NEGATIVE CONTRIBUTION OF GROUNDWATER INPUT FROM SUBSURFACE SPRING TO CORAL REEF BLEACHING

Hironori Yamaguchi[a]*, Ichio Asanuma[a], Hideki Shimamura[b]

[a] Tokyo University of Information Sciences, 4-1, Onaridai, Wakaba, Chiba, Japan - (yamaguchi, asanuma)@edu.tuis.ac.jp
[b] PASCO, 1-1-2, Higashiyama, Meguro, Tokyo, Japan - hideki_shimamura@pasco.co.jp

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ABSTRACT:

The bleaching in 1997 and 1998 left the largest damage to the coral reefs in Okinawa Islands, Japan. Among these coral reefs, some corals were recovered to 2000 and others were completely damaged and no further recovery is expected. The environmental changes, forced those damages, are still under discussion among the increase of water temperature, increase of sediments or turbidity, and other associated human activities. In this study, we discuss a possibility of groundwater input from subsurface springs along the coast line, which is contributing to the environment of coral reefs. As a capacity of groundwater is considered to be estimated by the amount of woods or forests over the region, the normalized vegetation index (NDVI) which is given as the contrast index between near infrared and red band may suggest the amount of water supply through the subsurface springs near the coast to the coral reef. To understand the historical disaster of the coral reefs due to the change of land activities, the temporal changes of NDVI along the coast are mapped to monitor a change of forests with considering the changes of underground water supply through subsurface spring along the coast line. Also, coral reefs are mapped with a classification being alive, recovered, and bleached. In-situ measurements were conducted over the coral reefs, where alive, recovered and bleached with CTD profiling, water sampling and analysis. From our in-situ measurements, the salinity and temperature, exhibited the clear difference over the coral reefs alive or bleached, could be the first parameters to determine the environment of coral reefs to keep in alive or bleached. The nutrients including nitrate, phosphate, and silicate could be the parameters to determine the environment, but it was difficult to discuss their contributions under the current measurements. We discuss a possible protocol to monitor the groundwater supply through the submersible layer and their contribution to the environment of coral reefs.

1. INTRODUCTION

Coral bleaching is defined as the response of coral reef to a stress culminating in loss of symbiotic dinoflagellate algae (zooxanthella) from coral tissues (Lough 2000, Maynard et al. 2008). The stress could be a change of environmental factors, temperature and/or salinity change when those parameters exhibit extreme high or low values (Nakano, 2002).

In the global scale, the increase of average water temperature during 1998 was one warmest stress to the coral reef (Lough 2000). The increase of water temperature caused the bleaching in the Great Barrier Reef in Australia in 1998, which was associated with the severe El Nino, and in 2002 with out side of El Nino (Liu and Strong, 2003, Hancock et al., 2006). Liu and Strong (2003) reported the migration of hot spot, which is the high sea surface temperature observed by satellite, around the ocean and caused the bleaching.

In July of 1998, the bleaching was observed in the major region of Okinawa, where major spices of coral reef including Stony corals were damaged (Loya et al., 2001). Along the Ryukyu Islands, the certain regions were completely damaged and the certain regions were recovered from the bleaching depending on the divergence of water temperature from mean one, and the period of exposed to the higher temperature, with the additional environmental parameters including the light condition, the current, and the turbidity (Nakano 2004). There

were reports on contributions to bleaching by the warming of sea water temperature, which is affected by other climatic factors such as solar radiation, wind and water flow (Kleypas et al. 2008).

Back et al. (1979) hypothesized the contribution of groundwater to the coastal environment with mixing of waters of different chemistry may be an important geomorphic process in similar geologic-hydrologic settings. Gagan et al. (2002) discussed the contribution of the nitrogen dissolved in groundwater will stimulate organic carbon production in the photic zone, however suggested that the CO_2 enriched groundwater with a lower concentration of Ca ion reducing coral calcification in the coastal water and contributing to the recent reef degradation. Although there could be positive or negative changes to groundwater fluxes with coastal deforestation, groundwater utilization and tropical precipitation (Gagan et al., 2002), we don't have a sufficient study on the groundwater.

The bedrock around the On-nason village is layered from limestone layer, phyllite layer, gravel layer, and others, which provide the bedrock aquifer, of which organization is different from the Japan mainland without a sedimentation basin (Konishi et al., 1971). Although a detailed structure of bedrock around the On-nason village is not clear, there are two possibilities of water runoff from the bedrock. A fresh water could be provided through the groundwater tunnel above the sea

level. A brackish water could be provided through the groundwater tunnel beneath the sea level. In this region, there is not any water runoff above the sea level, there is a possibility of groundwater runoff beneath the sea level.

In this study, we proposed one hypothesis that the groundwater has a negative impact to the bleaching of coral reef, while the increase of water temperature is the major factor to the bleaching of coral reef. It is our objective to verify our hypothesis from in-situ measurements and satellite observations. Our target area is the west coast of middle of the Okinawa Island, where the bleaching was observed in 1998 and some regions exhibited recovery of coral reef. The ground environment as the vegetation index observed by satellite sensor was discussed in this study.

2. MATERIALS AND METHODS

2.1 In-situ measurement

We have conducted the in-situ measurement along the On-nason village in the western coast of Okinawa Islands on August 2, 2007 as indicated on Figure 1. The Okinawa Islands is located as the most southern prefecture in Japan with islands scattered from 24 to 27 degree North and from 123 to 128.5 degree East under a subtropical climate.

Figure 2 is the mosaic of aerial photography taken on January 26, 2006 over the On-nason village. As marked on Figure 2, three stations were selected for this study. The coral reef at the station 1, called a horse shoe by divers, was bleached in 1998 and recovered to now. The coral reef at the station 2 was bleached in 1998 and it is not expected to be recovered. The coral reef at the station 3 was not bleached in 1998 and exhibits a healthy condition up to now.
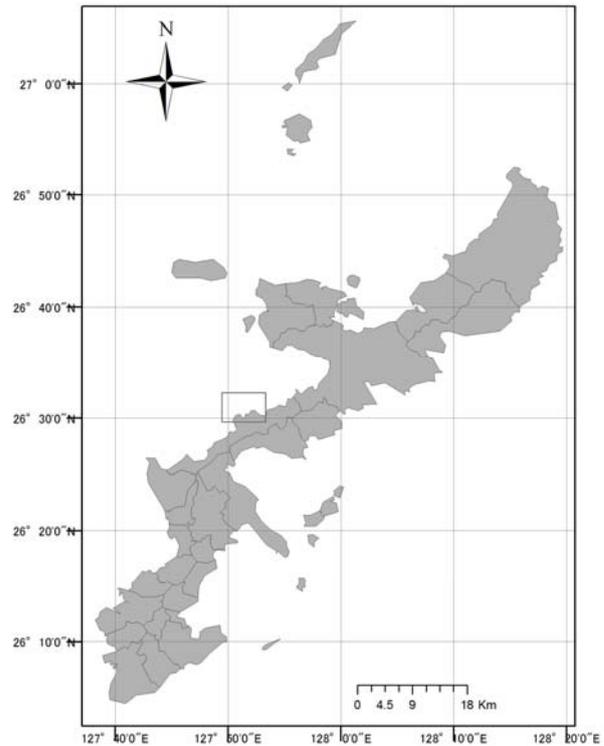

Figure 1. Study site, marked with a rectangle box, along the On-nason village located in the west coast of the Okinawa Islands.
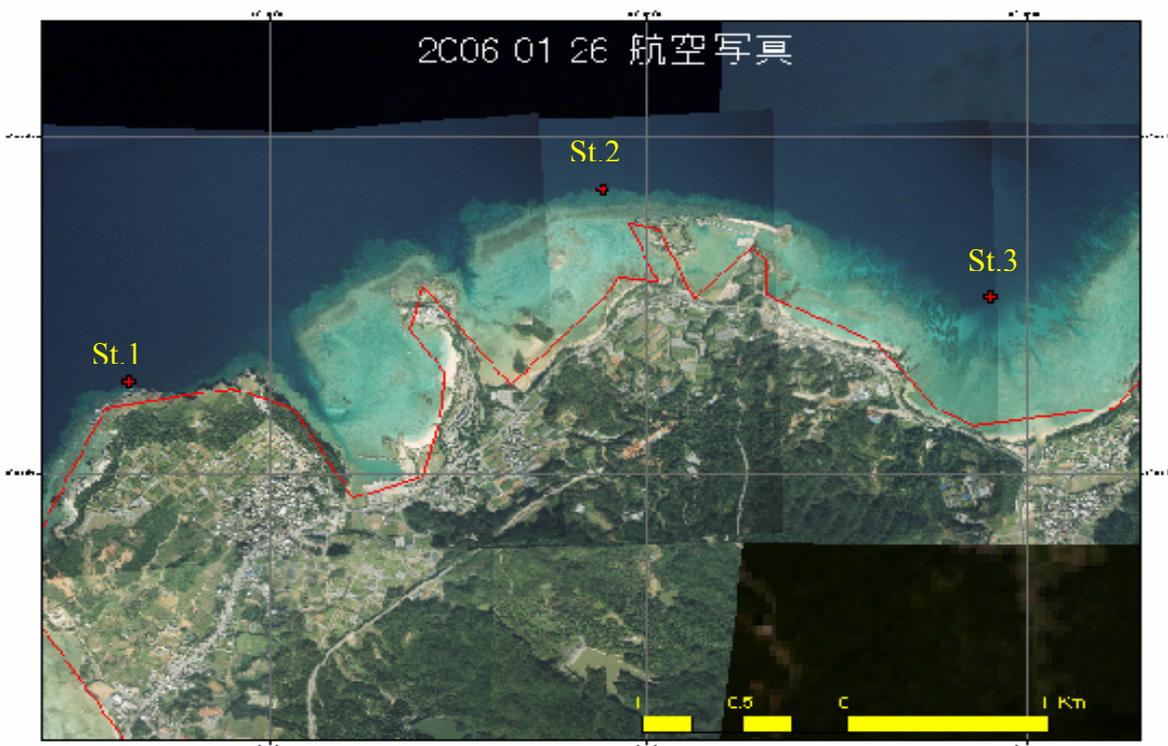

Figure 2. Mosaic of aerial photographies over the test site taken on January 26, 2006. St.1: Bleached in 1998 and recovered, St.2: Bleached in 1998 and not recovered, St.3: Not bleached in 1998 and healthy condition up to now.

720

On August 2, 2007, we have conducted the in-situ measurements including a bucket water sampling from the surface water, a Niskin water sampling from the bottom water, and CTD profiling of temperature, salinity, and photosynthetically available radiation as a function of depth.

The nutrients concentrations of nitrate nitrogen (NO3-N), nitrite nitrogen (NO2-N), phosphate phosphorus (PO4-P), and silicate silicon (SiO2-Si) were analyzed by the auto-analyzer. The sampled waters were pre-filtered using a Milipore filter of 0.2 um pore size, kept in frozen condition, and sent to the laboratory.

The chlorophyll-a concentrations were determined by the fluorometric method. The sampled waters were filtered by the GF/F filter and were kept in frozen condition and sent to the laboratory. The frozen filters were soaked by the dimethylformamide (DMF) for 24 hours and the chlorophyll-a concentration were determined using the Turner fluorometer.

The densities of sea water for each depth were calculated from the temperature and salinity observed by the CTD profiler using the international equation of state of sea water (UNESCO 1981).

2.2 Satellite observation

The surface reflectance of the coast was analyzed to discuss a change of environment in this region, which may have a significant contribution to the groundwater and an associated influence to the coral reef. The satellite data observed by the Thematic Mapper (TM) on the Landsat 5 on June 5, 1989 and the Enhanced Thematic Mapper Plus (ETM+) on the Landsat 7 on May 28, 1992 and September 29, 1999 were applied for this study.

A normalized vegetation index (NDVI) was calculated from the remote sensing reflectance in the near infra-red (0.76 – 0.90 um) and red (0.63 – 0.69 um) band of TM and ETM+. The NDVI provides the greenness of the land, where the growing plants reflect the near infra-red band and absorb the red band, with the calculation of contrast between two bands. A change of NDVI on the coast between two observation periods may suggest coastal deforestation.

3. RESULTS AND DISCUSSION

3.1 CTD measurement

Figure 3 shows vertical profiles of temperature and salinity at each station. The vertical structure of temperature at St. 1, over the shallow coral reef called the Horse shoe, exhibited a mixing from surface to 2.5 m around 29.2 C and a slightly decrease to 29.0C at the bottom. The vertical structure of temperature at St. 3 also showed the vertical mixing to 4 m around 29.0C with a decrease of temperature like a thermocline from 4 to 6 m, and a constant temperature of 28.8 to 28.7C toward the bottom of 10 m. The vertical structure of temperature at St. 2 showed the temperature decrease from 28.9 to 28.2 at 5.5 m like a stratification and a constant temperature to bottom of 8 m. St. 2 exhibited a slightly colder temperature from other two stations, but with the difference of 0.3C in the surface and with the difference of 0.5C at the bottom.

The vertical structure of salinity from the surface to 5.5 m at St. 1 and St. 3 showed the same structure 34.45 to 34.47 PSU and a

slightly increase to 34.50 PSU at 10 m at St.3. In contrast, the vertical structure of salinity at St. 2 exhibited a vibration to 5.5 m, which is corresponding to the thermal stratification indicated by temperature profile to 5.5 m, and the bottom layer from 5.5 to 8 m exhibited a stable salinity.
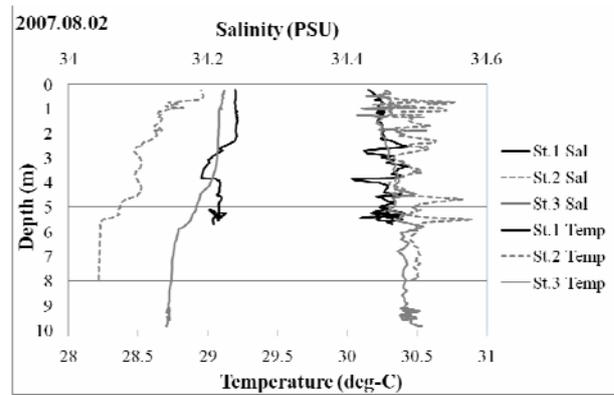

Figure 3. CTD measurement of Temperature and Salinity

Figure 4 is the calculated density of sea water for each station. The vertical profile of density at St. 2 shows a presence of low density water for all depth relative to other stations. It is difficult to discuss the mechanism of low density sea water at St. 2 if the low density water being the result of the groundwater under the current observation.
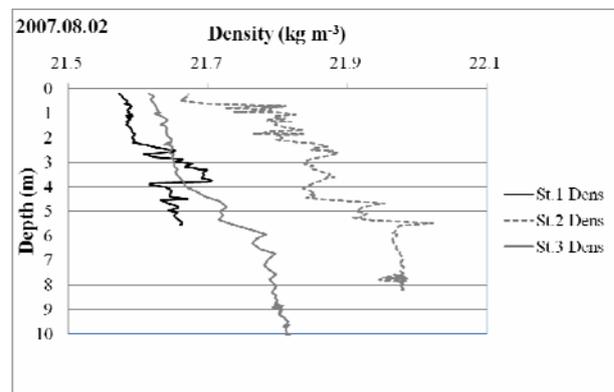

Figure 4. Calculated density of sea water

3.2 Nutrients distribution

Table 1 shows the results of nutrient analysis in this study. The phosphate phosphorus at each station was not detected with a possibility of depletion of phosphorus. The silicate silicon at each station was low as the detection limit. The nitrate nitrogen at each station was low except the surface water at St. 1. This analysis suggests that the typical Kuroshio water, which shows the depleted phosphorus and lower silicon, is touching this region except St. 1. The higher nitrate nitrogen at St. 1 in the surface suggests the intrusion of nitrate rich water from the ground.

Location	Depth(m)	NO_2-N	NO_3-N	PO_4-P	SiO_2-Si
St.1	0	0.000	0.88	0.00	1.33
	5.6	0.000	0	0.00	1.28
St.2	0	0.011	0.25	0.00	1.34
	8.2	0.005	0.08	0.00	1.25
St.3	0	0.001	0	0.00	1.26
	10.1	0.000	0.07	0.00	1.25

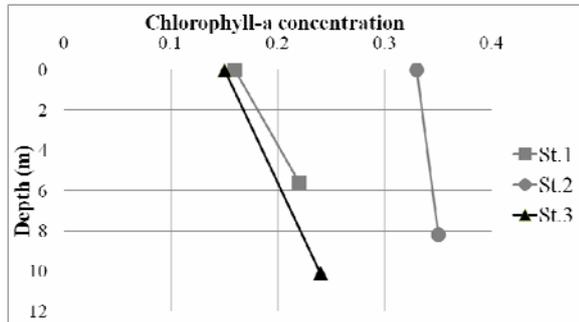Table 1. Nutrients concentration in $\mu m\ L^{-1}$

Figure 5. Chlorophyll-a concentrations from two depths at each station.

3.3 Chlorophyll-a concentration

Figure 5 shows the chlorophyll-a concentration at each sampling station. The station 2 exhibits higher chlorophyll-a concentration at the surface and bottom relative to two other stations. As the phosphorus being depleted, the silica showing a low concentration, the nitrate nitrogen could be only one parameter to determine a mechanism of nutrient consumption in this region.

As higher chlorophyll-a concentrations in the surface and in the bottom layer were observed at St. 2 (with bold characters on Table 2), phytoplankton in the water column at St. 2 could be the major consumer of nitrate nitrogen, because of missing symbiotic dinoflagellate in a bleached coral reef.

The symbiotic dinoflagellate within the active coral reef at St. 1 and St. 2 could be the major consumer of nitrate nitrogen, because of low chlorophyll-a concentration at the bottom layer of two stations, and depleted nitrate nitrogen at both stations.

In the surface layer at St. 1, the nitrate nitrogen was a high concentration but the chlorophyll-a was a low concentration. It is difficult to discuss the mechanism of low chlorophyll-a concentration and to determine the nutrient consumers in this layer at this station from these measurements, where further discussion is necessary.

Location	Depth(m)	$\mu M\ L^{-3}$ NO_3-N	$mg\ m^{-3}$ Chl-a	no unit Symbiotic Dinoflagellate
St.1	0	0.88	0.16	NO
	5.6	0	0.22	YES
St.2	0	0.25	0.33	NO
	8.2	0.08	0.35	NO
St.3	0	0	0.15	NO
	10.1	0.07	0.24	YES

Table 2. Possible combination of nutrients consumers

3.4 NDVI along the coast

The NDVI estimated from TM on Landsat 5 on June 5, 1989 (Figure 5), and on May 28, 1992 (Figure 6) represent the land coverage by forest before the coral reef bleaching in 1998. The NDVI on September 29, 1999 (Figure 7) estimated by ETM+ on Landsat 7 represents the land coverage by the forest just after the coral reef bleaching in 1998.
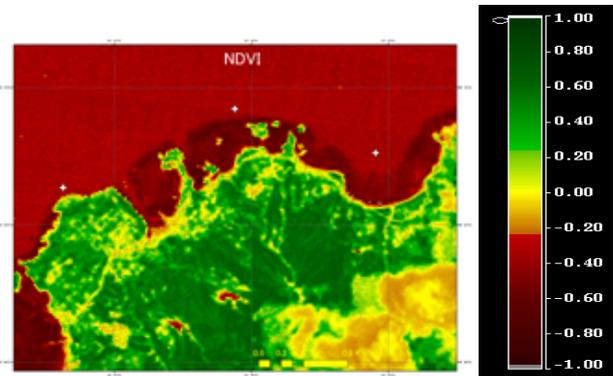

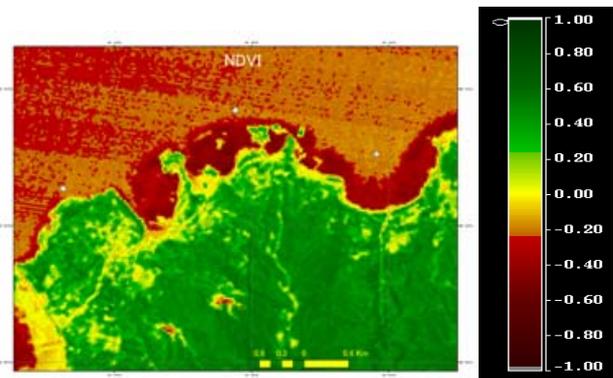Figure 5. NDVI on June 5, 1989 estimated from TM.

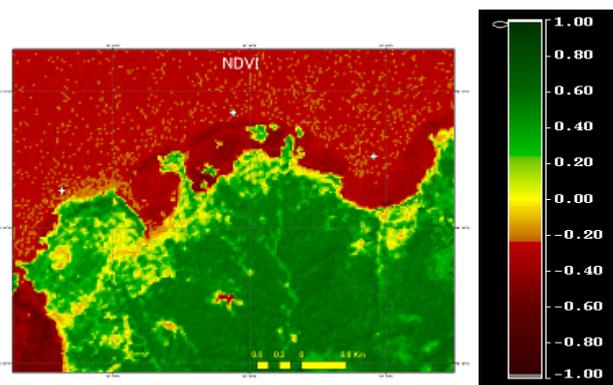Figure 6. NDVI on May 28, 1992 estimated from TM.

Figure 7. NDVI on September 29, 1999 estimated from ETM+.

The NDVI on the peninsula close to St. 1 shows trees along the coast with a constant NDVI more than 0.5, where the constant groundwater contribution to St. 1 is expected.

The NDVI on the coast located in the South of St. 2 shows number of yellow spots where the big yellow spot is observed in 1989 although it was recovered in 1992 and 1999. This region is configured from sugar cane fields and housings, where is a possibility of less groundwater contribution to St. 2.

The NDVI on June 5, 1989 shows a lower value in the southern side of St. 3, where no vegetation is expected. But the vegetation is recovered in 1992 and 1999 at this location. This change of NDVI could be a positive impact to the coral reef at St. 3.

As discussed in the introduction section, a bedrock structure of the On-nason village is not clear and it is difficult to explain the route of the groundwater to coral reefs. But it may be possible to estimate the contribution of groundwater to coral reef from the nearest coast, where the land coverage may determine the amount and quality of groundwater.

The dark green region on NDVI is corresponding to woods and the light green region is corresponding to agriculture field including sugar canes and other commercialized agriculture crops on crop fields. The woods, indicated by a dark green on NDVI, would have a significant contribution to the groundwater with providing or holding water on the land surface layer and providing nutrients. But nutrients supply depends on the structure of woods being deciduous trees or evergreens, where entrainments of nutrients are expected by the activities of bacteria.

3.5 Structure of observation points

Although the observation period is restricted to January 26, 2006, the aerial photograph on Figure 2 clearly offers details of land covers, which are difficult to identity from the NDVI image estimated from TM and ETM+ observation.

The peninsula close to St. 1 holds woods along the coast line. Fields for sugar cane and other crops are located inside of woods along the coast line. Housings are limited to the street side. The woods along the coast line may have a important contribution to producing the groundwater. St. 1 is located very close to the coast, where a small cliff continues along the coast line without sand beach and the groundwater is expected to have an immediate input and a direct contribution to the coral reef.

On the beach close to St. 2, crop fields are located along the coast line and woods area is located in the mountain side. St.2 is located at the top of fan like reef, where the groundwater will exhibit a divergence flow to all directions.

St. 3 is located at the centre of the bay, where the western part of the beach is covered by woods and the eastern part of the beach is covered by housing area. St. 3 is located at the hinge like point of fan and surrounded by reefs, where the ground water will show a convergence flow into St. 3.

Figure 8 shows the bedrock structure along the coast from the point of groundwater around the On-nason village (Konishi et al., 1971). The groundwater could be classified into a fresh, brackish, and sea water depending on the mixing process relative to the sea level height and an intrusion of sea water into the bedrock aquifer. The runoff of the groundwater into the sea water exhibits three different saline waters depending on the height of mouse relative to a sea level
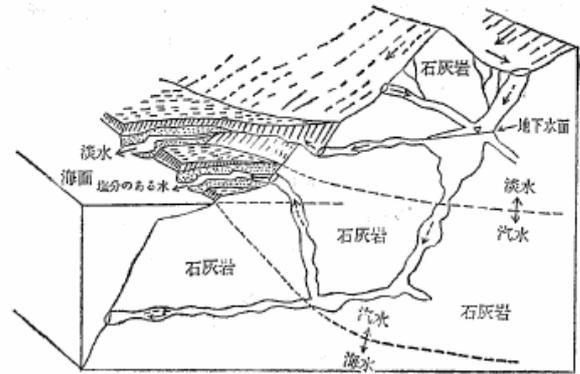

Figure 8. Groundwater in the northern part of the Okinawa Island (Since Konishi et al., 1971).

4. CONCLUSION

Coral reefs along the beach of the Okinawa Island were studied from the point of groundwater with in-situ measurement of temperature, salinity, nutrient, chlorophyll-a concentration and with the satellite observation of NDVI. We conducted the in-situ measurement on three coral reefs, where St. 1 had experienced the bleaching in 1998 and recovered, St. 2 had experience the bleaching in 1998 but is not recovered, and St. 3 is alive through 1998 without bleaching.

From our measurement, we found that the nitrate nitrogen is depleted almost by the symbiotic dinoflagellate algae in the bottom layer at St. 1 and St. 3, where the coral reef is alive. Also, we could explain that the phytoplankton was the dominant user of nitrate nitrogen in the surface and bottom layer at St. 2, where the coral reef was bleached.

The NDVI distributions estimated from satellite observation show a temporal change of land coverage from the point of woods along the coastal area. It was possible to discuss a difference of NDVI in details between woods and agricultural fields by combining the high resolution aerial photography.

Although we have proposed a hypothesis that the groundwater has a negative impact to the bleaching of coral reef, our measurements need further observation and it was difficult to verify our hypothesis.

Further in-situ measurement is necessary to study a mechanism of nutrients consumption by the symbiotic dinoflagellate algae relative to phytoplankton with developing methods to estimate and evaluate the contribution of groundwater. As there is a possibility of contribution by the Kuroshio to the coral reef around the Okinawa Islands, the seasonal response of the coral reef on the nutrient consumption could be studied relative to the variation of Kuroshio.

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