3.4 The Japanese experience: pearl oyster mortalities and constraints

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ABSTRACT

This paper provides a historical overview of pearl fishery in Japan and discusses the different disease organisms encountered by the pearl farming sector. These include parasites and pathogens, fouling organisms, predators and red tide. Mass mortalities of Akoya pearl oysters experienced in the 1950s, 1970s and 1990s are discussed. The paper was concluded with an emphasis on the importance of evaluating the susceptibility or tolerance to disease when pearl oyster seed are translocated as this is fundamental to preventing potential mass mortalities that may be caused by infectious pathogens. which need to be understood by These concepts are fundamental to the prevention of mass mortality caused by infectious pathogens and must be understood by farmers, scientists and policy makers.

HISTORY OF FISHERY OF PEARLS IN JAPAN

The earliest record of a pearl fishery appeared in India in 400 BC. Since then, fishermen have collected wild oysters from the sea and harvested the natural pearls throughout the entire distribution of the species in the Mediterranean Sea, the Red Sea, the Persian Gulf, Sri Lanka, the Middle East, Atlantic, South and North Pacific Oceans including Japan and China (Wada, 1991). The natural resources of oysters decreased partly due to over-fishing in most of beds and partly due to the low productivity of natural pearls from wild animals. For example, Ogushi (1938) reported that only natural pearls weighing 9 rin (1 rin = about 3.75 mg which is international unit of pearls for trading) could be harvested from visceral parts of about 200 Japanese (Akoya) pearl oysters *Pinctada fucata martensii*. It is interesting to note that Japan is located at the most northern latitude of the natural distribution of pearl oysters in the world and that the culture technique has been developed in this country by using the northern subspecies of tropical species (*Pinctada fucata*).

The Japanese government issued regulations to control over-fishing of natural pearls and conducted transplantation and culture experiments before World War II. Culture of pearls started at the end of 19th century. In 1893, Kokiti Mikimoto did the first experiments in which he succeeded in producing semispherical pearls. Tatsuhei Mise and Toukichi Nishikawa, were also famous figures in the history of methods for producing spherical pearls. These three pioneers are often cited as inventors of the main techniques for the insertion operation for producing spherical pearls, which were mostly established by about 1916. The introduction of hanging methods for rearing the animals has increased the production of cultured pearls. The Japanese pearl industry contributed to many techniques of operation for insertion of nucleus and graft, wintering, cleaning the shell, collecting and rearing natural spat, juveniles and adult oysters, and hatchery production of seed (Ikenoue, 1992).

The number of cultured pearls produced was carefully recorded during the initial stage of the industry (1926-1945). There were, for example, 669 in 1926, 7 749 in 1935 and 10 883 in 1938. Estimated maximum weight of annual production was 2 500 to 3 000 kan (1 kan = 3.75 kg) during this period. Production was about 50 kan when culture restarted in 1946 after World War II and increased to 1 000 kan in 1950. There was a remarkable increase of production during the period from 1955 (6 543 kan) to 1966 (39 522 kan). The rapid expansion of the production depended primarily on the demand of world market as well as Japanese economy and also on the development of new techniques and expansion of culture sites throughout the distribution of the pearl oyster population in Japan. However, a long economic slump in 1975 resulted in a production decrease to 1 298 kan. Recovery from reduced production after a long slump of about ten years occurred and production was around 17 000 kan every year from 1985 to 1995. Due to mass mortality which became acute in 1996 and 1997, the annual production recently decreased to less than half of the value produced during each year of the last decade. The causes of increased mortalities are under investigation.

PARASITES AND PATHOGENS

Parasites of *P. fucata martensii* have been known since the early stages of development of the Japanese pearl industry. Damage to the pearl industry by parasites has been of particular significance since 1952. The rapid increase in damage over the whole pearl oyster-producing area seems to have been caused by the transplantation of the pearl oyster and complicated by the lack of biological data on the parasites. Mudworms, sponges and a trematode are the main parasites affecting production of pearls.

Mudworms of the genus *Polydora* produce a mud tube and blister in bivalve shells. *Polydora ciliata* (Johnson) is recognized as the most important parasite (Mizumoto, 1975). Since 1960, damage to the industry by mudworms has been occurring in the whole pearl-culturing area. Oysters are fatigued, resulting in heavy mortality. In 1970, more than 50 percent of pearl oyster cultivated were infected by mudworm in the main farming areas (i.e. Mie, Wakayama, Oita, Kumamoto, Miyazaki and Kagoshima prefectures) in the central and southern waters of Japan. Spawning of the mudworm occurs in May, June and October in Ago Bay, Mie Prefecture. Larvae settle on the shell and mud tubes and blisters are formed in summer and winter. To exterminate mud worm, the industry use brine treatment in the larval setting season. The pearl oysters are dipped into sea water for about five min, followed by a 15 min freshwater treatment, then in 22 percent brine for about 20 min and then exposure air in the shade for 15 min. Biological control using natural enemies of mud worm is also being explored (Funakoshi, 1964; Mizumoto, 1975).

The extent of the damage caused by the trematode *Bucephalus varicus* in the pearl industry was recognized around 1960 and the life history of this parasite has been studied and reported by Sakaguchi (1968). Pearl oysters infected by worms cannot be used in any pearl production, either as mother shell or as mantle piece donor because they only produce poor pearls with spotted or thin pearl layers. The infection has spread over the whole pearl-culturing areas and a rate of infection as high as 40 percent was reported in some farms in Japan. The pearl oyster is the first intermediate host of the parasite. Larval trematode stages found in pearl oysters are young sporocytes. The sporocytes mature in spring when the water temperature rises. The germ-balls in mature sporocytes develop into cercariae, which are motile and are released from the oyster tissues through summer and autumn. The second intermediate hosts are small fish, such as *Atherina bleekeri, Spratelloides japonicus* and *Engraulis japonica*, which are abundant in the waters near the pearl farms. The *B. varicus* cercariae invade the muscular tissue of the fish and encyst as metacercariae. Fish species, such as *Caranx sexfasciatus*, *C. equula* and *C. ignobilis* are the final hosts, which ingest fish infected with the metacercariae. Once ingested, the metacercariae emerge from their cysts and mature into adults in the digestive system of the fish. Another trematode species *Proctoeces ostrea* has also been found in the internal organs of pearl oysters and is common throughout the pearl farms, but damage to the industry is not severe (Sakaguchi, Kamakura and Kusuda, 1970). A proposed practical method to control these parasites is to avoid culture of pearl oysters in September when these trematodes undertake their peak period of transmission. It is impossible to remove the host fish from the coastal areas (Sakaguchi, 1968; Mizumoto, 1975).

There are fewer reports of microbial pathogens (bacteria and virus) causing mortalities of Japanese pearl oysters than those in the tropical species. Kotake and Miyawaki (1954, 1955) isolated two strains of unidentified bacteria from Japanese pearl oysters during an episode of mortality. Miyazaki *et al*. (1999) reported isolating an unidentified virus as a cause of the mass mortality that has emerged recently. These results were not confirmed, either as to the identity of the pathogen or its pathogenicity to pearl oysters (Nakajima, 1999; Hirano, Kanai and Yoshikoshi, 2002). Suzuki, Kamakura and Kusuda (1998), Suzuki (1999) and Kitamura, Jung and Suzuki (2000) also isolated a birnavirus from Japanese pearl oyster.

FOULING ORGANISMS

Many species of invertebrates and seaweeds inhibit growth and injure pearl oysters by attaching to the shell, particularly at the hinge, often interfering with the opening of the shell, which may cause mortality. Fouling organisms include barnacles, sponges, worms, edible oysters, and seaweeds. The dominant species of barnacles in the Japanese pearl farms are *Balanaus variegatus tesselatus* and *B. amphitrite.* The polychaete worms *Hydroides norvegica* and *Dexiospira forminosus,* as well as the bryozoan, *Dakaria subovoidea*, are also fouling organisms in Japan. Periodic physical cleaning of the shell or dipping the oysters in fresh water are the practical defense measures taken against these organisms. Shell cleaning is carried out during the period from April to November. Freshwater treatment is effective particularly for removing larvae or young stages of fouling animals on the shell.

PREDATORS

The predators of cultured pearl oysters include the eel, *Anguilla japonica*, the black porgy, *Sparus* sp. and globe fish, *Sphoroeides* sp., as well as the octopus, *Octopus* sp. They especially attack the pearl oysters just after the nucleus operation.

RED TIDE

One of the important constraints has been the effect of red tide on marine cultured organisms. *Gymnodinium mikimotoi* is a well-known dinoflagellate red tide which was named after the late Kokichi Mikimoto, one of the inventors of pearl culture in Mie Prefecture, where they found this species. Since then many records have described the damage to the pearl oyster by this dinoflagellate in Japan. The other red tide species reported are *Heterocapsa circularsquama*, *Gonyalaux* sp. and *Cocurodium* sp. Abnormal blooms of these toxic dinoflagellates have been suspected as the cause of mass mortalities in pearl farms in localized areas. Most of the Japanese pearl farms are located in semi-closed coastal estuaries or small bays, sites that favour abnormal blooming of red tides in Japan.

A large-scale bloom of *Heterocapsa circularsquama* occurred in Ago Bay in 1992 causing a new type of red tide mass mortality that had not seen before with red tides of *Gymnodinium mikimotoi* or other species (Matsuyama *et al*., 1995). They reported that in the summer of 1992 in Ago Bay the maximum cell density of *Heterocapsa* sp. was 87 420 cells/ml and it caused mass mortality of pearl oysters, although mortalities of cultured and feral finfish were not observed. That was the first report of this species of red tide causing mass mortality of pearl oysters in Japan. Many studies have been reported in Japan on the factors that stimulate phytoplankton blooms, physiological damage and mortality of pearl oyster, prediction of blooms on the basis of the field observation and experimental exposure of animals to red tide dinoflagellates (e.g. Honjo, 1994; Nagai *et al*., 1996; Iwata *et al*., 1997). Nagai *et al*. (1996) used laboratory experiments to determine the mechanism by which *H. circularsquama* caused mortality of juvenile pearl oyster. The lethal dose 50 (LD_{50}) was approximately 20 000 cells/ml after 24 hr of exposure to *H. circularsquama*. They suspected that the cause of death was the direct action of cells. Immediately after exposure to algal cells, animals rapidly contracted their mantles, closed their shell valves, then contracted gills and heart beat became irregular until it stopped. Transporting the pearl nets that hold pearl oysters from the bloom area to a non-blooming site is a usual procedure to avoid mortalities in the case of red tides in Japan.

MASS MORTALITY

In pearl farms located at the end of semi-closed estuaries or bays, mass mortalities occurred in the summer season in Mie Prefecture between the 1950s and 1970s. Based on the analysis of seawater data, high temperature was considered to be the primary cause of the mortalities, which ranged from 4 to 70 percent. At the time of summer mortalities, water temperatures rose over 29 °C, the oxygen content was low and hydrogen sulphate concentration was high, particularly near the bottom, all of which are suspected to have contributed to the mass mortalities. Physiological condition of the pearl oysters is variable and is dependent on the phytoplankton availability in pearl farms before and during periods of high water temperature. Mortalities are strongly influenced by physiological condition. These experiences motivated the farmers and scientists to recognise the importance of monitoring the condition of seawater in pearl farms. Co-occurrence of high water temperatures and low levels of planktonic food are sometimes the main cause of mass mortalities. Food availability and temperature are important environmental factors for physiological conditioning of bivalves in culture. Elucidation of the influences of food deprivation on the mortality of pearl oysters was studied in laboratory rearing experiments (Numaguchi, 1995a, b). Two-year-old pearl oysters were held in tanks of seawater filtered through a series of filters (10, 5, 1 µm) for 115 days during June to September at the natural temperature of 23 °C to 29 °C. The mortality of unfed oysters increased remarkably when the condition index (dry meat weight/dry shell weight) dropped below 4 (initial value 13.7), dry meat losses increased more than 70 percent and the weight of the crystalline style decreased below 10 mg (initial weight: 30 mg). A level of 28 °C is a critical temperature indicator for some physiological effects in pearl oysters based on experiments on filtering rate, food intake and oxygen consumption (Uemoto, 1968; Numaguchi, 1995a, b). Mass morality observed in western Japan from summer to autumn may, therefore, be caused by these factors in association with the effect of oceanic seawater which is warmer and includes less food plankton than coastal seawater.

Since 1994, mass mortalities have been occurring which are causing significant economic losses to the pearl culture industry in western Japan (Sorimachi, 2000). This disease occurs from summer to autumn and the affected oysters exhibit a yellowish-red coloration of the adductor muscle. Histopathological changes commonly appear in the loose connective tissue of the mantle and adductor muscle in the affected pearl oyster. Various factors such as toxic dinoflagellate blooms, infectious diseases caused by a filterable virus-like agent and environmental factors were suspected as causes of the mortality. To clarify the cause of this epizootic, experimental transplantation of the mantle piece of the affected oyster into healthy oysters, cohabitation of affected and healthy oysters and inoculation of filtrate of affected oyster hemolymph into healthy oysters were performed. After 2 to 3 months, healthy oysters displayed the signs similar to those of spontaneously affected oysters and mortality occurred. These results indicated that the mass mortality of the cultured pearl oysters is caused by an infectious filterable agent. However, the agent of the disease has not been conclusively identified. Mortality decreased when water temperature declined in October-November indicating the disease is highly dependent on water temperature. Low water temperatures in the previous winter appeared to suppress the occurrence of the disease during the following growing season (Kurokawa *et al*., 1999; Miyazaki *et al*., 1999; Muroga, Inui and Matsumoto, 1999; Morizane, 1999; Takami, 1999; Yoshikoshi, 1999; Nakajima, 1999; Sorimachi, 2000; Maeno *et al*., 2001; Morizane *et al*., 2001; Uchimura *et al*., 2001; Tomaru, Kawabata and Nakano, 2001). Management practices have been recommended for the pearl farmers to reduce mortalities. In some regions, prohibition on transplanting live pearl oyster shells from the area where the infection was suspected has been proposed. Imports of live oysters from out of Japan are generally prohibited.

Funakoshi (1999) discussed the history and current problems caused by mass mortality to pearl culture in Japan. He commented that after the 1970s many pearl farmers have tended to produce fast-growing and large-size mother-of-pearl (MOP) shell for oyster production. These appear more resistant to mass mortalities and can produce larger pearls. This has resulted in most MOP shells being produced from natural or artificial (hatchery) setting spat at the southwestern region of Japan. The new infectious disease emerged in part of these regions around 1995 and then spread over to pearl farms in other regions after 1997. It was suspected that the unknown pathogen was introduced by the transplantation of seeds or MOP. Also there have been introductions of live shells from out of country for genetic selection or crossing, and this is suspected, without evidence, as the cause of invasion of the pathogen.

CONCLUSION

When live shells are introduced from other prefectures or areas, or when pearl oyster seed are introduced, it would be desirable to carefully evaluate their susceptibility or tolerance to disease. These concepts are fundamental to the prevention of mass mortality caused by infectious pathogens and must be understood by farmers, scientists and policy makers. Routine monitoring of the physiological condition of cultured animals and oceanographic aspects of water quality by farmers, cooperatives or local governments at every culture site is also necessary.

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