioremedition, mutual benefits to the co-cultured organisms, economic diversification and less risk of disastrous environmental consequences (Chopin *et al.* 2001). As we have seen, aquaculture can have significant impacts even on large embayments, like Jiaozhou Bay. In smaller bays or lagoons, like Xincun Bay, this integration is essential if we are to avoid a cycle of rapid expansion and disastrous looses. The next step is to learn how to effectively integrate fed and extractive aquaculture. We must learn to utilize the remediation capabilities of extractive aquaculture to reduce eutrophication and improve environmental quality and to optimize fed aquaculture and reduce waste. These are not easy tasks.

Hydrodynamic/biological ecosystem models provide tools to visualize the potential consequences of aquaculture activities, but the alternative approach must be tested and verified.

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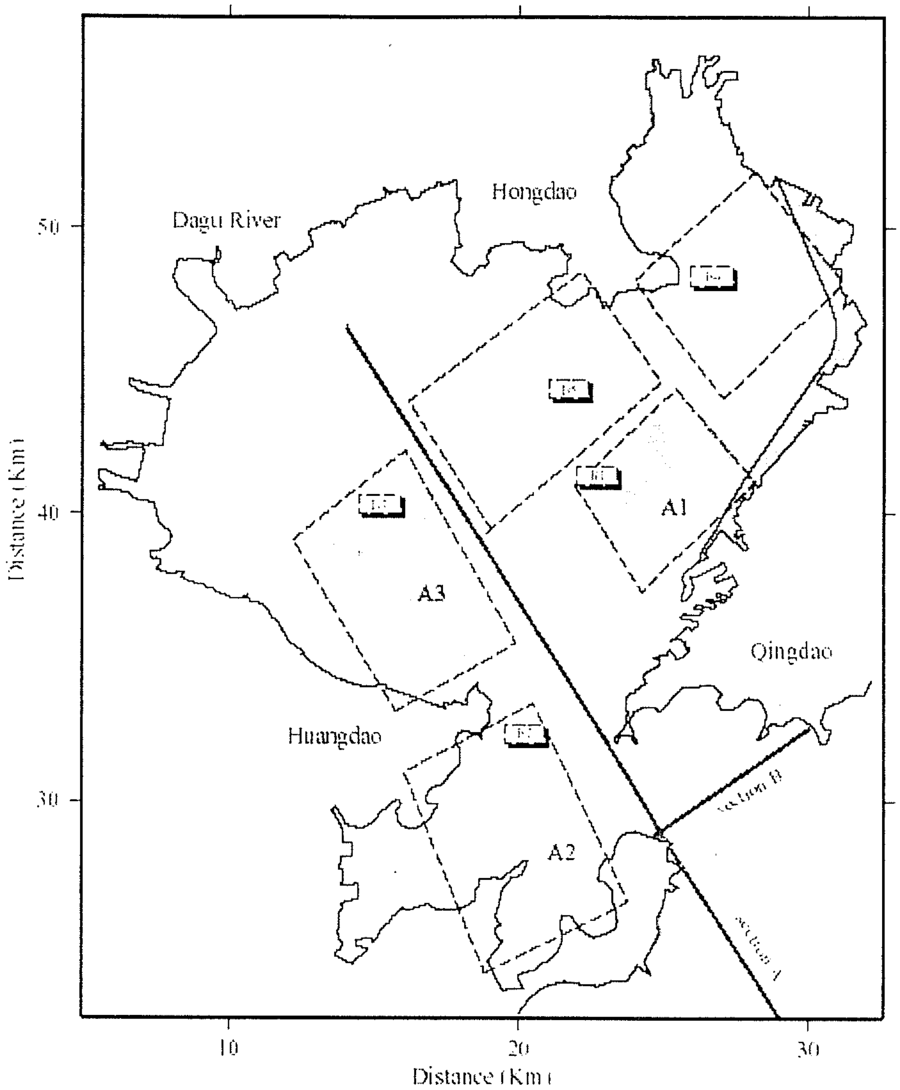

Figure 1. Locations of the shellfish aquaculture sites (shaded area) and selected regions for the flux estimation of nutrient and phytoplankton (areas enclosed by dashed line). (The heavy solid lines indicate two sections used to represent our model results on cross-bay section (section A) and flux calculation into or out or the Bay (section B).

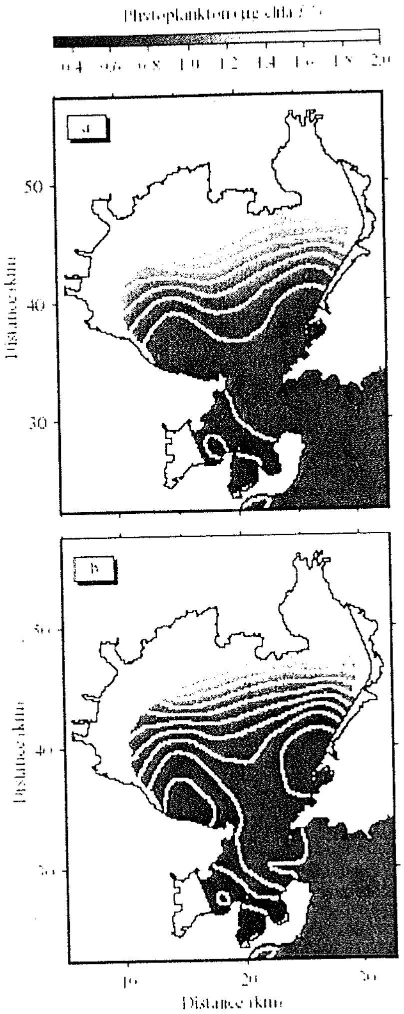

Figure 2. Tidal-cycle averaged surface distribution of phytoplankton at the 20 model days for the case with the shellfish culture densities of (a) 12 and (b) 24 individuals m^{-3}. Physical forcings are tide, freshwater discharge and a southeasterly wind (5 ms^{-1}).

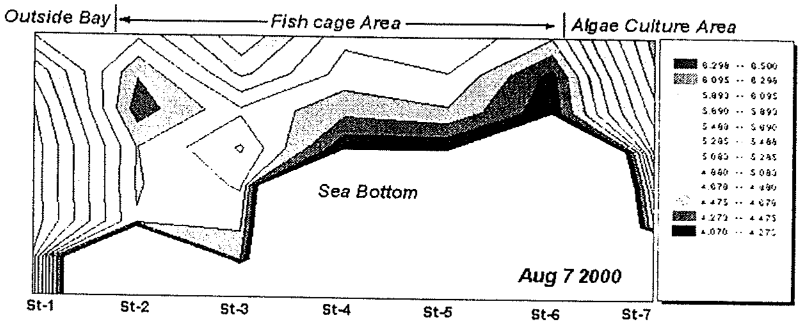

Figure 4. DO concentration

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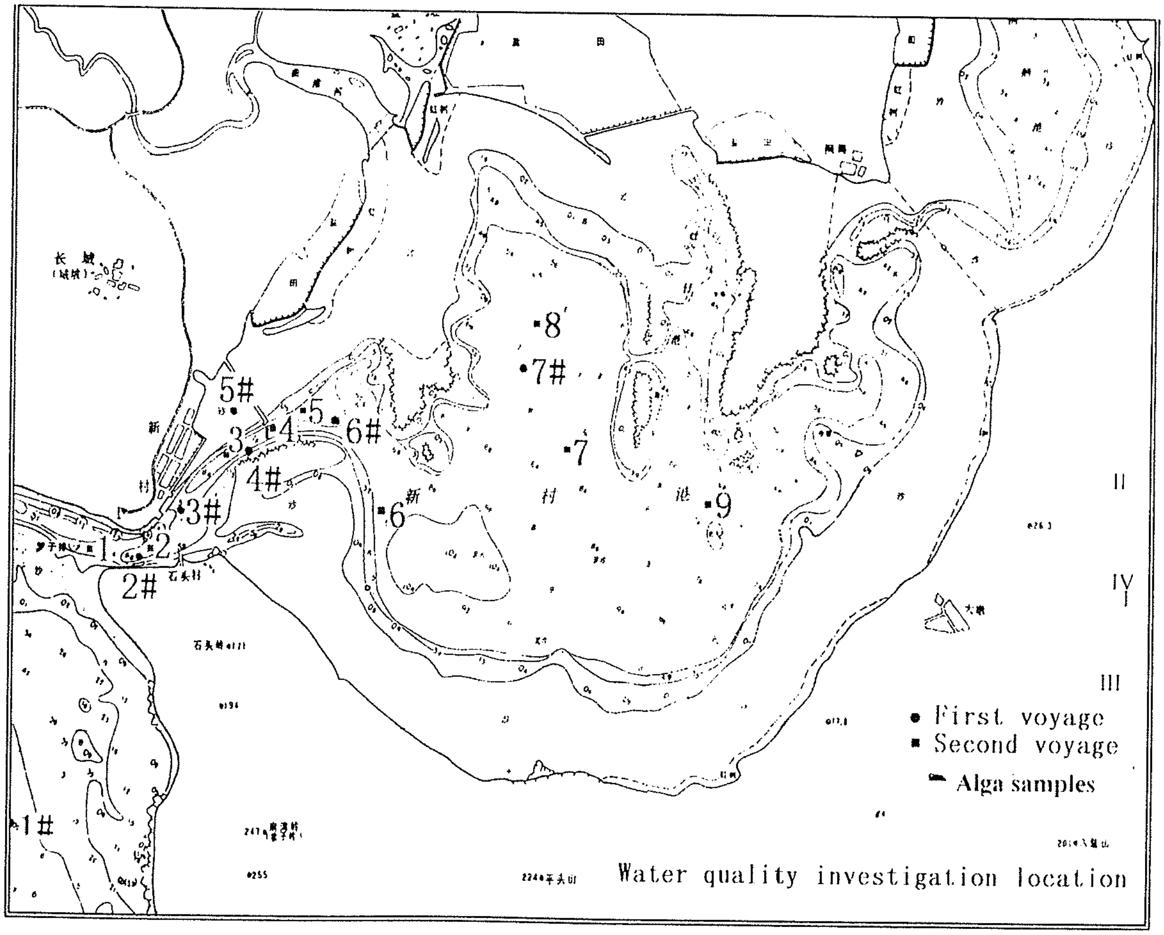

Figure 3. Map of Xincun Bay with sampling