# Manila Clam and Pacific Oyster Culture in Isahaya Bay -For the Sustainabl Production in Stressful Environment-

# Manila Clam and Pacific Oyster Culture in Isahaya Bay — For the Sustainable Production in Stressful Environment —

Junya HIGANO*1, Keiji HIRANO*2, Shigeru KITAHARA*2, Masahiko MATSUDA*2, Kohji MIZUTA*2, Akihiko FUJII*2, and Akira SHINAGAWA*3

**Abstract** Isahaya Bay is a branch of Ariake Sound, Kyushu, where the tidal range is the largest in Japan. Culture of Manila clam, *Ruditapes philippinarum,* commenced in the 1970s and is currently the most important industry in the Konagaicho Fisheries Cooperative. The Cooperative introduced a demarcated fishery for Manila clam culture, so that the fishermen are in charge of the management of their own culture grounds, such as sand placement on muddy substrate, installation of facilities for accumulating the juvenile clams and preventing predators, and registering landings under the cooperative sales. The annual landing normally reaches 400-700 metric tons for about 100 individual fishermen. But Manila clam culture has occasionally suffered from mass mortality during summer since 1998 when the barrage in the Isahaya Reclamation Project closed the inner bay area in the previous year. We studied the mass mortality from the aspects of environment and clam physiology and determined that the main cause of mass mortality was anoxia by means of continuous monitoring of water quality factors and analysis of organic acids in the pallial cavity fluid of Manila clams. For sustainable and stable production of Manila clams, prediction and prevention of anoxic water intrusion to the culture grounds are of critical importance. Suspended culture of Pacific oyster, *Crassostrea gigas,* was introduced in late 1990s in Isahaya Bay, which had naturally produced delicious native oysters near the shoreline. The oyster culture industry has grown up to 175 metric tons a year by 42 fishermen in 2005. However, there are several problems constricting the increase in production; namely, summer mortality after spawning, heavy fouling by barnacles, and lower consumer demand in the local market. Increasing market demand and improvement of the culture technique are necessary.

**Key words:** Manila clams, Pacific oysters, pen shells, Ariake Sound, summer mortality

## Introduction

Isahaya Bay, a branch of Ariake Sound where tidal range reaches ca. 5 m, possesses a large tidal flat of 29 km$^2$ out of 100 km$^2$ in the total bay area (Figure 1). The sediment of the tidal flat in Isahaya Bay and Inner area of Ariake Sound mostly consists of silt and clay (Kamata 1980). However, the tidal current in inner Ariake Sound is very strong because of tidal movement and the resonance of stationary waves (Inoue 1980). In Japan, the coastline has been artificially changed for many years, especially in sheltered bays where reclaimed lands and artificial structures such as dikes, breakwaters, and jetties have replaced the natural coastal line. Reclaiming tidal flats is the easiest way to extend farmland, industrial zones, and residential areas. Ariake Sound has been gradually reclaimed for a long time since the 6th century in accordance with natural land forming. After the Meiji era (from 1868), a huge

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*1 National Research Institute of Aquaculture, Fisheries Research Agency, 422-1 Nakatsuhamaura, Nansei, Watarai, Mie 516-0193 Japan
higa@fra.affrc.go.jp
*2 Nagasaki Prefectural Inst. of Fisheries, 1551-4 Taira, Nagasaki, Nagasaki 851-2213 Japan
*3 Gakushuin Women's College, 3-20-1 Toyama, Shinjuku, Tokyo 162-8650 Japan

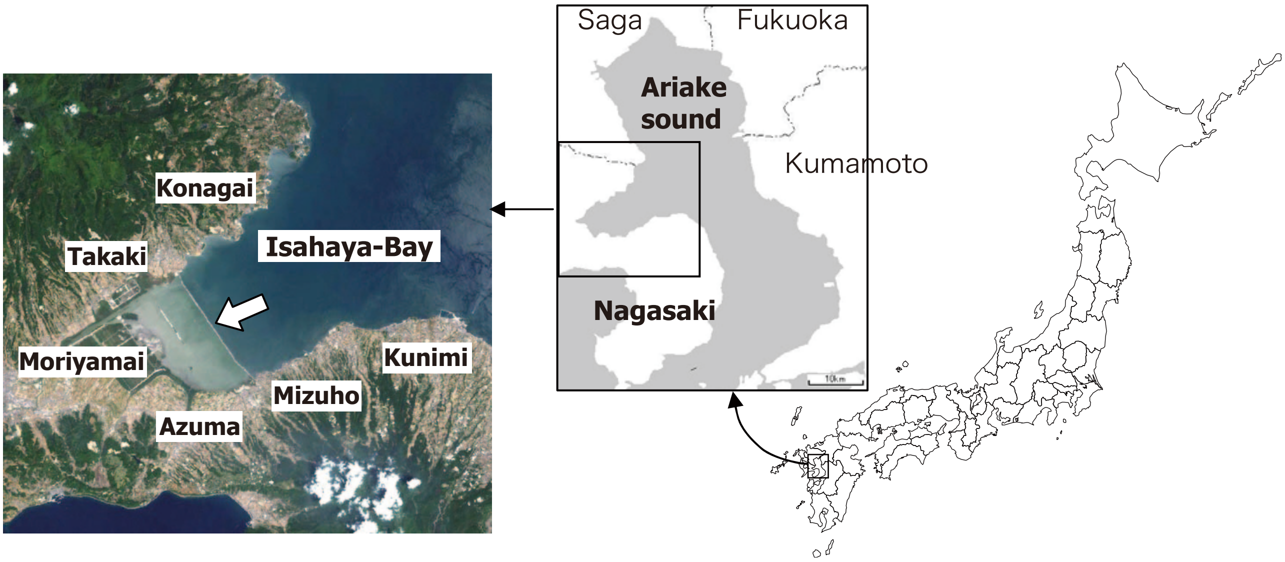


Fig. 1. Location of Ariake Sound and Isahaya Bay. Ariake Sound is surrounded by four prefectures. In Isahaya Bay, six fisheries cooperative had existed but three were abolished due to the construction of barrage in Isahaya reclamation project (arrow).

undertakings of reclamation was started and the shoreline moved forward up to 5 km (Satoh 2000). In Isahaya Bay, construction of the Isahaya Reclamation Project was started in 1989. A dike and water gate were constructed up to 1996 without opening 1.2 km out of 7 km total width. In 1997 the opening was completely closed (Sasaki 2005). In Isahaya Bay as well as other tidal flats of Ariake Sound, there was a good habitat for large amounts of filter feeding bivalves and fishes along with laver, *Porphyra yezoensis*. culture (Coastal Oceanography Research Committee 1985), so that a lot of fishing activity has occurred. However, recent environmental changes including reclamation, barrage construction, port construction, seabed collapse by coal mining and excavation of the seabed, presumably brought about negative ecological impact to indigenous marine organisms (Sasaki, 2005).

In this paper, Manila clam culture in Konagaicho Fisheries cooperative is described as an ideal example of development of a Manila clam aquaculture system in the face of difficult conditions in an altered environment. Moreover, we introduce the fact that hanging culture of Pacific oysters contributes to the production system in the bay.

## Pen Shell Fisheries in Isahaya Bay

Pen shell, *Atrina pectinata*, was a dominant fisheries product in Konagai Fisheries Cooperative and caught by means of diving. Figure 2 shows the annual production of *A. pectinata* in each prefecture surrounding Ariake Sound. Production of *A. pectinata* periodically fluctuated presumably due to dominant year classes. Landing and sales of *A. pectinata* in three fisheries cooperatives surrounding Isahaya Bay are shown in Figure 3. In 1989, annual landings of the adductor muscle valuable as edible meat, reached 300 metric tons. It corresponds to three thousands metric tons of total animal weight. As sales reached 800 million yen, pen shell was the most important fisheries product in Isahaya Bay. Nevertheless, only four year after starting the construction of Isahaya Reclamation Project production was diminished in 1993.

## Manila Clam Culture in Isahaya Bay

Figure 4 shows the annual production of Manila clam in each fisheries cooperative surrounding Isahaya Bay. Takaki and Azuma occupied half of total production in the 1970s and 1980s, but both were diminished with the progress of reclamation in the mid-1990s. Instead of these, Konagai became dominant after 1990. Manila clam culture commenced in the 1970s and is currently the most important industry in Konagaicho Fisheries Cooperative in accordance with the decrease of pen shell landings. The annual landing in the Cooperative normally reaches 400-700 metric tons by about 100 individual fishermen (Figure 4).

The characteristics of clam culture in the Cooperative are the introduction of a demarcated area for Manila clam culture. Each member owns an average of 1 ha of culture ground in the intertidal zone. Individual fishermen manage their own culture ground by taking actions such as placing sand on muddy substrate, developing facilities for producing juvenile clams and preventing predators.

According to Mori (1982), introduction and development of Manila clam culture in Konagaicho Fisheries Cooperative is as follows. Although the substrate on most of the tidal flat in Konagai consists of silt and clay with high iron content, successful production of Manila clam has been possible by placing sand placement on the muddy substrate. Trial and error of sand placement led to the determination that a sand mound was suitable for seawater circulation and prevention of mud accumulation. Thus sand placement contributes to

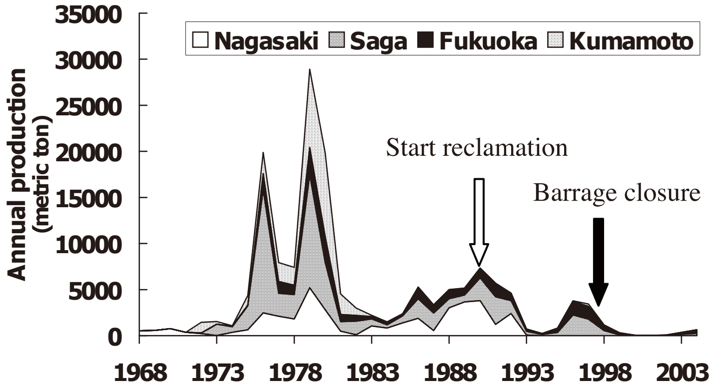


Fig. 2. Annual production (with shell) of pen shell, Atrina pectinata, in Ariake Sound. Each prefecture was shown in Figure 1.

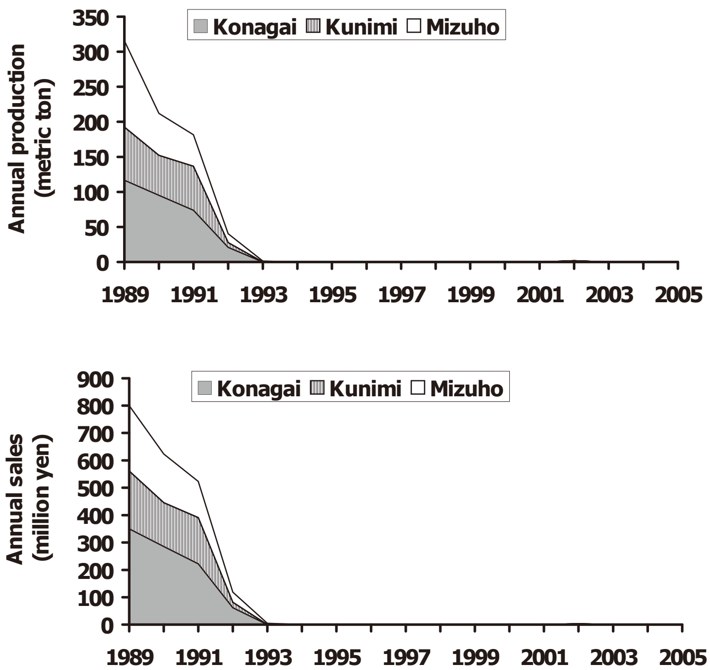


Fig. 3. Annual production (edible meat: adductor muscle) and sales of pen shell, Atrina pectinata, in main fisheries cooperative of Isahaya Bay

increase the area of high productivity, and the production reached up to 4.2 kg/m$^2$ from 1.2 kg/m$^2$ before sand placement. In addition, the following devices have been used for maintaining productivity of the culture ground. Fine mesh net was applied to prevent sand from sinking on extremely soft substrate. Setting of sand bags on the created sand flat can control bottom sand movement and create a natural nursery. Rakes and waterjets from submerged pumps are recognized as effective means of removing accumulated mud and dead shells from the bottom substrate. Each culture ground is enclosed by net fence in order to prevent the invasion of longheaded eagle rays, *Aetobatus flagellum,* which are predators of shellfish (Yamaguchi *et al.* 2005).

The cost of purchasing seed and sand against annual total sales of Manila clam in Konagaicho Fisheries Cooperative is shown in Figure 5. Total sales were affected by the total production and unit price, but cost of seed has been constant and cost of sand has been increasing since the mid-1990s. So the benefit is extremely depressed in lean years and recent decrease of total sales is disadvantageous for the business of Manila clam culture in the Cooperative. The proportion of the production to the seed amount in each year is shown in Figure 6. The proportion is higher in 1988, 1999, 1995, 1996, and 1997, but lower in 1991, 1992, 1994, and after 1998. Recovery of released seed should affect the budget of the culture business. In fact the ratio of production/seed is significantly correlated with the benefit (r = 0.609, $p<0.05$). Production is relatively low in comparison with the amount of seed released, so benefit only comes from the increase in unit price after growth

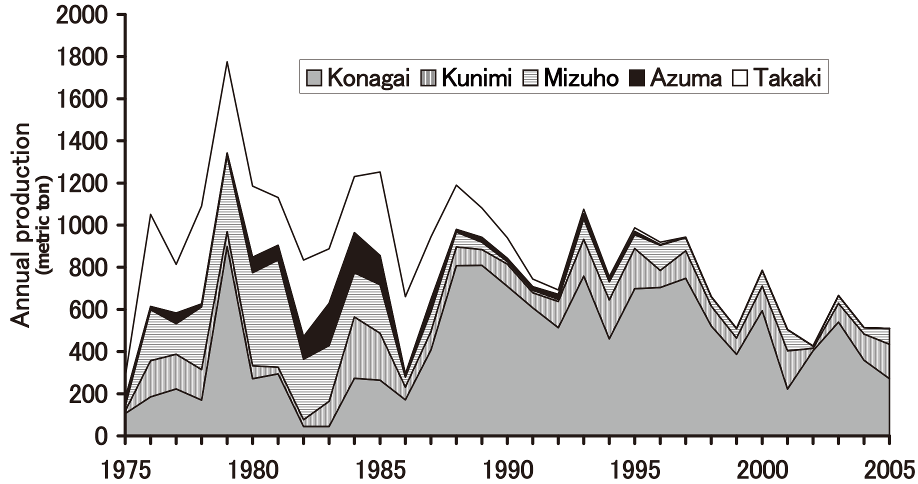


Fig. 4. Annual production of Manila clam, Ruditapes philippinarum, in main fisheries cooperative of Isahaya Bay. Only Konagai, Kunimi and Mizuo were running at present.

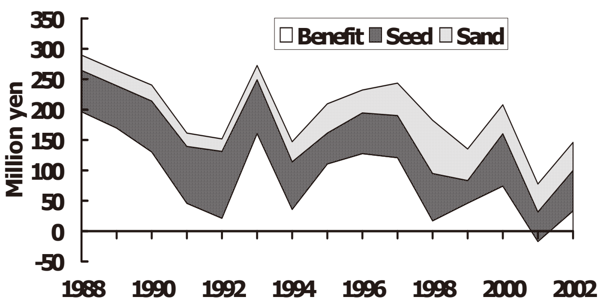


Fig. 5. Annual balance of cost and benefit on Manila clam culture at Konagaicho fisheries cooperative. The upper line shows the annual total sales of Manila clam.

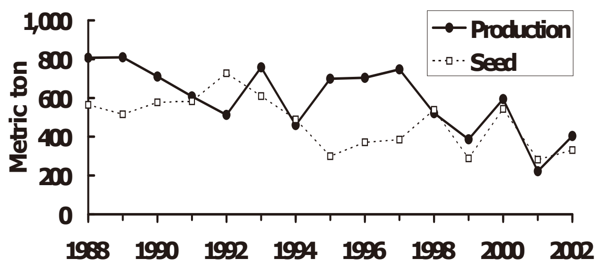


Fig. 6. Annual production and amount of seed for planting to aquaculture ground on Manila clam culture at Konagaicho fisheries cooperative.

of Manila clam seed. But Manila clam culture has occasionally suffered from mass mortality during summer since 1998 when the barrage in Isahaya Reclamation was closed in the preceding year. Actually, mass mortality on the Manila clam culture ground in Konagai was reported in 1994, 1998, 1999, 2000, 2001, 2002, and 2004.

### Mass Mortality of Manila Clam on Culture Grounds of Konagai and Search for a Causal Effect of Anoxia

The Manila clam is the most important product in the Konagaicho Fisheries Cooperative, but it occasionally suffered from mass mortality during summer since 1998. It brought severe adverse impact for production of the Manila clam for the following couple of years. The certain fact was recognized that only a pile of dead shells emerged at ebb tide. The cause of the mortality had not been understood, although anoxia and/or red tide had been thought to be main factors associated with mass mortality in Isahaya Bay.

In order to make clear the possible cause of mass mortality and find out the appropriate management strategy for Manila clam culture, we have been studying the relationship between the physiological condition and environmental factors. During the summer season (June - September) from 2003 to 2005, continuous real-time monitoring of water quality and periodic monitoring of survival and physiological condition of Manila clam on the culture ground were performed (Figure 7). Water temperature, salinity, and dissolved oxygen were measured with a Hydrolab Co. DS-4 water quality meter connected with a cellphone transmission module and a solar electric supplier. Data were transferred by cellphone communication to the mail server and recorded on a hard drive. Manila clams were placed in plastic baskets with sand on the culture ground and checked for survival rate and carbohydrate contents fortnightly. In august 2004 we encountered highly anoxic water and mass mortality of Manila clams during normal monitoring and intensive observation. From late July to early August in 2004, it had been hot and dry. Red tide of *Chattonella marina* and *C. antiqua*, Raphidophyceae, had broken out on August 5, and extremely low oxygen was observed from August 11-14 intermittently (Figure 8). All the Manila clams in the area died during that period.

According to the monitoring of Manila clam in baskets, carbohydrate contents of soft tissues were stable from May to July and still showed more than 30 mg/g wet weight of soft tissue and 80% survival on August 2. It is thought that the

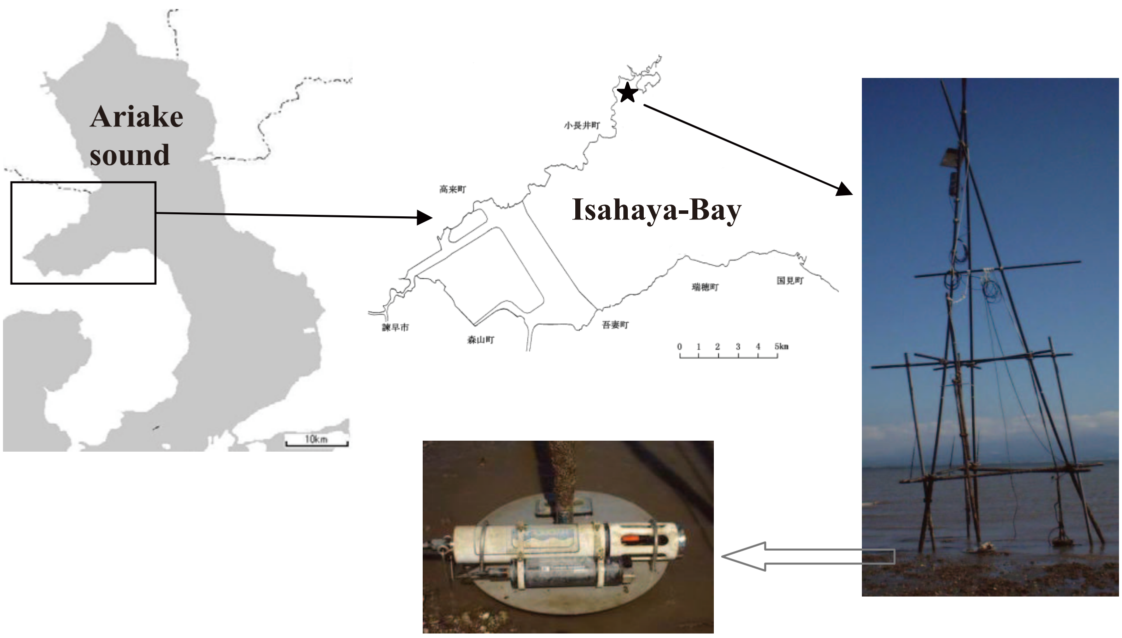


Fig. 7. Research site at Manila clam culture ground in Isahaya-Bay and scaffolding water quality meter is equipped. Solar cell module and cell-phone module are installed on the top.

Manila clams had conserved enough energy until mass mortality occurred.

Figure 9 shows the survival rate and organic acid contents in pallial cavity fluid of Manila clams put in mesh bags placed on the bottom of the culture ground at 1500 August 10 along with the record of dissolved oxygen. Both succinate and propionate, which are known as end products of

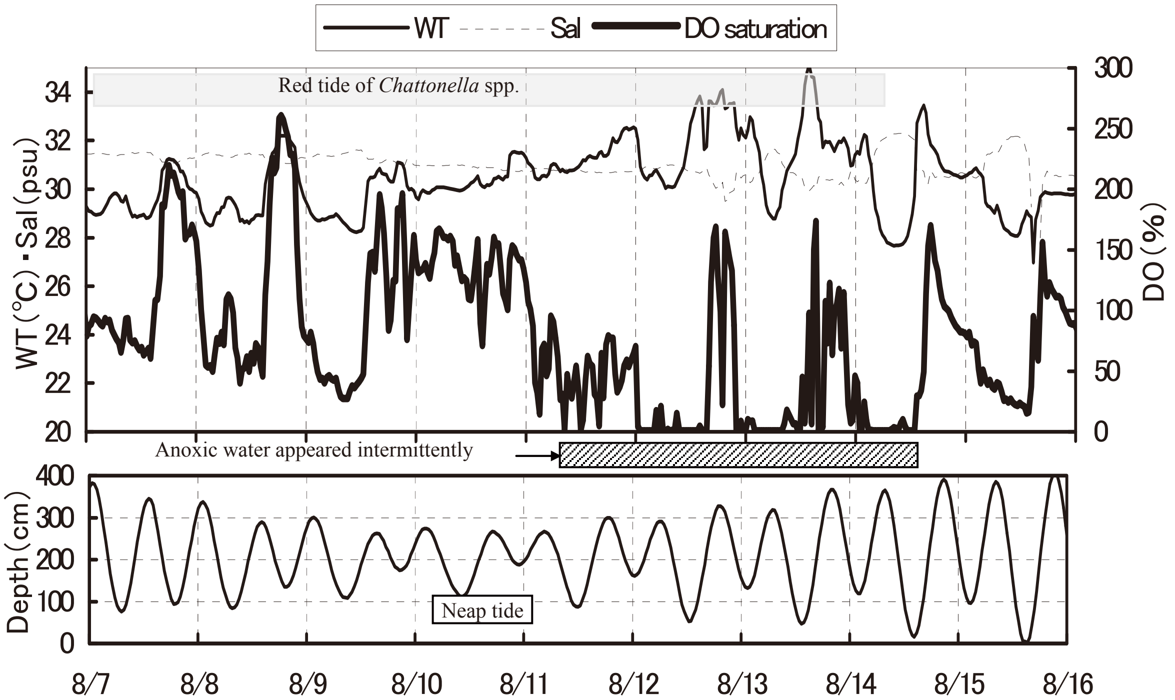


**Fig. 8.** Water temperature, salinity, dissolved oxygen and depth in second week of August, 2004 on the bottom of Manila clam culture ground recorded by water quality meter.

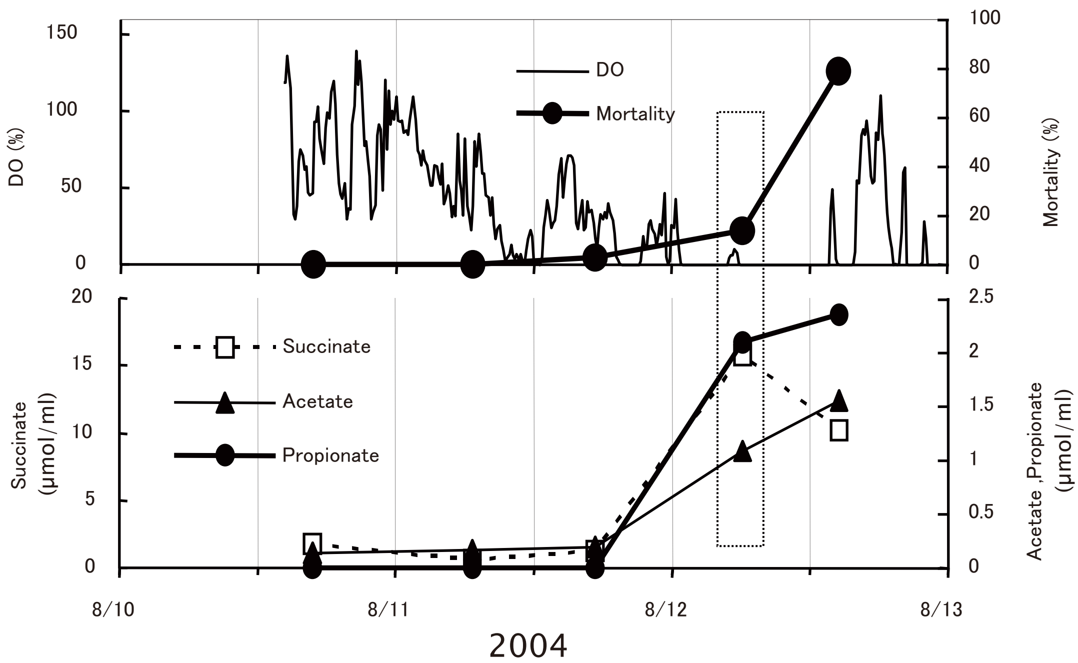


**Fig. 9.** Dissolved oxygen concentration at the Manila clam culture ground in Isahaya-Bay and the clam mortality (upper), and organic acid contents in pallial cavity fluid of Manila clam placed in mesh bag on the bottom (lower). Organic acids significantly increased before rapid rise of fatality (framed rectangle).

anaerobiosis (Hochachka 1984, Zwaan 1983) significantly increased by 0600 on the 12th before a rapid rise of fatality. The propionate concentration of 2 μmol/ml indicates no recovery state to the aerobic pathway in Manila clams even if they are supplied sufficient oxygen (Shinagawa, personal communication). In fact, most of the clams died until 1400 on the 12th. Average water temperature during the period exceeding 30℃ even including anoxic water flowed into the culture ground. This fact demonstrates that the clams exposed to anoxic water for 13 hours from the evening of the 11th to the morning of the 12th had reached the fatal step of anaerobiosis. The anoxic water had a strong odor of hydrogen sulfide and the sulfide concentration of the bottom water ca. 5 km from this site was 3 mg/l on 13 August. A tank experiment in which Manila clams were exposed to anoxic water and plus hydrogen sulfide at 30℃ demonstrated that hydrogen sulfide increased propionate in the pallial cavity fluid within 13 hours. Anoxia and (normoxia, sometimes hypoxia) alternated with the interval of 15 hr, (6 hr), 14 hr, (13 hr), 12 hr within 60 hours from August 12 at 0030 to the 14th at 1230. It is thought that the combination of hydrogen sulfide generation with anoxic water at high water temperature above 30℃ brought Manila clams to the fatal state of metabolite accumulation.

The cultured Manila clam was lost by only a three days event, namely anoxia. It is foremost important to establish measures to prevent mass mortality by anoxia. Research on the development of simple facilities to prevent the invasion of anoxic bottom water and on a device to efficiently supply oxygen to the bottom layer where Manila clam inhabits is currently progressing.

## Pacific Oyster Culture in Isahaya Bay

In Isahaya Bay native oysters have long been utilized at local retail shops and seafood restaurants along the shoreside road before the reclamation construction. The native oysters have been in high repute with good flavor although their size is quite small. But most of the oyster reefs were diminished with the construction. Suspended culture of the Pacific oyster, *Crassostrea gigas*, was introduced to Isahaya Bay in the late 1990s. Figure 10 shows the increasing number of fishermen and facilities for oyster culture in the Konagaicho Fisheries Cooperative and they reached ca. 40% of the members and averaged 1.5 rafts in 2005. The growth of cultured oysters is good and can be harvested after only a half year of growout. Annual production and sales of the oysters in Konagaicho Fisheries Cooperative is shown in Figure 11. Production increased constantly except in 2004 due to damage by a typhoon on the 18th of September, 2004.

Production and the sales in 2005 reached 175 tons and 74 million yen. The spat of cultured oysters were transported from Miyagi Prefecture, northern Japan. The oyster rafts are placed 2-4 m of the depth at low water spring tide in several locations of Isahaya Bay, so suitable area for culture are limited. They grow fast, but summer mortality occurs during the culture period by

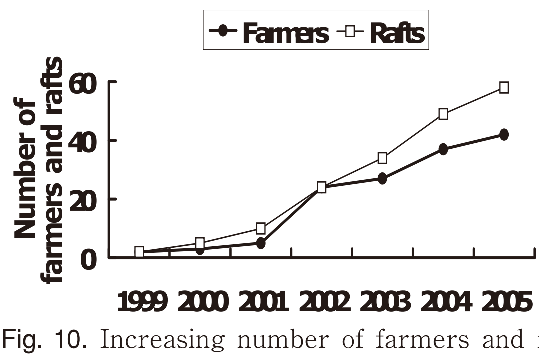

Fig. 10. Increasing number of farmers and rafts on Pacific oyster culture at Konagaicho fisheries cooperative.

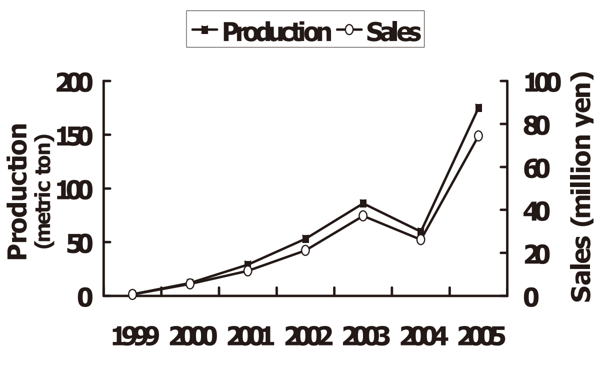

Fig. 11. Annual production and sales of Pacific oyster at Konagaicho fisheries cooperative.

oysters weakened after spawning because of high water temperature and sometimes perhaps hypoxic water. More effort to introduce native oysters to hanging culture is essential not using spat from coldwater areas in order to avoid summer mortality. Heavy fouling by barnacles, ascidians and other animals is a constraining factor for the management of oyster culture. Attachments and/or settlement of larvae are inevitable in shallow water, so development of novel equipment and methods against fouling animals is necessary.

## Discussion and Conclusions

After the crash of the pen shell fishery, Manila clam culture has been the most important industry in Isahaya Bay. Oyster culture helps compensate for the reduction of Manila clam production (Figure 12). These transitions could support total income of the fishermen in Konagaicho Fisheries Cooperative so far. Nevertheless both Manila clam and Pacific oyster culture haven't compensated for the entire portion of the lost pen shell industry. In order to increase the production of both species, technical and administrative supports are necessary. For Manila clam culture, establishment of effective measures to prevent anoxic water is indispensable. Development of the reproduction system of natural seed on the culture ground is essential in order to reduce costs. Development of methods and devices for improving substrate on the culture grounds is necessary for reducing the costs of sand. For oyster culture, improvement of the culture technique including using local broodstock is necessary. Exploit of the market demand is inevitable for further increasing total production. Furthermore, the problem is that the culture of both species is faced with the reduction of productivity due to environmental factors.

For sustainable shellfish production in Isahaya

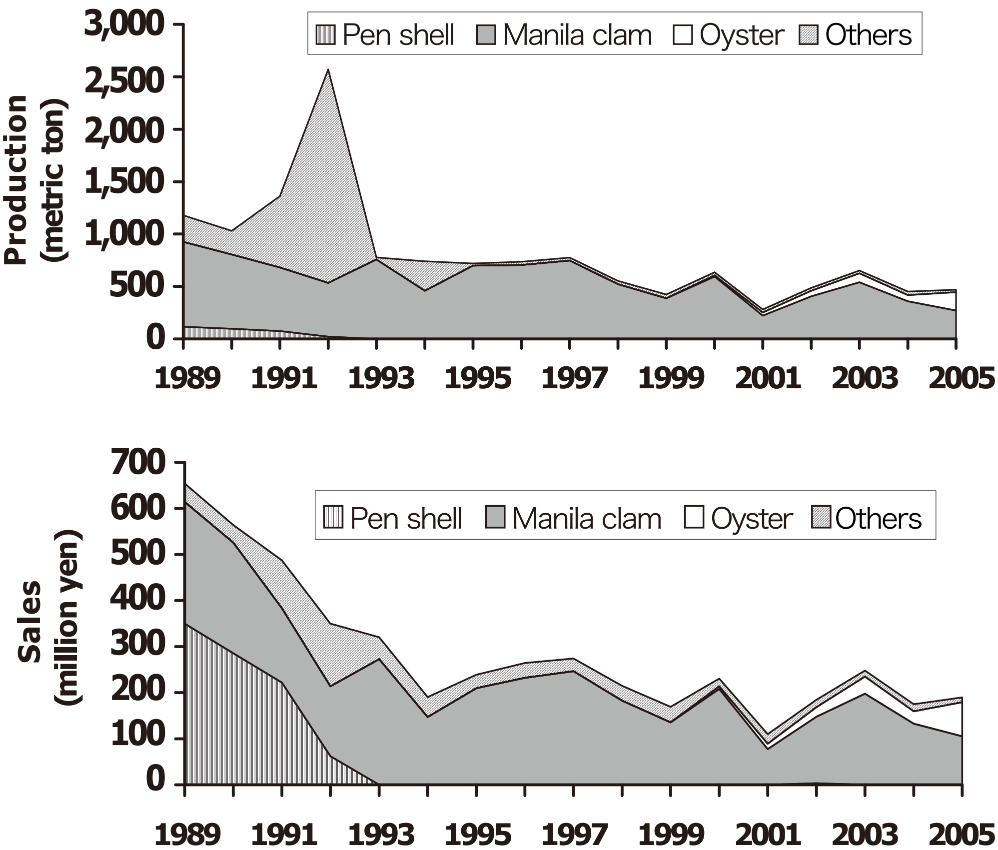


Fig. 12. The breakdown of main fisheries products in terms of production and sales at Konagaicho fisheries cooperative. The production of pen shell is expressed as amount of edible meat.

Bay, a fundamental solution is necessary for generation of hypoxic/anoxic water. Rapid decrease of the nutrient removal from the ecosystem, i.e. fisheries production, may cause increased harmful phytoplankton blooms and anoxic water through collapse of the balance between the inflow and the outflow of nutrients. Extractive culture, such as Manila clam and oyster culture, must contribute to restoration of the environment. So, we should make a great effort to enhance bivalve culture in Isahaya Bay. Both the Manila clam and Pacific oyster are key species for a balanced ecosystem through their filter feeding activities and harvest without feeding in terms of removing organic matter from the ecosystem (McVey *et al.* 2002).

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