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Environmental carrying capacity in an aquaculture ground of seaweeds and shellfish in Sanriku coast

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Abstract In non-feeding aquaculture of seaweeds and shellfish the culture organisms compete with natural populations for resources, viz. nutrient salts and food particles. Therefore evaluation of carrying capacity of coastal waters is crucial for sustainable exploitation of biological productivity. For this two major criteria are proposed: accurate estimation of phytoplankton primary production which governs the magnitude of total biological productivity, and understanding of oxygen dynamics based on a preliminary study in a bay on the northeastern coast of Japan.

Key words: carrying capacity, shellfish culture, seaweed culture, Sanriku coast

Non-feeding aquaculture of seaweeds and shellfish recovers nutrient loadings from the land. Since there is no other industrial way of recovery, this function is very important in controlling nutrient cycling between land and coastal waters. The amount of the recovery by short-neck clam fisheries is estimated to be about a sixth of the total input of nitrate in Hamana Bay in central Japan (A. Hino, personal communication). Knowledge of material cycling in the natural ecosystem is prerequisite to utilize coastal productivity in a sustainable manner, as the cultured organisms are dependent on the natural ecosystem. Nutrients, the key factor that fuels primary production, are supplied by advection, riverine input and regeneration, and utilized by phytoplankton and macroalgae competitively. Then, organic matter produced by phytoplankton, naturally occurring and cultured macroalgae is consumed not only by zooplankton and benthic organisms, but also by cultured scallops and oysters. Thus it is important to quantify the production at different trophic levels for evaluation of the carrying capacity of coastal waters.

Tatara (1992) partitioned the distribution of organic matter produced by primary producers to heterotrophs and traced a grazing food chain. In this work, several factors were considered that determine the carrying capacity of coastal waters for fisheries production. One of the major hurdles recognized was the poor availability of biological data. In coastal areas, primary production of phytoplankton markedly fluctuates in the time scales of hours to weeks. Although the bottle incubation technique has been traditional and standard in the measurement of primary production, its spatio-temporal coverage is strictly limiting.

A study on material cycling in an aquaculture ground for seaweeds and shellfish is in progress in Otsuchi Bay. The bay located at 39 ° 20'N, 141 ° 56'E is 8 km long and 2 km wide, and opens into the western North Pacific Ocean. Owing to the freshwater flow into the innermost part, and the long and narrow topography of the bay, exchange of water in the bay is expected to be brought about as, a seaward outflow of the surface water over landward-moving inflow of denser, more saline subsurface water from outside the bay (Shikama, 1990). This circulation occurs fre-

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quently during winter and spring when the westerly seasonal wind prevails. Conversely, an inflow of surface water over outflow of deeper water is also observed during the summer. This circulation pattern may alter from the former to the latter, and vice versa in summer, depending on the difference in water density between inside and outside the bay. The formation of spring bloom depends on the wind-driven circulation. The outward flow of the surface water interrupts formation of the spring bloom, and transports phytoplankton population seaward (Fig. 1, Furuya *et al.*, 1993). By such water movements, a significant amount of nutrients in the bay is brought out, or replenished into the bay in the subsurface layer, depending on water masses located outside the bay. Therefore, the water movement governs in- and outward flux of materials in the bay. Owing to this physical condition, high temporal resolution of observation is of particular importance in the study of material cycling in the bay.

Preliminary results of the study are summarized in Furuya (2004) and briefly outlined here.

Primary production and dissolved oxygen on the bottom

A bio-optical approach was used for rapid monitoring of chlorophyll a and primary production with high temporal resolution. The

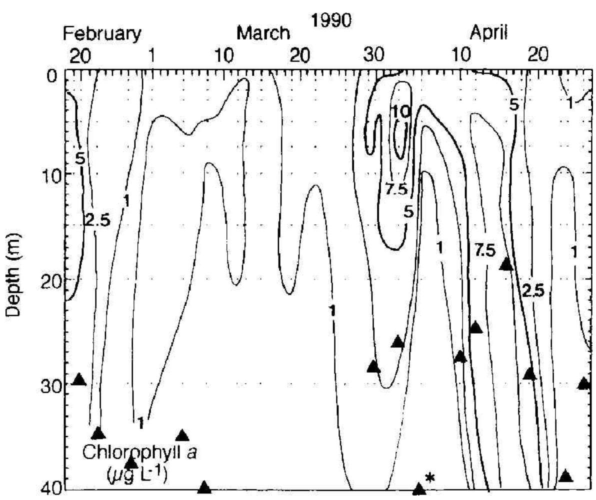

Fig. 1. Chlorophyll *a* at a station in Otsuchi Bay during the spring of 1990 (Furuya *et al.*, 1993)

natural fluorescence technique (Chamberlin and Marra, 1992) was improved for use in coastal waters (Yoshikawa and Furuya, in press) and applied for estimating chlorophyll a and phytoplankton primary production in the bay. Both calculated chlorophyll a and primary productivity from natural fluorescence showed significant correlations with the directly measured values during four seasons.

The integrated primary production throughout the water column was estimated from data obtained by a moored fluorometer, and extrapolated to the production of the whole bay. The primary production of the entire bay was estimated to be 1.7×10^3 ton C during a period from mid January to late April.

The cultured kelp *Undaria. pinnatifida* (locally called wakame) showed steady growth until March, while growth was much reduced in April (Yoshikawa *et al.*, 2001). Maximum biomass of 840 ton in wet weight (28.3 ton C, and 2.54 ton N) was recorded in early March, just prior to the harvest, and these figures decreased as the harvest continued. During April a major portion of the primary production was lost by removal of aged part of the thallus. Production of cultured *U. pinnatifida* throughout Otsuchi Bay increased steadily in January and February, and reaching maximums of 1055 kg C d^{-1} and 99.0 kg N d^{-1} in March. Erosion of the alga began in early March, and peaked at a rate of 469 kg C d^{-1} and 43.1 kg N d^{-1} in mid March. Erosion declined gradually as harvesting continued, and was comparable to production rates during the month of April.

The biomass harvested was 38.7 ton C (81 % of total) while that lost due to erosion was 10.8 ton C corresponding to 19 % of the total biomass produced.

Phytoplankton primary production consistently exceeded that of *U. pinnatifida* by more than 20 times and was 38 times higher on average (Fig. 2). Variations in phytoplankton primary production was ascribed primarily to the change in phytoplankton biomass, which was largely controlled by water circulation (Furuya *et al.*, 1993).

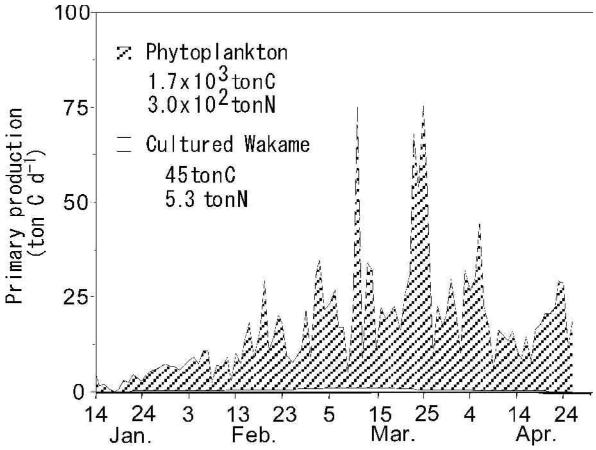

Fig. 2. Primary production of phytoplankton as measured by natural fluorescence and that of wakame (Furuya, 2003)

Organic matter loadings and dissolved oxygen concentration in bottom waters were examined near the shellfish culture areas under culture rafts of a scallop *Patinopecten yessoensis* and the Japanese oyster *Crassostrea gigas*. Sinking flux of organic matter, mainly composed of fecal matter was significantly higher under the culture rafts of the oyster than under those of the scallop. The flux under the oyster rafts was 21.6 mg C m^{-2} d^{-1} on average in spring and summer, while that under the scallop rafts was 7.75 mg C m^{-2} d^{-1}. The mean flux outside the raft area as control was 5.75 mg C m^{-2} d^{-1}. Oxygen consumption rate of bottom seawater taken under the scallop rafts as determined by dark bottle incubation ranged from 0.26 to 3.07 mg L^{-1} d^{-1} with a mean of 1.49 mg L^{-1} d^{-1}. The mean *in vitro* rate implied rapid depletion of dissolved oxygen near the bottom in 5 days. However, *in situ* dissolved oxygen was never exhausted in summer varying between 4.34 and 7.19 mg L^{-1} d^{-1}. *In situ* continuous monitoring showed steady but slow decrease in dissolved oxygen during the summer at a mean rate of 0.041 mg L^{-1} d^{-1}. This apparent rate indicates that it should have taken 160 days to produce anoxic water. These observations show continuous supply of dissolved oxygen through water flow along the bottom is large and maintain the favorable oxygen field near the bottom in summer. Wind-induced circulation, density current and, in particular, internal tide are responsible for the inflow of the outside water along the bottom (H. Otobe, in preparation).

In Sanriku coast there is an array of bays with similar topography to that of Otsuchi Bay. Therefore, an active inflow of subsurface water can be expected from outside which prevents depletion of dissolved oxygen. On the contrary, anoxic water mass is formed near the bottom of Ofunato Bay which located in the southern part of the Sanriku coast. There is a sill in the mouth part of the bay that reduces water exchange considerably, being responsible the formation of anoxic water together with the intensive culture of the Japanese oyster. With comparison of the water circulation and associated oxygen field near the bottom sediment between Otsuchi Bay and Ofunato Bay, it is clear that dissolved oxygen is important for sustainable exploitation of biological productivity in aquaculture areas. Other bays on the Sanriku coast, water exchange is likely active according to bottom topography. Therefore, the Sanriku area is in general suitable for aquacultures in a point of view of oxygen supply.

Shellfish culture

Cultures of scallop and oyster occupy more than 95 % of total annual production of shellfish in Japan (Fig. 3). The annual production has been rather constant over recent ten years.

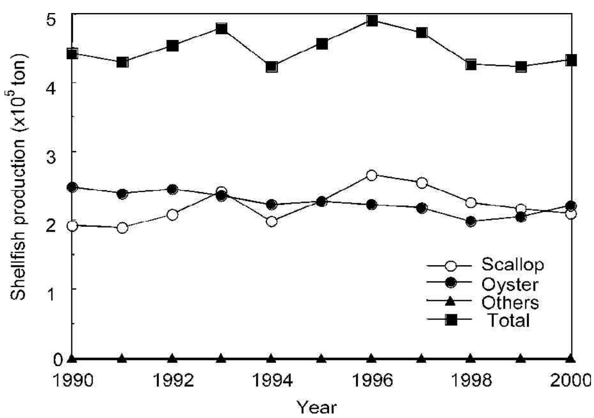

Fig. 3. Annual production of shellfish culture in Japan (Ministry of Agriculture, Forestry and Fisheries Japan, 2001)

Almost all of the production is consumed as foods for human with a small portion for pet foods. Among the major reasons for the constant production over years, saturation of market and maturation of culturing technique are considered to be most responsible (H. Kurokura, personal communication). Considering the significance of shellfish culture as recovering means of nutrient loadings, utilization of unexploited potentials of shellfish culture should be challenged intensively. For development of the market, one possibility is use of shellfish as materials of forage production. Since there is increasing demand of foods of livestock and fish culture in Japan, self-support ratio of food is under the influence in Japan. Potential importance of shellfish as protein source may be acknowledged by selection of suitable species for culture, and technical development of food processing for forage production. Nevertheless, there should be various uncertainties how compatible a new species is introduced with current culture of scallop and oyster. Therefore, optimized utilization of biological production is emphasized for the introduction of new species as well as sustainable development of scallop and oyster culture.

Conclusion

The observation during the study serves development of numerical physical-biological coupled models (Kawamiya *et al.*, 1995; Kishi *et al.*, 2003; Kishi *et al.*, in prep.). Kishi *et al.* (2003) incorporates the aquaculture of both wakame and shellfish into the model. The continuous monitoring of flow field, chlorophyll a, primary production and dissolved oxygen with high temporal resolution serve robust validation of the model performance and improvement of the model. Evaluation of carrying capacity of the bay is in progress using the model to understand the importance of phytoplankton primary production and dissolved oxygen and to identify other key factors. The model is intensively used to optimize aquaculture production of seaweeds and shellfish with least environmental impacts in the bay.

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