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Nutrient Load and Environmental Conditions for Lower Trophic Level Production on a Reef Slope in Miyara Bay, Ishigaki Island, Japan

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Abstract

To elucidate the anthropogenic nutrient load, nitrate + nitrite and phosphate concentrations were measured at an upstream point where there is little tidal change in the Miyara River, Ishigaki Island, Japan. The environmental conditions of lower trophic level production were observed, and factors related to the relatively high coral cover rate were investigated on the reef slope, although there have been heavy loads on the reef flats and inside the reef edge of Miyara Bay. Though the nitrate + nitrite load was always high, the environmental conditions for lower trophic level production were found to be within an appropriate range for coral growth.

Discipline: Fisheries/Agricultural environment
Additional key words: chlorophyll *a*, coral, nitrate, nitrite, phosphate

Introduction

In Ishigaki Island, Japan, the Omoto mountain range extends along the north shore from east to west. A plain stretches south of the Omoto range, where agriculture and livestock rearing are actively conducted. The population is concentrated in an urban area on the southern part of the island. The Miyara, Todoroki, Arakawa, and Nagura rivers all flow to the south, with the watershed area of the Miyara River being the widest. Therefore, the Miyara has the largest river flow. One type of coral reef, called a fringing reef has developed around Ishigaki Island due to the subtropical oceanic climate, and the wonderful landscape is recognized as communal property in Japan.

Coral reefs in the vicinity of Ishigaki Island have been greatly impoverished by local terrestrial loads over several decades, however, in addition to coral bleaching and damage caused by the feeding of crown-of-thorns starfish. In response to the effects of red soil erosion on the coral reefs, certain laws have been enacted to reduce the volume of eroded materials. Coral communities have adapted and evolved in oligotrophic waters, and are affected by a nutrient load derived from fertilizer, livestock excrement, and drainage.

Banzai and Nakamura[1] observed that suspended solids (SS) and total phosphorus (TP) levels at the Hegina Sluice on the Miyara River increased exponentially with greater river flow. Shimoda et al.[13] investigated the relation between the growth grade of coral reef and the nutrient environment and appropriate range of nutrient concentrations in which coral communities showed a good growth grade. About 50% of the reef slope in Miyara Bay is covered by corals[7] and a high density of coral larvae has been found along the edge of the reef on the west side of Miyara Bay[12].

In this study, we aimed to evaluate the terrestrial nutrients loads supplied to the Miyara reefs, and monitor the nitrate + nitrite and phosphate concentrations in the Miyara River every month at a upstream location with almost zero salinity, in order to investigate why a relatively developed coral reef exists on the reef slope in Miyara Bay, where relatively large red soil and nutrients loads have been received for decades in Okinawa[5,6]. Some factors related to the relatively high coral cover rate on the reef slope were also investigated.

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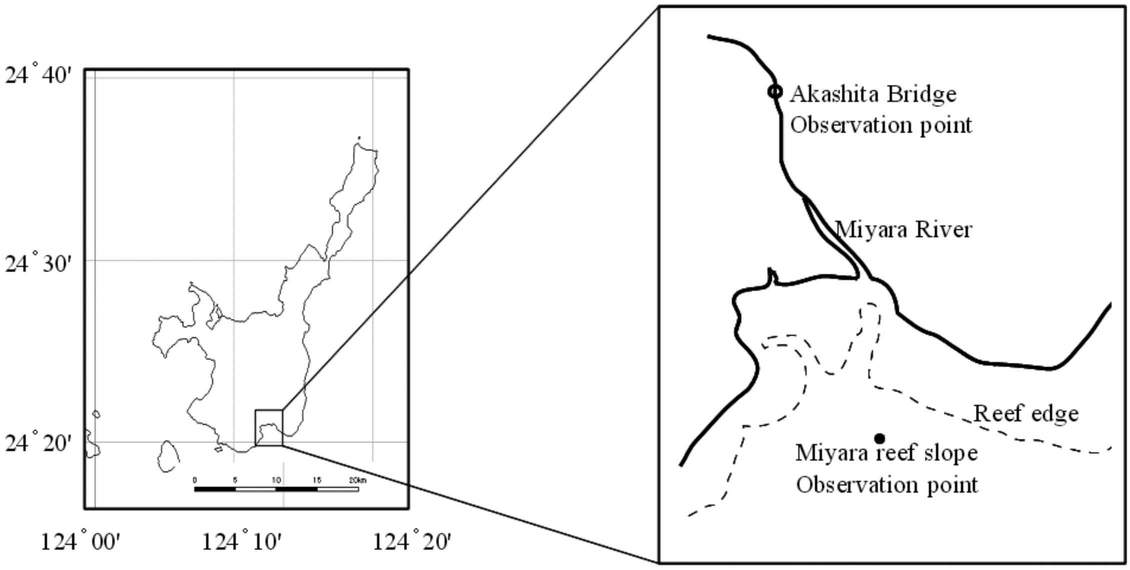

Fig. 1. Map of Ishigaki Island and sampling points on the upper Miyara River and the Miyara reef slope

Materials and methods

Ishigaki Island is located in the southwestern part of the Ryukyu Islands, and fringing reefs have developed around the island. Surface water temperature and salinity were measured using a YSI Model 30 meter, and surface water was sampled monthly to determine nutrients loads from the terrestrial region around the Akashita Bridge on the Miyara River (Fig. 1), where the depth was about 1 m and only subject to slight tidal changes, from April 2006 to December 2010. The investigations were conducted in low water of the spring tide.

Observations were conducted on the reef slope in Miyara Bay (24°20’ N, 124°13’ E) about 2.3 km offshore and at a water depth of about 20 m (Fig. 1), from April 2006 to April 2010 aboard the “Yaeyama” research vessel belonging to the Seikai National Fisheries Research Institute. The water temperature and salinity were measured vertically with a memory-type CTD (Alec Electronics Chlorotech-ACL-208). Water was sampled using 1.2-L or 5-L Niskin sampling bottles from the surface and the bottom (19 m). Unfortunately, some data could not be acquired due to equipment failure and/or adverse weather conditions. Also due to the logistics, investigations at the Akashita Bridge and on the reef slope could not be conducted on the same day.

Water samples from the river and reef slope were filtered through Whatman GF/F filters for collecting chlorophyll *a* (Chl. *a*) in the laboratory, and the filtrate was used for nutrients analysis. For the analysis of Chl. *a*, the filters were soaked in *N*, *N* – dimethylformamide[15]. Chl. *a* was extracted in solvent and analyzed using a fluorometer (Turner Designs 10-AU-005-CE). The nitrate + nitrite and phosphate concentrations were measured with the standard method[10] using the Auto Analyzer 3 (Bran+Luebbe).

Results

The water temperature at the Akashita Bridge varied from 15.8°C to 29.5°C (Fig. 2), and was highest from June to August. The nitrate + nitrite concentration fluctuated greatly between 22 and 420 μM (Fig. 3). Although a clear seasonal tendency was not observed, the nitrate + nitrite concentration was often slightly elevated every summer (i.e., in July of 2006-2008 and 2010, in August of 2009). Although the phosphate concentration mainly remained less than 1 μM, it occasionally spiked (Fig. 3).

The surface water temperature on the reef slope of Miyara Bay (Fig. 4) showed a tendency to rise from April through May, and to fall from September through October. The maximum difference in temperature between the surface and bottom layer was 1.03°C. Surface salinity of about 34.5 remained almost constant from January to April, with variations tending to be more notable from May (Fig. 5). The maximum difference in salinity between the surface and bottom layer was 1.94 in June 2008, when there was heavy rainfall of about 140 mm/d lasting two days before the observation[4]. The nitrate + nitrite concentration at the surface (Fig. 6) was low from January to April, also with large variations from May, corresponding to those of salinity. Moreover, the maximum concentration was 4.0 μM in July 2008. Since the nitrite + nitrate concentration was often high in July or August at the upstream point of the Miyara River, the concentration at the surface was high in summer. It was also high in October and November 2009. In November 2009, there was particularly heavy rainfall that

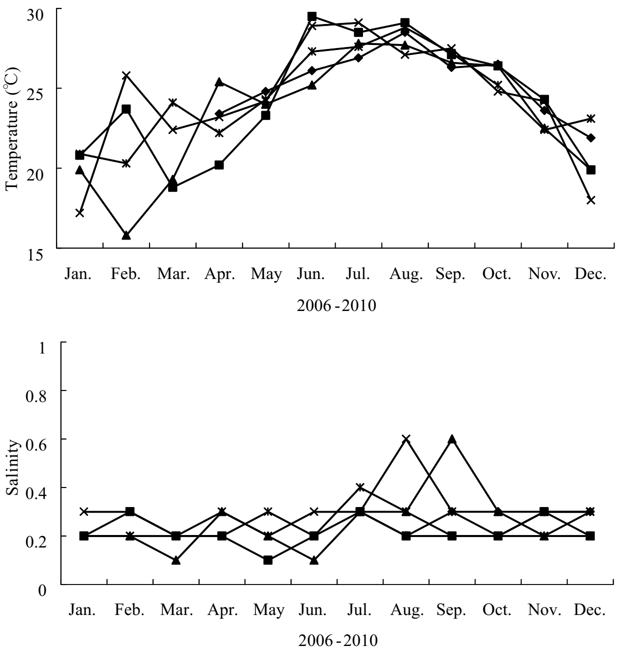

Fig. 2. Water temperature and salinity at the Akashita Bridge on the Miyara River

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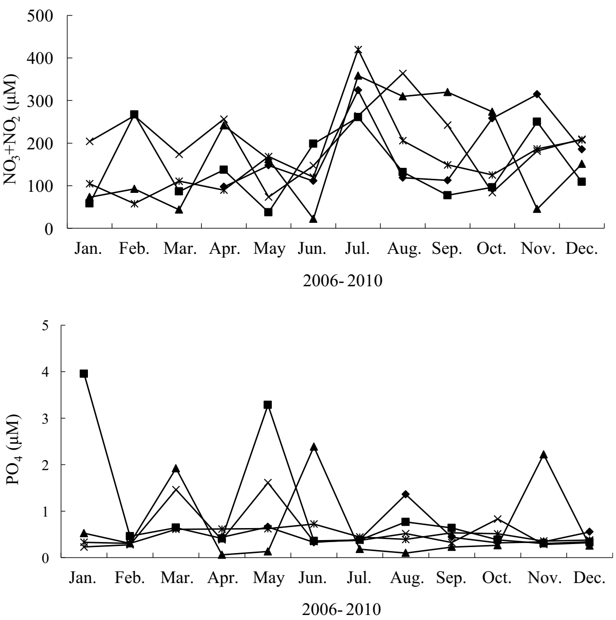

Fig. 3. Nitrate + nitrite ($NO_3 + NO_2$) and phosphate (PO_4) concentrations at the Akashita Bridge on the Miyara River

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exceeded 100 mm for four days prior to the observation[4], and that rainfall influenced the concentration. The nitrate + nitrite concentration in the bottom layer (Fig. 6) was lower than that at the surface, and the maximum concentration in the bottom layer was 0.9 μM. The surface phosphate con-

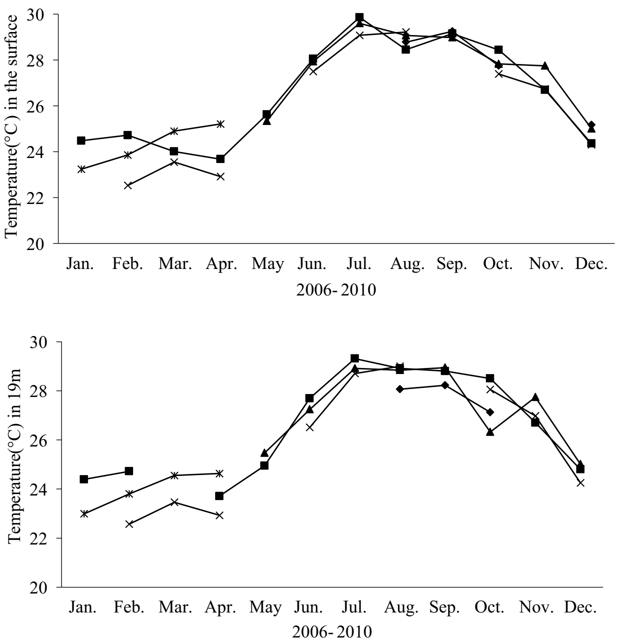

Fig. 4. Water temperature on the surface and at 19 m on the Miyara reef slope

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(Because rough weather and problems with the observation equipment resulted in some failed measurements, data are given where appropriate.)

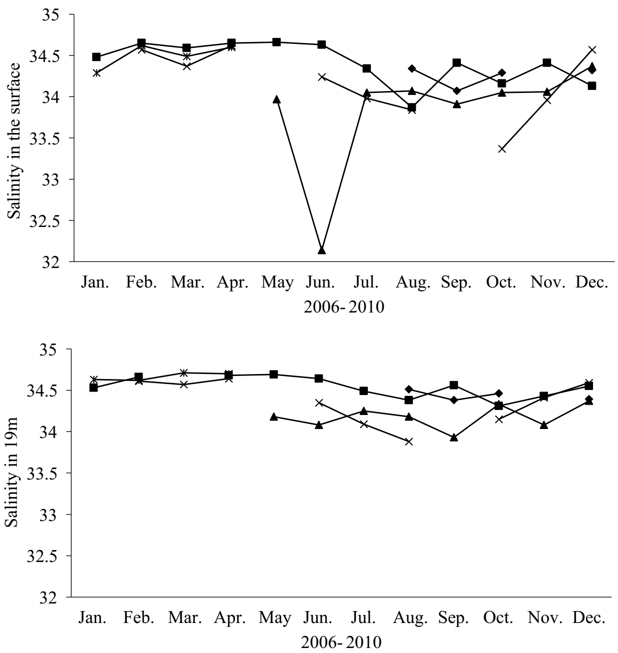

Fig. 5. Salinity at the surface and at 19 m on the Miyara reef slope

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centration on the reef slope (Fig. 7) ranged from 0.1 to 0.3 μM (except in December 2008 when it was low in the bot-

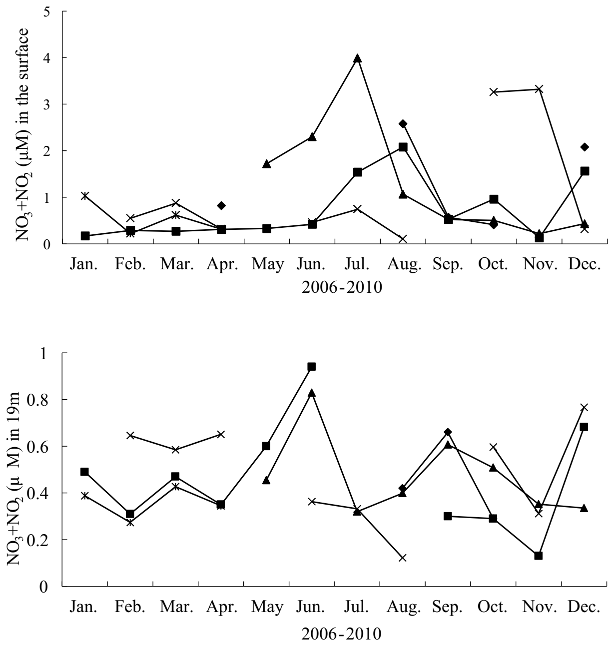

Fig. 6. Nitrate + nitrite concentration at the surface and at 19 m on the Miyara reef slope

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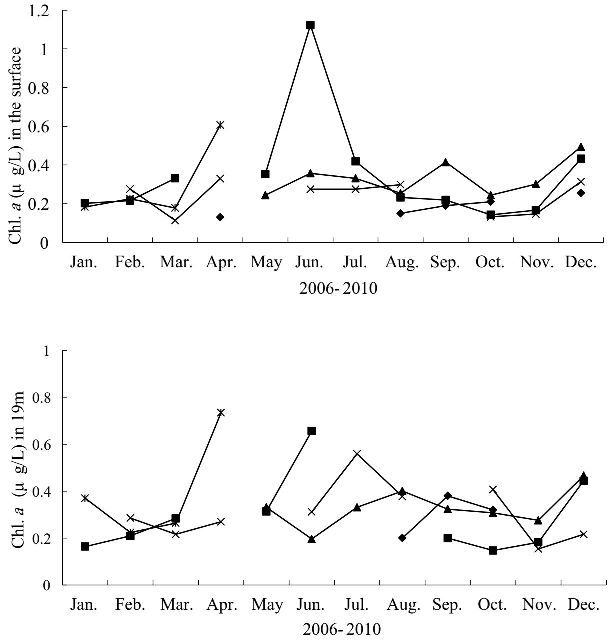

Fig. 8. Chlorophyll *a* concentration at the surface and at 19 m on the Miyara reef slope

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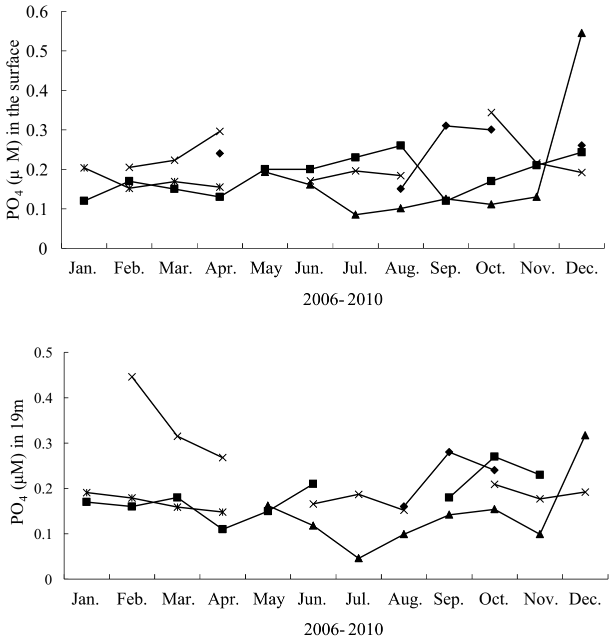

Fig. 7. Phosphate concentration at the surface and at 19 m on the Miyara reef slope

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tom layer, and most values ranged from 0.1 to 0.2 μM). The surface concentration of Chl. *a* (Fig. 8) ranged from 0.1 to 0.6 μg/L except in June 2007, and it ranged from 0.1 to 0.7 μg/L in the bottom layer and most values were less than 0.4 μg/L.

Discussion

As the salinity ranged from 0.1 to 0.6 (Fig. 2) at the Akashita Bridge and salinity values on the Miyara reef slope were mostly above 34 (Fig. 5), it was thought that seawater hardly influenced the area adjacent to the Akashita Bridge. The nitrate + nitrite concentration was always high compared to the open ocean as the maximum concentration was 420 μM at the Akashita Bridge on the Miyara River, and presumably had a large influence on oligotrophic waters. Agriculture and livestock farming are very active in the plains on Ishigaki Island. The fields for sugarcane, pineapple and grass for cattle account for 30.2%, while rice paddies only account for 3.7%[2]. Nakanishi et al.[8] reported that the nitrogen loading factor was estimated at 40% after using fertilizer on Miyako Island near Ishigaki Island. Since Miyako Island is a low island, it has no high mountains or rivers. But Ishigaki Island is a high island with high mountains and some rivers. Nitrogen in fertilizer oxidizes rapidly and changes into nitrate, which has high water solubility. Therefore, it penetrated underground and flowed to the river. Conversely, the phosphate concentration was low under normal water conditions (excluding rainy conditions). Given the low diffusion of sewage disposal on Ishigaki Island, the phosphate concentration would rise in case drainage from land development was a load source. Phosphorus in fertilizer is generally adsorbed into soil particles, and only slightly penetrates the groundwater as compared with nitrogen. And since more than 2000 head of cattle were bred in the Miyara watershed[2], the nutrient load from excrement from livestock farming might also be large. Therefore, the nitrate + nitrite concentration was assumed to have been derived from farmland and livestock farming. Moreover, the nitrate + nitrite concentration was often high in July except in 2009. According to statistical data of the Japan Meteorological Agency covering a 30-year period[4], the mean precipitation in July is low. In addition, the evaporation rate is high in July and August[17]. Therefore, nitrogen released from agriculture and livestock farming was presumably concentrated in river water.

The Hegina Sluice is located upstream on the Miyara River and regulates river flow by being open or closed. Water is also supplied from this sluice to another region by pumping water mainly to sugarcane fields, except on rainy days. Therefore, calculating the flow is difficult. Banzai and Nakamura[2] tried to calculate the flow corresponding to these situations at the Hegina Sluice. As a result, the flow was calculated as being 1,195 mm from July 2000 to June 2001, which equates to 149,433 m^3/day. The average nitrate + nitrite concentration was 173 μM during the total observation period. Based on this data when calculating the discharge of nitrate + nitrite, 132 tN/y was roughly estimated as being discharged from the Miyara River. This value is about double the TN discharge of 68 tN/year from July 2000 to June 2001 as calculated by Banzai and Nakamura[2]. Note that 173 μM in the nitrate + nitrite concentration is converted to 2.4 mgN/L. This value is also about twice higher than the TN measured by Banzai and Nakamura[2]. The nitrogen load might have gradually increased for several years. At least the maximum load was observed in 2010. The discharge of phosphate totaled 1.1 tP/year. This is lower than the TP calculated by Banzai and Nakamura[2]. Banzai and Nakamura[1] also measured suspended solids (SS) and total phosphorus (TP) in the Miyara River, and found a correlation between the outflow of SS and TP. Moreover, a similar relation was observed in the Todoroki River, north of the Miyara River[9]. The phosphate concentration was low under normal water conditions and spiked after rainfall according to the Automated Meteorological Data Acquisition System (AMeDAS)[4] at Ishigaki station. It was assumed that phosphate as well as particulate phosphorus entered the coastal area with soil particles after heavy rainfall. Thus, 1.1 tP/y was presumably an underestimate of phosphorus load, because the higher particulate phosphorus load at precipitation was not considered.

As Miyara Bay is open to the ocean, the water temperature on the reef slope was higher than that in the rivers in winter, and the salinity approximated that of open ocean water. Low salinity surface water derived from river water was found in June 2008, and the difference in salinity between the upper and bottom layers reached 1.94. Many

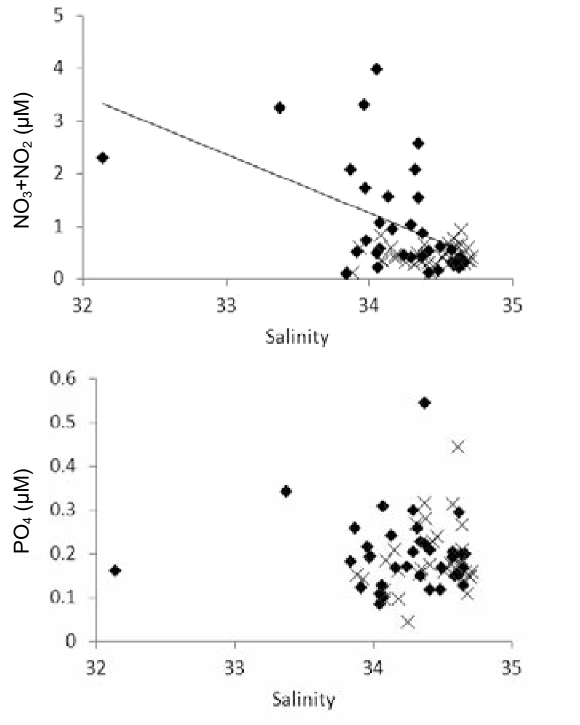
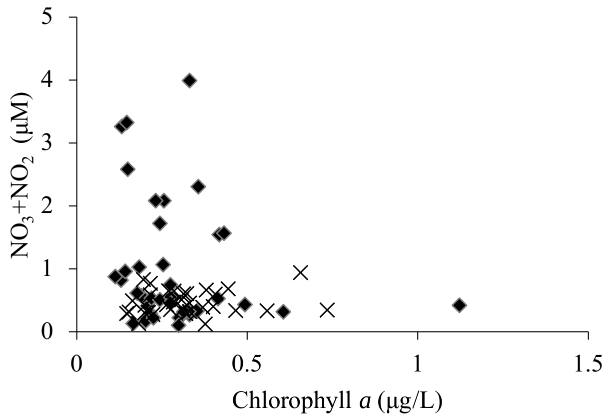


Fig. 9. Relation between salinity and nitrate + nitrite, and between salinity and phosphate
◆: 0m, ×: 19m

observations found that the nitrate + nitrite concentration was also higher in the upper layer than in the bottom layer. Though a significant negative correlation (r=0.490, p<0.001) was shown between salinity and the nitrate + nitrite concentration on the Miyara reef slope, it was not found for the phosphate concentration (Fig. 9). Given the generally low phosphate load, phosphorus was presumably carried as particulate matter on rainy days.

Bell and Elmetri[3] suggested eutrophication threshold values for fringing reefs as being 1 μM in dissolved inorganic nitrogen, 0.1-0.2 μM in phosphate, and 0.3-0.5 μg/L in Chl. *a* from studies conducted in Kaneohe Bay, Hawaii[14], and in Barbados[16]. The concentrations at some points in the Ryukyu Islands where coral growth was good were reportedly 0.1-1.4 μM for nitrate, 0-0.16 μM for phosphate, and 0.11-0.41 μg/L for Chl. *a*[13]. There is no coral reef on the reef flats and inside the reef edge due to the heavy load of sediment that previously affected this area. However, a region with 50% coral cover on a reef slope[7] and a high density of coral larvae along a reef edge[12] was identified in Miyara Bay. Red soil might not easily accumulate on the slope and the current velocity might be fast there. Moreover, a significant negative correlation relation was found in the nitrate + nitrite concentration and salinity (Fig. 9). Conversely, a correlation was not shown between the chlorophyll *a* and nutrients concentrations (Fig. 10). Though the nitrate + nitrite concentration did not correlate to chlorophyll *a* (Fig. 10), it was low and the chlorophyll *a* concen-



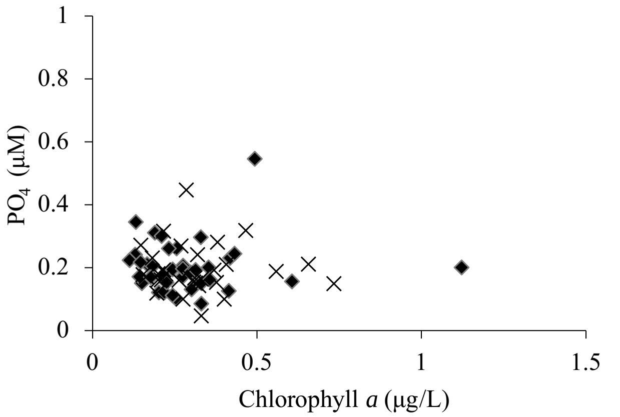


Fig. 10. Relation between chlorophyll *a* and nitrate + nitrite, and between chlorophyll *a* and phosphate
◆: 0m, ╳: 19m

tration increased over the boundary of 0.5 μg/L. Thus, the nitrate + nitrite concentration was apparently consumed as Chl. *a* increased. On the other hand, under the boundary of 0.5 μg/L in the Chl. *a* concentration, the nitrate + nitrite concentration was largely dispersed. As a correlation was found between salinity and the nitrate + nitrite concentration (Fig.9), it was suggested that the nitrate + nitrite concentration was determined by the inflow of river water and the physical mixture with seawater. The phosphate concentration was low and fluctuated at around 0.2 μM. Many measurements from Figs. 6 and 7 found the ratios of nitrate + nitrite and phosphate to be lower than 16:1 in terms of Redfield ratio[11]. Nitrogen was suggested as being a limiting factor for phytoplankton growth. Both the physical mixture and diffusion were presumably large due to the steep slope from edge of the Miyara reef. Therefore, nitrate + nitrite diffused, the concentration thereof was suppressed to being low, and thus the environmental conditions for lower trophic level production would offer an appropriate range for coral growth on the Miyara reef slope.

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