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# Effects of fish aquaculture on inorganic nutrient levels in Gokasho Bay

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**Abstract**: Eutrophication derived from aquaculture effluent and consequent environmental deterioration are becoming increasingly problematic in many parts of the world. On the other hand, eutrophication has been reduced in coastal waters of Japan because of mitigation efforts over the past thirty years. While such efforts have positive effects on maintaining environmental integrity, excessive reduction of nutrient load to the coastal environment is thought to have reduced the productivity of many fishery resources and unfed aquaculture. Our hypothesis is that putting aquaculture effluent into practical use enhances the production of coastal fisheries and unfed aquaculture. To acquire basic information on the influential extent of aquaculture effluent on carrying capacity of coastal waters, environmental surveys were conducted to investigate the behavior of nutrients and primary production covering the whole bay area and more intensively around the red seabream, *Pagrus major*, aquaculture cages in Gokasho Bay, Mie, Japan. Seawater samples were collected monthly at 3 depths (surface, mid-layer and bottom) at 19 points in the bay, and seasonally at surface and depth of 5 m (i.e. midpoint of the cage depth) at 47 points approximately 20 m apart from one another around the red seabream aquaculture cages. The concentration of the following nutrients was analyzed: dissolved inorganic nitrogen (DIN: $NH_4$-N, $NO_2$-N, $NO_3$-N), $PO_4$-P and $SiO_2$-Si. A CTD was used to obtain the vertical profile of temperature, salinity, dissolved oxygen (DO), and chlorophyll *a* from the surface to the bottom. Although the DIN-N and DO levels in December 2016 were comparable to those from the same month in 1980s where aquaculture was more prosperous, the $PO_4$-P level was an order of magnitude lower probably due to diminished aquaculture production and improved feeding management, including the switch from raw bait to formulated feed. 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 higher $NH_4$-N levels at the center and 20 m outside the red seabream cage area in January 2017. The chlorophyll *a* level was higher and $NO_3$-N was lower around the cages than in the surrounding water. 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, thereby indicating that DIN-N excreted from red seabream may not travel a long distance from the cages before absorbed by primary producers. In order to fertilize seaweed with red seabream aquaculture effluent, the seaweed should be cultured near the fish cages. The elevation of chlorophyll *a* indicates the possibility of productive co-culture of red seabream and bivalves.

**Key words**: dissolved nutrients, oligotrophication, primary production

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## Introduction

With the global expansion of aquaculture production, eutrophication derived from aquaculture effluent and consequent environmental deterioration are becoming increasingly problematic in many parts of the world. On the other hand, eutrophication has been reduced in coastal waters of Japan because of mitigation efforts over the past thirty years. The Total Pollutant Load Control System (TPLCS) has been implemented for water pollution management of Seto Inland Sea, Tokyo Bay and Ise Bay since 1979; it regulates the allowable amount of terrestrial nitrogen/phosphorus discharge to the sea. Allowable discharge of aquaculture effluent to the surrounding environment has been regulated by Sustainable Aquaculture Production Assurance Act (APAA) issued by the Fisheries Agency since 1999. Aquaculture operators set the stocking density of their commodities in consultation with prefectural government under APAA.

While such efforts have positive effects on maintaining environmental integrity, excessive reduction of nutrient load to the coastal environment is thought to have reduced the productivity of many fishery resources and unfed aquaculture in Japan. The oligotrophication of coastal waters has reduced the carrying capacity of the coastal ecosystem, resulting in a continuous decline in fishery resources and reduced productivity in unfed aquaculture, which relies on naturally available nutrition. The reduction of benthic fish fisheries production in Seto Inland Sea, for instance, is considered to be related with the declining dissolved inorganic nitrogen (DIN) level in the coastal water (Handa and Harada, 2012). Bleaching of *nori* (*Pyropia yezoensis*) thalli due to insufficient DIN has been problematic in Seto Inland Sea and Ariake Sound since 1990s, causing a great economical loss to the *nori* farmers (Nishikawa and Hori, 2004; Yamamoto, 2003).

Fed aquaculture of finfish usually has high feed conversion ratio (FCR). The FCR of red seabream (*Pagrus major*), for instance, is between about 2.1 and 2.7 when fed artificial diet (Furukawa, 2008; Ono and Nakahara, 2009), meaning that it takes 2.5 kg (i.e. FCR = 2.5) of feed to produce 1 kg of fish. Thus, 1.5 kg of the feed is wasted as feces, metabolites and leftover. Such aquaculture effluents used to be a cause of eutrophication of water and sediment resulting in environmental deterioration. However, eutrophication has subsided due to reduced aquaculture intensity and improved feeding techniques.

Our hypothesis is that moderate eutrophication is favorable for primary production and putting aquaculture effluent into practical use enhances the carrying capacity and, thus, production of coastal fisheries and unfed aquaculture. This paper is a partial report of the long-term periodical monitoring of water quality in Gokasho Bay, Mie, Japan, the results of which will be used as a basis for designing effective integrated multi-trophic aquaculture (IMTA) techniques (Chopin, 2006).

## Materials and Methods

To acquire basic information on the influential extent of aquaculture effluent on carrying capacity of coastal waters, environmental surveys have been conducted to investigate the behavior of nutrients and primary production covering the whole area of Gokasho Bay, Mie prefecture, Japan, and also more intensively around the red seabream (*Pagrus major*) aquaculture cages in Hasamaura Cove in Gokasho Bay.

Seawater samples have been collected monthly at 3 depths (surface, mid-layer and bottom) at 19 points in the bay, and seasonally at surface and depth of 5 m (i.e. midpoint of the cage depth) at 47 points approximately 20 m apart from one another around the red seabream aquaculture cages using a Kitahara water sampler since November 2016. An aliquot (12 ml) of the seawater samples were filtered with a 0.2 μm syringe filter and stored at -30℃ until analyses. The concentration of the following nutrients has been analyzed: dissolved inorganic nitrogen (DIN: $NH_4$-N, $NO_2$-N, $NO_3$-N), $PO_4$-P and $SiO_2$-Si with an auto-analyzer (TRAACS 800, Bran+Luebbe).

A CTD (RINKO profiler, JFE Advantech) has been used to obtain the vertical profile of temperature, salinity, dissolved oxygen (DO), and chlorophyll *a* at depths of every 10 cm from the surface to the bottom. The DO concentration was calibrated using more precisely analyzed values with a DO meter (MM-60R, TOA DKK) in the laboratory.

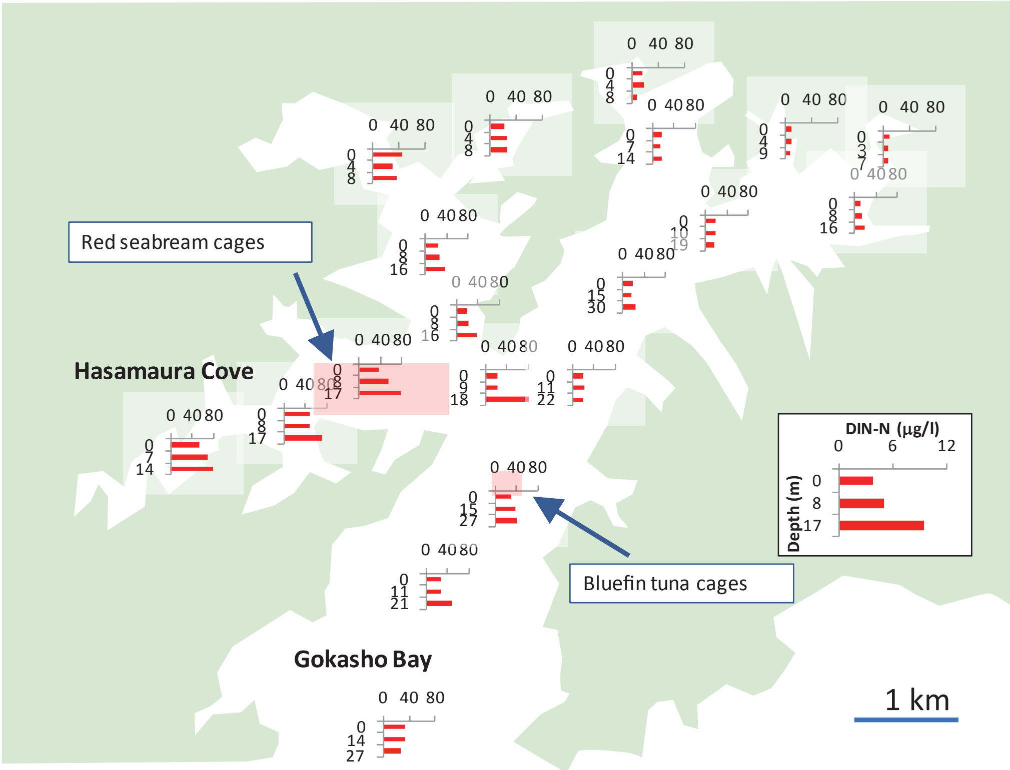


**Fig. 1.** Dissolved inorganic nitrogen (DIN-N) concentration in Gokasho Bay, Mie, Japan in December 2016.

The chlorophyll *a* concentration was obtained by converting the fluorescence intensity of the CTD, using the relationship between the CTD readings and chlorophyll *a* concentration of cultured phytoplankton (*Pavlova lutheri*) measured with a chlorophyll fluorometer (10 AU fluorometer, Turner Designs).

Horizontal distribution of the nutrients and chlorophyll *a* around the red seabream aquaculture cages were obtained by R software with the Akima add-on package for linear interpolation and mapping.

## Results and Discussion

The DIN-N (i.e., the sum of $NH_4$-N, $NO_2$-N, $NO_3$-N) levels were often found to be higher in the area with red seabream aquaculture cages and the inner part of Hasamaura Cove, especially in the bottom water in our monthly water parameter monitoring. An example of the DIN-N concentration distribution in December 2016 is shown in **Fig.1**. The DIN-N concentrations in the red seabream aquaculture area were more than double of those at the mouth of Gokasho Bay opening to the Pacific. The DIN-N concentration did not differ with the depth at the bay mouth, which is considered to be under a strong influence of outer seawater. The $PO_4$-P concentration showed similar trends with DIN-N (**Fig.2**). These indicate that effluent from red seabream aquaculture elevates dissolved inorganic N and P concentrations in Hasamaura Cove. Higher nutrient concentrations in the bottom water may be partially attributable to decomposition of sediment organic matter on the sea bottom deposited from the fish culture.

A comparison of nutrient levels in the aquaculture area in December was made between 2016 and 1980s. The National Research Institute of Aquaculture conducted water nutrient monitoring in Gokasho Bay in late 1980s (Sugiyama *et al.*, 1991), where red seabream and yellow tail (*Seriola quinqueradiata*) aquaculture was more intensive than recent years and self-pollution was an issue (Abo, 2000). The DIN-N concentration was reduced by about 25% from 1980s (the mean of 1986 - 1988) to 2016 (**Fig.3**). The $PO_4$-P

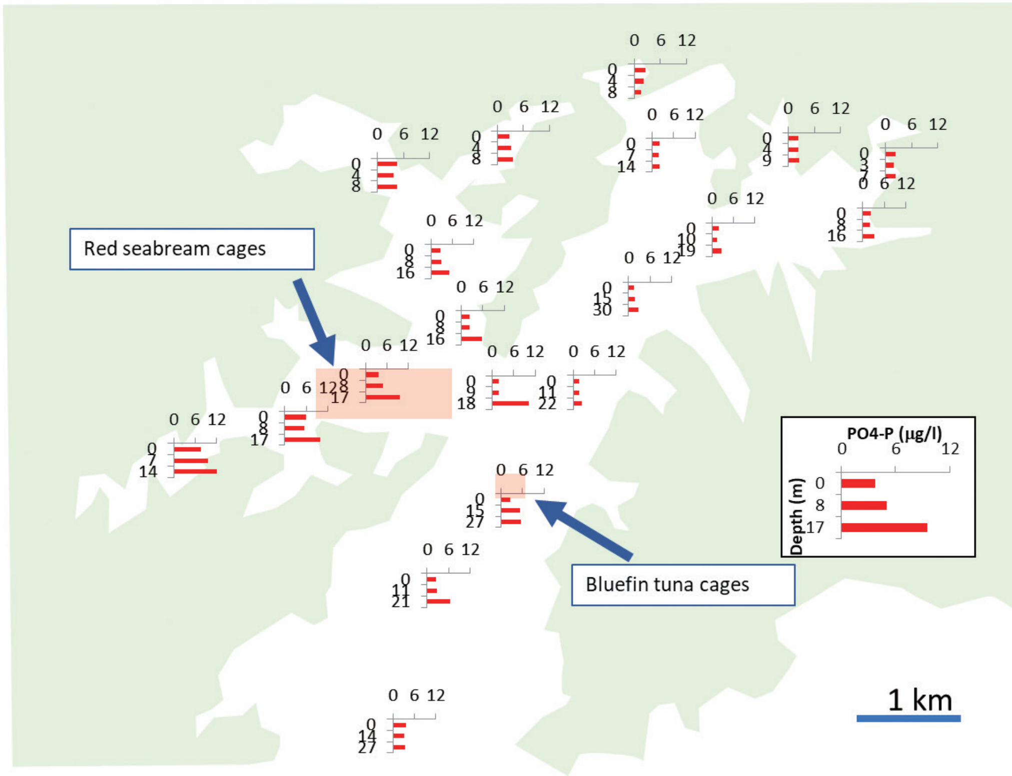


**Fig. 2.** Dissolved inorganic phosphate ($PO_4$-P) concentration in Gokasho Bay, Mie, Japan in December 2016.

concentration was reduced by about 80 % (**Fig.3**). The reduction in the nutrient levels may be related with the reduction of aquaculture production in the area. The large reduction of $PO_4$-P concentration may also be attributable to the shift of aquaculture feed from raw bait to formulated feed. The DO level has moderately increased in the bottom water. Supposedly, because of the reduced organic loads, and a reduction in harmful algal blooms and hypoxia of the bottom water which have no longer been rampant in Gokasho Bay in recent years.

However, diatom blooms sporadically occur in Gokasho Bay. In the case of a diatom bloom observed in November 2016, chlorophyll *a* concentration was higher in the surface and mid-layer water in the red seabream aquaculture area compared with the other locations in Gokasho Bay, reaching about 27 μg/l (**Fig.4**). Despite the diatom bloom, neither DIN-N nor $PO_4$-P were depleted in the aquaculture area, but $SiO_2$-Si was depleted (**Fig.5**). Nutrient load from the aquaculture seemed to maintain relatively high DIN-N and $PO_4$-P concentrations at the depletion level of $SiO_2$-Si, probably making $SiO_2$-Si the limiting factor for diatom production in this area. Reduced Si discharge from rivers to the marine environment associated with the entrapment at dams is perceived to enhance production of non-diatom species including harmful red tide species (Harashima, 2008).

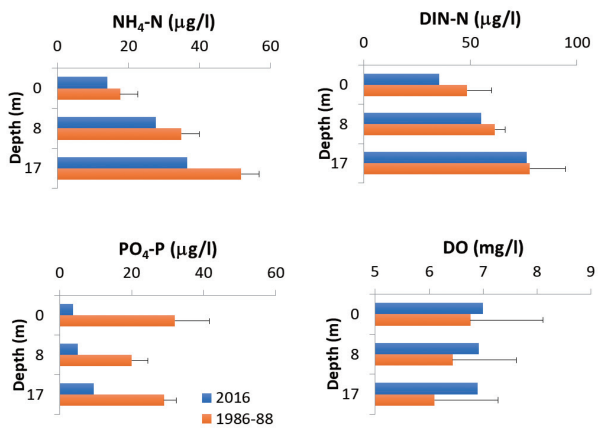


**Fig. 3.** Dissolved inorganic nutrient and dissolved oxygen levels near red seabream (*Pagrus major*) aquaculture cages in December 2016 and 1980s. Data for 2016 are from this study, and data from 1986 to 1988 are after Sugiyama *et al.* (1991).

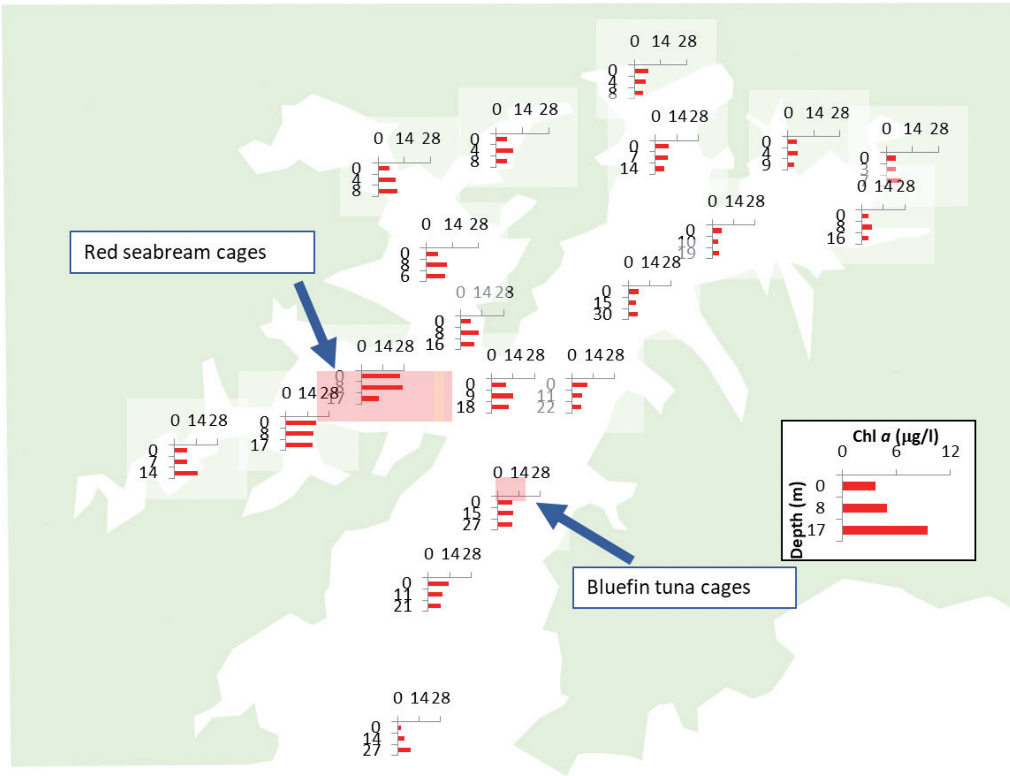


**Fig. 4.** Chlorophyll *a* concentration in Gokasho Bay, Mie, Japan, in November 2016.

Oligotrophication is problematic in some coastal waters in Japan, reducing unfed aquaculture profitability of some bivalves and seaweed (Handa and Harada, 2012; Yamamoto, 2003). In Gokasho Bay, Hasamaura Cove with red seabream aquaculture had relatively higher dissolved inorganic N and P concentrations, which may be used to enhance unfed aquaculture productivity through integrated multi-trophic aquaculture (IMTA) approach (Robinson and Chopin, 2004; Chopin, 2006).

During the intensive water analysis around the red seabream aquaculture cages in Hasamaura Cove in January 2017, there were spots with a higher $NH_4$-N level at the center and 20 m outside the cage area (**Fig.6**). The chlorophyll *a* level was higher, and $NO_3$-N was lower around the cages than in the surrounding water (**Fig.6**). 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 also the background $NO_3$-N in the area. Under this assumption, DIN-N excreted from red seabream may not travel a long distance from the cages, being readily consumed by localized primary production. In Gokasho Bay, green alga (*Monostroma nitidum*) is intensively cultured. To effectively fertilize the seaweed with the red seabream aquaculture effluent, the seaweed should be cultured near the

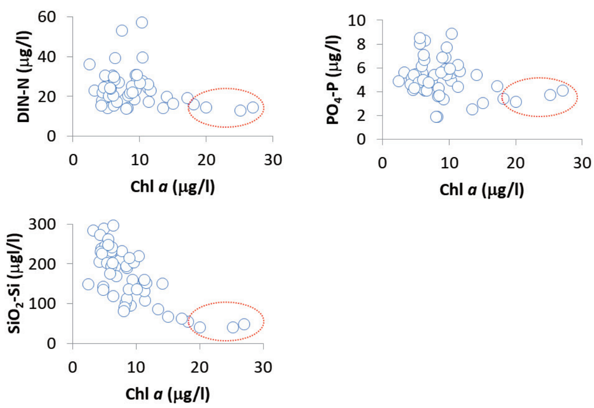


**Fig. 5.** DRelationship between chlorophyll *a* concentration and DIN-N, $PO_4$-P and $SiO_2$-Si concentrations during a diatom bloom in Gokasho Bay, Mie, Japan, in November 2016. Dotted red circles indicate the data from the red seabream aquaculture area in Hasamaura Cove.

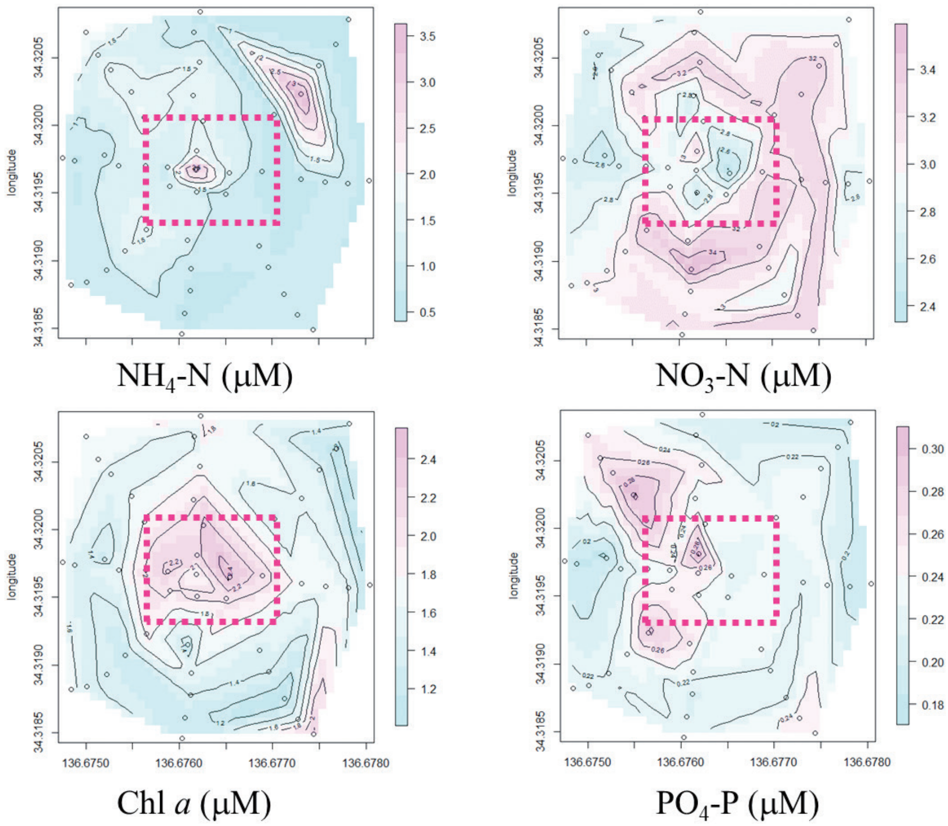


**Fig. 6.** Horizontal topography of $NH_4$-N, $NO_3$-N, chlorophyll *a* and $PO_4$-P concentrations at 5 m depth around the red seabream aquaculture area. Dotted red rectangles indicate the area with red seabream cages.

cages. The elevation of chlorophyll *a* in the fish cage area indicates that the red seabream aquaculture can increase food availability for aquaculture of bivalves, such as Pacific oyster (*Crassostrea gigas*) and Manila clam (*Ruditapes philippinarum*). Field experiments should be further carried out to design an effective IMTA system including these species.

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(1) Yamamoto T., 1992: Constant uptake of ammonium-N and nitrate-N by *Porphyra yezoensis* thalli. *J. Fac. Appl. Bio. Sci. Hiroshima Univ.*, **31**, 155-159.

The author experimentally determined the uptake rates of ammonium-N and nitrate-N by *Porphyra* (currently *Pyropia*) *yezoensis* using $^{15}N$ as a tracer. *Pyropia yezoensis* (laver or *nori*) is an important seaweed in Japan. Specific uptake rate of ammonium-N (0.0017/hr) was more than 8 times higher than that of nitrate-N (0.0002/hr). The uptake rates were constant over the 120-minute experiment, unlike in the case of phytoplankton that is known to rapidly absorb nutrients to satiation. Fertilizers with ammonium-N as the main component may be suitable for *nori* aquaculture. The nitrogenous fertilizer should be provided to *nori* at a low concentration over a long duration to avoid induction of phytoplankton bloom.

(2) Kakehi S., Fujiwara T., and Yamada H., 2005: Seasonal variation in the nutrient standing mass and nutrient budget of Ise Bay. *Umino Kenkyu* (Oceanography in Japan), **14**, 527-540.

The authors estimated the standing mass of dissolved inorganic nitrogen (DIN) and dissolved organic phosphorus (DIP) by the linear regression of apparent oxygen utilization (AOU) or the interpolation of the surface and bottom nutrient concentrations to elucidate the seasonal variations in Ise Bay, Japan. The DIN standing mass in the bottom layer ranged from 1500 to 2600 t, tending to be higher in summer than in winter. The DIN was smaller in the surface layer than in bottom layer in summer, and comparable between the two layers in winter. The DIP standing mass showed more distinct seasonal trend. It was 200 t in surface and bottom layer in winter; whereas it increased to 400 t in the surface and 800 t in the bottom later in summer. The temporal change of the standing mass of the nutrients was more dependent upon biological and chemical processes than physical processes such as seawater exchange. Chlorophyll level is inversely related with DIN and DIP in the surface layer in summer, but DIN and DIP are not completely synchronous. The DIP seemed to be released from the sea sediment in summer where hypoxic water is formed in the bottom layer. Denitrification seemed to take place year-round.