Environmental Deterioration of Fish Farms in Japanese Enclosed Bays and Measures for their Environmental Management

11

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Fish farming using net pens in some Japanese enclosed bays started in the late 1950s and was referred to as "the conversion of catching fisheries to rearing fisheries." Net pen aquaculture has increased rapidly in popularity in the enclosed coastal areas of Japan since the 1970s. Total yields from net pen aquaculture recently reached approximately 270,000 metric tons, the majority of which is contributed by the culture of yellowtail, salmon, and red sea bream (Shirota 1990, MAFF 2005). A major problem of using net pens that has yet to be solved is that the fish are reared at extremely high densities with limited space and they require large amounts of food. Dissolved oxygen (DO) tends to decrease in the water in the net pens during the night due to respiration of the fish and the cessation of photosynthetic activities of phytoplankton (Hirata and Kadowaki 1990). Only 10% - 20% of the food fed to cultured fish contributes to their somatic growth. The remainder tends to be discharged as waste in the form of organic particles and inorganic nutrients outside the net pens, often causing organic enrichment of the sediment just below the fish farm and eutrophication of the water in the coves and bays where the fish farms are located (Tsutsumi and Kikuchi 1983; Hirata et al. 1994).

The organically enriched sediment that is formed on the sea floor in the enclosed coves and bays with restricted water exchange often causes depletion of dissolved oxygen in the bottom water, production of hydrogen sulfide in the sediment during the warm season (Tsutsumi et al. 1991; Pawar et al. 2001; Yokoyama 2003), and often results in a catastrophic disturbance of the benthic community (Tsutsumi and Kikuchi 1983; Tsutsumi and Inoue 1996; Yokoyama et al. 1997). The eutrophication of the water and organic enrichment of the sediment due to net pen fish farming raises concerns not only about the management and development of fish farming, but also over the environmental disturbance of the ecosystem in the enclosed bays or coves where the fish farms are established.

Measures to decrease the negative impacts of fish farming on the surrounding environment have been studied since the 1970s. Initial measures conducted in Japan were mostly based on civil engineering techniques, including dredging the organically enriched sediment from the sea floor, digging the sea floor of the mouth of the bays or coves to increase the water exchange, creating sand covers over the organically enriched sediments, etc. (Kawai et al. 1990; Kimura 1990). These measures were shown to be ineffective and too expensive.

A micro-bubble generator was utilized to increase the DO supply to oyster, pearl oyster, and scallop farms (Onari 2001). This device produces tiny air bubbles several µm in diameter, with an extremely large surface area relative to their volume, due to their small size and high dissolving efficiency in water (Onari 2001; Sadatomi et al. 2005). Advantages of this device over conventional bubbling devices include efficient introduction of dissolved oxygen into the water and in reduced costs and energy consumption for aeration of the water. The use of this device, however, is now restricted for temporarily aerating the water in shellfish culture. Its power supply is generated by a fishing boat engine. Use of the device on an offshore fish farm would require continuous monitoring from a raft set beside the fish farms, because of the higher rate of oxygen consumption by cultured fish compared to that of shellfish.

A micro-bubble generating system with an independent electric power supply was developed in a joint research project with Tashizen TechnoWorks, Co. Ltd. (Srithongouthai et al. 2006) (Fig. 1). Treating the organically enriched sediment deposited on the sea floor just below the fish farms requires decomposition of the organic matter in the sediment. With previous techniques, bacterial agents and some chemicals were created and marketed. Unfortunately, they had a very limited effect on only the surface of the sediment.

In this study, decomposition of the organic matter was promoted by utilizing the biological activities of a small deposit-feeding polychaete, *Capitella* sp. I (identified by J. P. Grassle), and its closely related sibling species. These species are common in the benthic communities found in organically enriched sediments throughout the world (Pearson and Rosenberg 1978). They have a life cycle of only 4-6 weeks, and they multiply very rapidly in the organically enriched sediment when the bottom conditions are favorable (Grassle and Grassle 1974; Tsutsumi 1987, 1990). During the process of rapid population growth, the *Capitella* tend to quickly consume the organic matter in the enriched sediment by their feeding activities and stimulation of bacterial activities in the sediment (Chareonpanich et al. 1994; Tsutsumi et al. 2002).

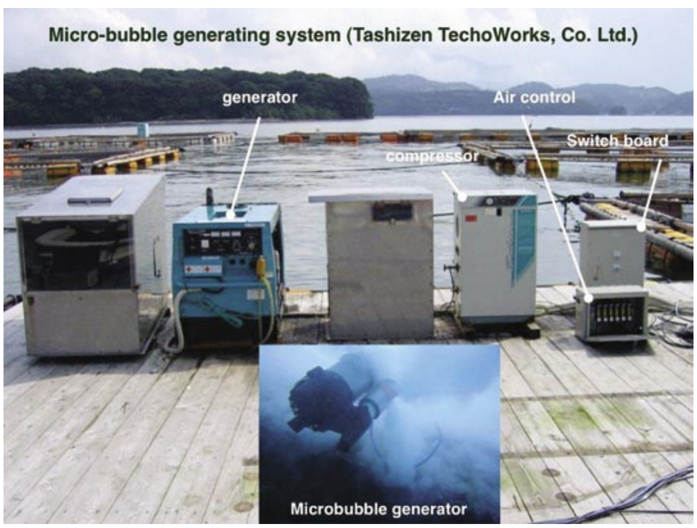

Figure 1. Micro-bubble generating system developed by Tashizen TechnoWorks Co., Ltd.

Tsutsumi and Montani (1993) proposed a bioremediation method for the treatment of the organically enriched sediment with artificially cultured colonies of the *Capitella* species. A joint research project of the author with marine bacteriologists, engineers of the microscopic bubble generator, and fish farmers was initiated in 2002, to improve the water quality at the fish farms using a microscopic bubble generator (Srithongouthai et al. 2006) and artificially mass-cultured colonies of *Capitella* species and bacteria associated with this species (Tsutsumi et al. 2005; Wada et al. 2005). Mass-cultured colonies of *Capitella* that had been generated by the team were spread just below net pens of red sea bream in a bay in Amakusa, Kyushu, in western Japan in the autumn of 2003 and 2004. The *Capitella* population increased very rapidly, reaching densities of approximately 130,000 individuals (ind.)/m^2 and 530,000 ind./m^2 in the sediment within three months in the winter of 2004 and 2005, respectively. As the *Capitella* population increased, the organic matter content and acid volatile sulfides of the surface layers of the sediment decreased markedly (Fig. 2). Thus, spreading the artificially cultured colonies of *Capitella* was shown to be an effective technique for treating the organically enriched sediment and preventing further progress of the organic enrichment of the sediment below the fish farm.

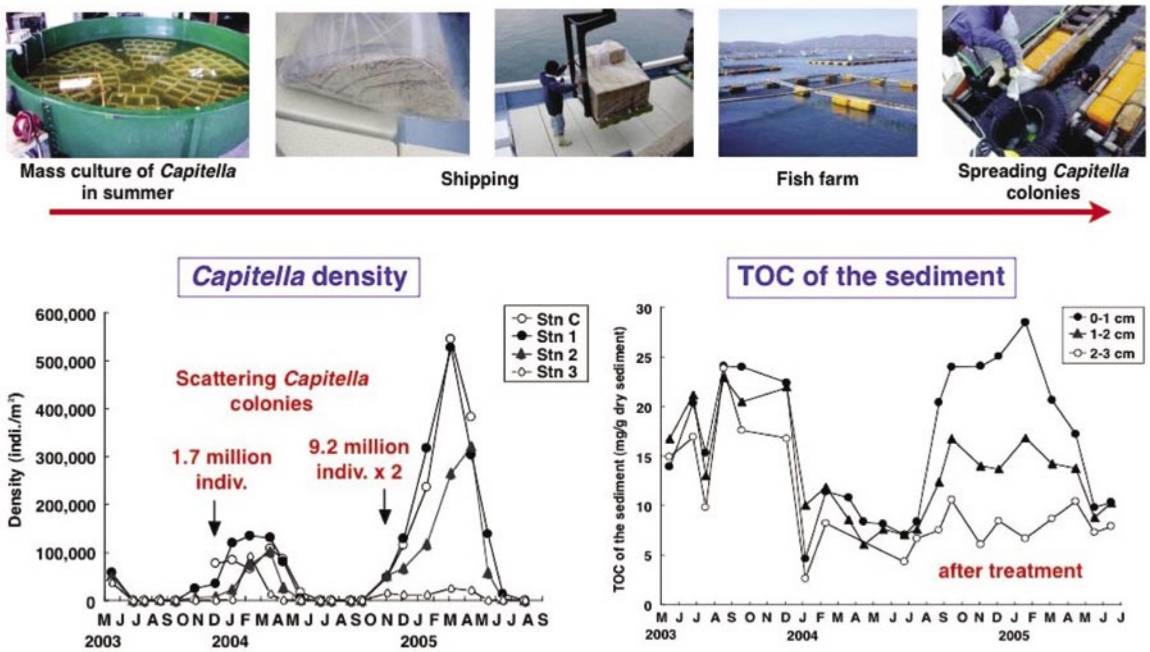

Figure 2. Mass culture of *Capitella* sp. in a factory and spreading of the culture just below a net pen of a fish farm and the effect of the bioremediation experiment for the organically enriched sediment using *Capitella* sp. colonies. Left: Density of *Capitella* sp. population in the bioremediation experiment just below a net pen. Right: TOC of the sediment treated by *Capitella* sp. colonies just below a net pen.

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