IMTA as a possible countermeasure for reduced aquaculture productivity in Japan

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Introduction

Aquaculture is a growing industry worldwide, and it is all the more becoming an important source of food and income for people. Intensive aquaculture, however, can have adverse effects to the environment. Aquaculture effluents may cause eutrophication of the water and sediment, resulting in consequent occurrence of algal bloom, hypoxia of the bottom water and production of toxic hydrogen sulfide. These may then lead to mass fish kills and oceanic dead zones. Intensive fed aquaculture of finfishes and crustaceans, for instance, can therefore be detrimental to the environment. Environmental deterioration are becoming increasingly problematic in many parts of the world.

On the other hand, eutrophication has been reduced in the coastal waters of Japan as a result of mitigation efforts over the past thirty years. In other words, "oligotrophication" is progressing in Japan. The Ministry of the Environment implemented the "Total Pollutant Load Control System (TPLCS)" in 1979 to mitigate the eutrophication of the enclosed sea areas (*i.e.* Tokyo Bay, Ise Bay and Seto Inland Sea). The TPLCS regulated the allowable discharge of chemical oxygen demand (COD, which is the amount of oxygen needed for the oxidation of all organic materials in water), total nitrogen (N) and total phosphorus (P) to the enclosed sea areas with poor seawater exchange.

Relative to the past, this oligotrophication of the coastal waters is considered to have caused a decline in the productivity of the coastal environment, resulting in a continuous decrease in some coastal fishery resources in some parts of Japan. For example, fisheries production of benthic finfishes in Seto

Inland Sea has decreased markedly, and the fishery production was found to be negatively correlated with the dissolved inorganic nitrogen (DIN) level in the coastal water (Handa and Harada, 2012). Productivity of unfed aquaculture of mollusks and seaweeds is also affected by the nutritional conditions of the coastal waters. Bleaching of cultured nori (*Pyropia yezoensis*) thalli has become problematic in Japan (*i.e.* darker color commands a higher price), and it is attributable to insufficient supply of nutrients (*i.e.* N and/or P depending on the area) to the coastal culture areas, especially at the end of the culture season in winter (Yamamoto, 2003).

In addition to TPLCS regulations that have reduced terrestrial nutrient loads, diminished production and improved feeding management of coastal finfish aquaculture, these have also contributed to the reduced nutrient levels in the seas.

Dwindling aquaculture production in Japan

The volume of aquaculture production of many aquatic organisms, including finfishes, bivalves, crustaceans and seaweeds, are on a long-term decreasing trend in Japan. Based on the national statistical data issued by the Ministry of Agriculture, Forestry and Fisheries, the total marine aquaculture production decreased by 20 % by volume between 1996 and 2016. In fed aquaculture of marine finfish, productions of the red seabream (*Pagrus major*), Japanese flounder (*Paralichthys olivaceus*) and horse mackerel (*Trachurus japonicus*), for instance, have declined markedly in both volume and value.

Eutrophication caused by fed aquaculture effluent has been regulated by Sustainable Aquaculture Production Assurance Act (APAA) issued by the Fisheries Agency since 1999. With the assistance of the prefectural extension workers, fisheries cooperative associations as a group or individual farmers are required to submit an Aquaculture Area Improvement Plan to the respective government office every five years. Typically, appropriate maximum culturing density of finfishes is set to be less than 95 % of the trimmed mean excluding the largest and the smallest values of the density from the previous five-year term. The reduced production also intends to prevent oversupply and subsequent price drop of the products. This may also be one of the causes of Japan's decreasing aquaculture production, along with various other socio-economic factors.

As for unfed aquaculture, production volume of many seaweeds which include nori, kelps (*Saccharina japonica* and *S. angustata*), wakame (*Undaria pinntifida*) and oysters (*Crassostrea gigas* and *C. nippona*) have decreased over the past twenty years. Fisheries production inclusive of bottom culture of transplanted seeds of the Manila clam (*Ruditapes philippinarum*) has decreased drastically in Japan. The production volume of the Manila clam peaked at 1.7 × 10^5 t in 1983, and it has gradually and continuously dropped to 7.1× 10^3 t in 2017 (*i.e.* 96 % decrease in 34 years). One of the reasons for this extreme decrease is considered to be reduced primary productivity due to oligotrophication of the coastal waters (Uchida, 2014).

Oligotrophication and reduced primary productivity

Statistical data for environmental parameters in Ise Bay, central Japan, reported by Mie Prefecture Fisheries Research Institute (1972–2016), showed that DIN level has a long-term decreasing trend over the past thirty years. The annual mean DIN level was 11.2 μM and 4.6 μM in 1985 and 2015, respectively (*i.e.* 58.9 % reduction in 30 years). P level, on the other hand, did not decrease between 1985 (0.59 μM) and 2003 (0.63 μM) and had a decreasing trend with large fluctuations between 2004 (0.79 μM) and 2015 (0.27 μM).

The difference observed in N and P levels between 1985 to 2004 might be attributable to the introduction of P-free detergents and establishment of coagulation-sedimentation method that were implemented at wastewater treatment systems in the late 1970s, which had already reduced the P level before 1985 (Washio, 2015). The denitrification method for N removal, on the other hand, did not become widely used until 1990s, resulting in over supply of N relative to P (*i.e.* N-P imbalance) during this period.

The ratio of N and P in seawater is known to alter phytoplankton species compositions (*e.g.* Rhee, 1978), which may subsequently affect aquaculture production of bivalves that feed on the phytoplankton.

Occurrence of harmful algal bloom (HAB) is closely linked with seawater nutrient levels (Honjo, 1994). The occurrence frequency of HAB has been markedly reduced in Ise Bay (Mie prefecture, 1972–2016). HAB was observed 31 times (*i.e.* gross number and not necessarily equals the actual occurrence) in 1985, whereas it was observed only once in 2015. Reduced nutrient level is probably one of the key causes of the long-term subsiding HAB.

Similarly, the surface chlorophyll *a* level has been in a decreasing trend in Ise Bay (**Figure 1**), indicating the reduced primary productivity of not only HAB species but also other phytoplankters which may play important roles in supporting the food web in the area.

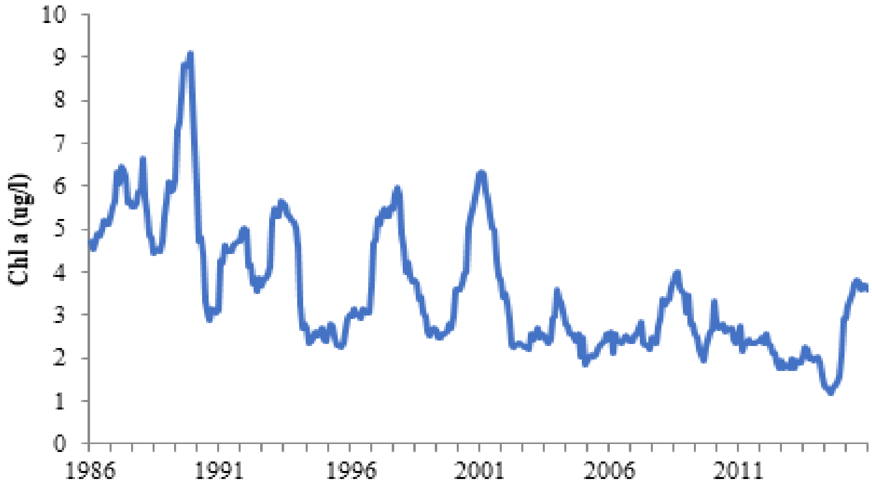

Figure 1. Trend in chlorophyll *a* level in Ise Bay

IMTA as a possible countermeasure for oligotrophication

Our hypothesis is that putting fed aquaculture effluent into practical use enhances the production of coastal fisheries and unfed aquaculture of bivalves and seaweeds. In addition, income from unfed aquaculture and added ecological value may revitalize fed aquaculture of finfishes.

Integrated multi-trophic aquaculture (IMTA) is an aquaculture approach that combines culture of economically important species from different trophic levels, typically finfish, organic extractive species (e.g. bivalve) and inorganic extractive species like seaweeds (Chopin, 2006). IMTA is usually operated to mitigate eutrophication of water and sediment as a responsible approach to environmental integrity. However, it should also be used as a counter measure for reduced primary productivity due to oligotrophication.

Our ongoing study on IMTA

To acquire basic information on the influential extent of aquaculture effluent on carrying capacity of coastal waters, we have been conducting environmental surveys to investigate the behaviour of nutrients and primary production covering the whole bay area and more intensively around the red seabream aquaculture cages in Gokasho Bay, Mie, Japan.

Seawater samples were collected monthly at 19 points within the bay. In addition, 47 points were seasonally sampled, from around the red seabream aquaculture cages to analyze the concentration of the following nutrients: dissolved inorganic nitrogen (DIN: NH_4-N, NO_2-N, NO_3-N), PO_4-P and SiO_2-Si. A CTD is used to obtain the vertical profile of temperature, salinity, dissolved oxygen (DO), and chlorophyll *a* from the surface to the bottom.

Results showed that there were general trends of higher DIN-N and PO_4-P levels near fish cages and deeper parts of caves in Gokasho Bay.

DIN-N and DO levels observed in the red seabream culture area in December 2016 were comparable to those from the same month in 1980s (National Research Institute of Aquaculture, 1991), when aquaculture was more prosperous. However, PO_4-P level was an order of magnitude lower (**Figure 2**), probably due to diminished aquaculture production and improved feeding management, including the switch from raw bait to formulated feed.

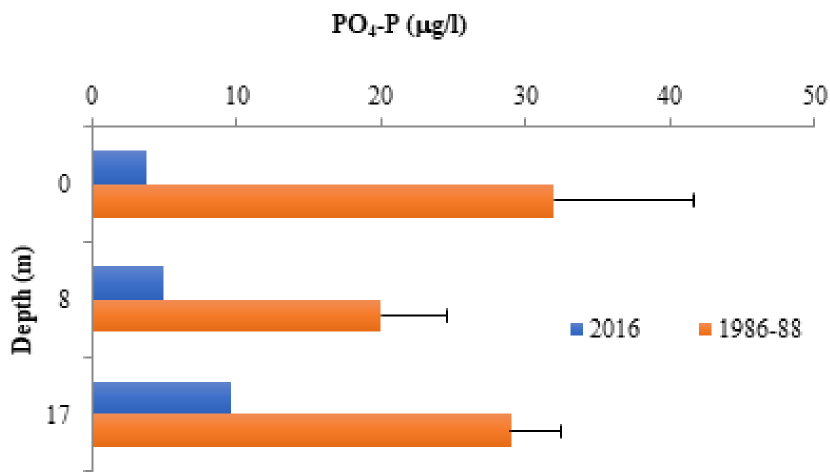

Figure 2. PO_4-P concentration in the vicinity of red seabream aquaculture cage, comparison with late 1980s.

During a diatom bloom observed in November 2016, the depletion of SiO_2-Si implied that the availability of Si, but not N or P, was the limiting factor for the diatom growth in Gokasho Bay.

There were spots with a higher NH_4-N level at the center and 20 m outside the red seabream cage area in January 2017. The chlorophyll *a* level was higher around the cages than in the surrounding water (**Figure 3**), and NO_3-N was lower around the cages conversely. The observed lower NO_3-N concentration may indicate that the enhanced primary production triggered by the NH_4-N supply from the aquaculture effluent rapidly consumed not only NH_4-N but the background NO_3-N in the area. This indicated that DIN-N excreted by the red seabream stocks may not travel a long distance from the cages before being absorbed by primary producers.

In order to fertilize seaweed with red seabream aquaculture effluent, the seaweed should be cultured in the vicinity of the fish cages. The elevation of chlorophyll *a* indicates the possibility of productive co-culture of red seabream and bivalves.

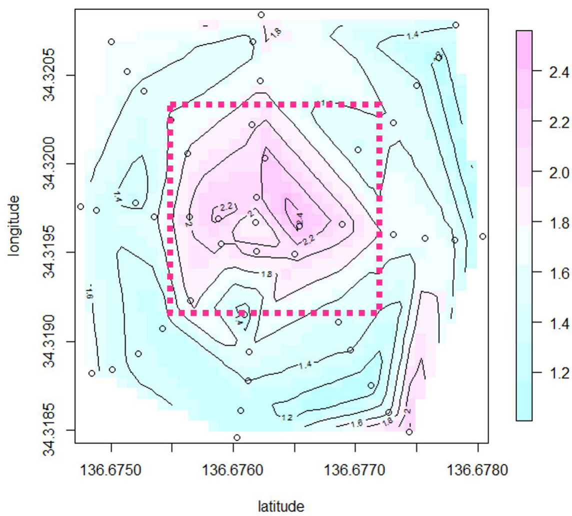

Figure 3. Chlorophyll *a* level in red seabream aquaculture area in January 2017. Dashed line indicates the area with fish cages (110 m × 150 m)

Therefore, IMTA has a potential to enhance aquaculture production by using what would otherwise be fish waste to be utilized by other organisms. However, for the practical realization of IMTA, there are challenges to be overcome. For example, our study so far showed that biofouling intensity is higher near a red seabream cage than in an oyster culture raft area (**Figure 4**). There was also a tendency that more crustaceans, such as *Caprellidae*, attaching to the culture containers near the fish cages.

Further studies are underway on aquaculture techniques to provide useful information for the establishment of effective IMTA systems to utilize aquaculture effluent in oligotrophic waters.

Figure 4. Intensive biofouling on an oyster culture basket hanged from a red seabream culture cage.

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