D-4.2.2 Nutrients Condition of Coastal Waters

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Abstract In order to find out the criterion to protect coral reef ecosystems at Ryukyu Islands from eutrophication due to developments, nutrient concentrations in reef waters and vegetative density of corals were investigated. DIN ranged from $10^{-1}\mu M$ to $10^{0}\mu M$ and DIP from $10^{-2}\mu M$ to $10^{-1}\mu M$, corresponding to a higher level of nutrient concentrations in tropical reefs. Corals tended to decline or give place to sargassum or zostella with progress of eutrophication or siltation. The relationship between nurient concentrations and vagetative density suggested, on the whole, that the standard of water quality in reefs for protection of corals should be established at a level of $10^{0}\mu M$ in DIN and $10^{-1}\mu M$ in DIP. Nucleic acid ratio (RNA/DNA) and carbon stable isotope ratio ($\delta^{13}C$) in corals were also monitored as indexes of physiological condition of corals. The observed characteristics of ratios suggested that RNA/DNA could be an index of growth and maturation potential and that the difference of $\delta^{13}C$ between zooxantella and coral tissue could be an index relating to symbiosis, that is, dependence of corals on photosynthetic product of zooxantella. These results should be confirmed with further observations and experiments.

Key words Coral reef environment, Nutrients concentration, Nucleic acid ratio, Carbon stable isotope, Ryukyu Islands

1. Introduction

There are lots of coral reef around the Ryukyu Islands with variety of coral species. However, corals in many reefs are declining with antholopogenic disturbances such as reclamation, harbor construction, sedimentation of red soil and/or eutrophication, along with population growth of crown-of-thorns starfish, due to urbanization and/or agricultural development[1]. Grigg and Dollar[2] revewed antholopogenic disturbances on coral reefs and poited out luck of quantitative investigation about the relationship between the disturbances and the dameges on corals by them. Also in Japan, there are many advanced studies on biology, ecology, geography and geology of coral reefs[1,3] while no study on the relationship between vagetative and/or physiological condition of corals and nutritive and/or sediment condition of reefs, along with the relationship between population growth of the starfish and eutrophication of coral reefs.

Refering to Grigg and Dollar[2], there is only one case of Hawaii as to the study on eutrophication of coral reefs. Urban sewage in Hawaii had been discharged into the coral reef lagoon in 1980s. Corals had declined and given place to sea weeds with water and bottom pollution caused by the sewage discharge but recovered in a few years after the sewage diversion to the offing[4]. Total concentration of ammonium, nitrate and nitrite (DIN) and concentration of phosphate (DIP) in the lagoon water were1.15 and 0.48 μ M under the sewage discharge and 0.78 and 0.15 μ M after the sewage diversion, respectively.

Eutrophication of reef water is probably not adequate to reef building corals because they adapt to the oligotrophic environment with a carbon to nitrohe ratio higher than that of their tissue[5]. This hypothesis was confirmed by breeding experiments of the corals. Ammonium intake and cell numbers of zooxanthellae increased while carbonhidrade intake of the coral polyps from zooxanthellae decreased, with ammonium addition to the breeding water, meaning deviation out of symbiosis. This result shuld be confirmed under the natural condition in stead of so much ammonium concentration of 20 to 50 μ M in the breeding water.

Thus, priority of the investigation about the relationship between anthopogenic disturbances and its' influences on Corals may be judged to be high.

2. Research Objectives

There is no special standard of coral reef water quality in Japan and, therefore, coral reef environment of Okinawa has been monitored only according to the COD standard established by Environment Agency for protection or recovery of water quality mainly against eutrophication of estuarines and embayments in Honshu. As to the starfish also, the coutermeasure is not preventive but only to exterminate them to land by hand. Thus, the countermeasure is insufficient and envestigation is necessary, in order to protect coral reef environment. Objective in this research is forcussed on getting *in situ* data of reef environment and coral vagetation, physiological condition of corals and water quality in coral reefs arround Ryukyu Islands, in order to get a hold of the water quality standard to protect reef building corals in Okinawa.

3. Research Method

It is not so easy to measure accurately the water quality in coral reefs becuase of so high oligotrophy. There are few data of water quality in the coral reefs arround Ryukyu Islands. Retrospective approach is impossible in this research. Experimental approach is also difficult because of the fields so far from our institute. Therefore, method to compare grades of coral vegetation and physiological condition of corals with water quality and soil sedimentation in coral reefs was adopted.

Obsevational dates, stations and item are shown in Tables and Figures. Observational stations in coral reefs were approached mostly from shore line by walking or swiming and only 5 times from offing by boat along the south to west coast of Iriomote Is. Vegetative condition and soil sedimentation were overlooked with swiming glasss. Sea water and corals were sampled. Ammonium (NO_4-N), nitrate (NO_3-N), nitrite (NO_2-N), phosphate (PO_4-P), paticulate nitrogen (PN) and phosphorus (PP), chlorophyll-a (Chl-a), suspended substance (SS) of the sampled water, nucleic acid ratio, RNA/DNA, and carbon stable isotope ratio, $\delta^{13}C$, of sampled corals were measured in laboratory.

4. Results and Discussion

(1) Relationship between coral vegetation and nutritive condition of reefs

Overlooked reef environment and grade of coral vegetation roughly judged at observational stations are demonstrated in Table 1. Most of stations were in lagoons because of the approach and, probably therefore, there were a few stations where a lot of corals vegetated densely. The bests were Tokasiki Is., Aragusuku Beach of Miyako Is. and the northern part of Ishigaki Is. while the worsts were Yone at the south of Naha City, Yonabaru in Nakagusuku Bay of Okinawa Is..

Observed water qualitiy is demonstrated in Table 2. Except Yone, Nakagusuku and Yonabaru, DIN ranged 10^{-1} to $10^{0}\,\mu M$ and DIP 10^{-2} to $10^{-1}\,\mu M$, corresponding to rather eutrophic level of tropical reefs[4, 7-11], on the whole. DIN observed in 1994 ranging one order higher than others may not unreasonable because of being the same level as those observed by Crossland[7] at Sesoko Is. in 1981. Thus, the water quality of reefs may be highly variable. In spite of this variabitity, it can be seen that corals tend to decline or give place to sargassum or zostella with progress of eutrophication or soil sedimentation, respectively. It may be interesting and important that the threshold shuld exist between the highest level of $20\,\mu M$, the same level as the ammonium addition experiments[6], and the lowest level of $10^{-1}\,\mu M$, in DIN.

Table 3 demonstrates the results obtained in Ishigaki Is. where whole of coral vegetation, water quality and RNA/DNA were observed simultaneously. Whole tendencies are coincident. Good vegetation coincides with the level less than $1\,\mu M$ in DIN and $0.1\,\mu M$ in DIP. This level corresponds to the most oligotrophic ones of tropical reefs and, therefore, establishment of the standard at this level may be too severe. The dates of observation in Ishigaki Is. might belong to one of good water quality periods. Summing up of data at more stations and more dates, along with referencing to tropical data[7-11], should make the standard converge to a lower level of $10^{0}\,\mu M$ in DIN and $10^{-1}\,\mu M$ in DIP. Thus, even though taking account of PN being in the same level of DIN, the standard should be established at a more severe level especially in nitrogen than that of the type I established by Environment Agency, 14.3 μM (0.2mg/l) in TN and 0.7 μM (0.02mg/l) in TP.

(2) Nucleic acid ratio, RNA/DNA

RNA/DNA observed monthly at Sesoko Is. are shown in Fig.1 and those at Ishigaki Is. in Tanle 3, which varied temporary and spacially but ranged almost 1 to 3, which being the level corresponding to starvation of sardine larva or copepods. This low level may agree with the adaprtation of corals to oligotrophic environment.

In Fig.1, RNA/DNA variation patterns of *Acropola nobilis* and *Porites lutea*, both vegetating mostly on reef flats to the reef edges, are same and seasonal, that is, minimum in summer, maximum in late autumn, minimum in mid winter and maximum in spring. This pattern corresponds probabaly to the physiological rism of the corals, that is, declinement with exhaustion by spawning and high temperature along with starvation in summer, recovery and growth with moderate temperature and weak bloom in autumn, declinement with low temperature and starvation in winter and growth and maturation with moderate temperature and bloom in spring. While, the seasonal patterns become vague in the cases of *Poccillopora damicorinis* and *Montipora degitata* both vegetating mostly in lagoons, probabaly because the environment of lagoon is controlled by temporal disturbances such as flood and neep tides or storms. Thus, RNA/DNA can be an index of growth and/or maturation potential.

In Table 3, RNA/DNA of the *Acropora* is 1.5 at oligotrophic stations and 1.0 at eutrophic stations while the *Poccillopora* is contrarily 1.0 at oligotrophic stations and 2.0 at eutrophic stations. This probabaly means that the former adapts to the oligotrophic environment and the latter to the eutrophic environment. Thus, RNA/DNA can also be an index of adaptation to environment.

(3) Carbon stable isotope ratios, $\delta^{13}C$

The $\delta^{13}C$ observed simultaneously with RNA/DNA probably are shown in Fig.2. Values of symbiotic algae, zooxanthella, ranged -17 to -9‰ and were almost always higher than those of coral tissue, samely as the case of Grate Barrier Reef[12].

On the whole in Fig. 3, there can be seen a positive correlation between $\delta^{13}C$ of zooxanthella and the difference of $\Delta\delta^{13}C$ between zooxanthella and coral tissue. This positive correlation suggests that the higher the photosynthesis of zooxanthella , the lower the dependance of corals on the photosynthetic product of zooxanthella, that is, the higher dependence of corals on external food. Thus, $\delta^{13}C$ and $\Delta\delta^{13}C$ can be an index of symbiosis, that is, potential of movement and/or mucus formation to catch external food.

5. Conclusion

(1) Reef building corals decline and give place to sargassum or zostella with progress of eutrophication or silt sedimentation in the reef environment. The standard of reef water

quality to protect corals should be established at a level of $10^0 \mu M$ in total nitrogen (TN) and $10^1 \mu M$ in total phosphorus (TP), which being more severe especially in nitrogen than the standard of type I by Environment Agency, 14.3 μ M (0.2mg/l) in TN and 0.7 μ M (0.02mg/l) in TP.

(2) Nucleic acid ratio of corals, RNA/DNA, can be an index of growth and/or maturation potential, along with adaptation to environment.

(3) Carbon stable isotope ratio of symbiotic algae, $\delta^{13}C$, and its difference between the algae and coral tissue, $\Delta\delta^{13}C$, can be an index of symbiotic condition, that is, dependence of corals on whether photosynthetic products of the algae or external food.

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Table 1. General condition of coral reef environment and coral vegetation at observational stations.
(Grade of vegetation, that is, no coral: X, sparse: △, comon: ○, verry good: ◎)

1992.10.15 (Sesoko Is., Okinawa)
Sesoko Beach (◎): *Acr.* and *Por.* on reef flat to edge, and *Poc.* and *Mon.* in lagoon.
Front of the Center (◎): Soft corals in reef with no lagoon

1993.09.04-05 (Overlook at shore of Okinawa Is.)
Yone (X): North of Itoman, not reef but tidal flat, turbid water just after a tyhoon.
Naha Marina (○): Newly constructed port, clear water, corals here and there on shore bank.
Kitatan Beach (○): Atificial bathing place made by reclamation, clear water.
Tancha (○): Natural beach in Onna village, fine sand and clear water .
Ige (△): Fine sand beach in Kin Bay, only sargassum on studded rocks, not so clear water.
Ike Is. (○): Offing boudary of Kin and Nakagusuku Bays, clear water, studded corals and weeds.
Nakagusuku (X): Soil sedimented by development, no corals and no weeds
Chinen (X): Sandy bathing beach, reef in the far offing.
Nago (△): Artificial shore bank, clear water but few corals.
Yagaji (X): Severe soil sedimentation.
Taira Bay (X): Red sand beach

1994.06.21-22, 23,28-29 (Okinawa Is.,Tokashiku Is. and Miyako Is., respectively)
Kinmisaki (○) : rocky shore, clear water, lots of *Acr.* and *Favia speciosa.*
Ige (△): Fine sand beach with soil, sparse corals on studded rocks in zostella forest.
Yonabaru (X): Fine sand beach, most polluted and durty, Padina on studded rocks.
West end of Aharen Beach (◎) : *Acr.* communities, clear wtater but sewage from campig area?
Tokasiku Beach (○): Clear water, lots of *Nemacystis* and lots of dead coral.
Sunayama Beach (○): Clear water, but lots of dead corals.
Aragusuku Beach (◎): Clear water, big *Acr.* communities and big *Por.* masses.

1995.08.30-09.1 (Ishigaki Is.)
Urasoko Bay, St.1～5 (◎): Communities of table corals.
St.6～9 (○):Traces of feeding by the starfish.
St.10 (△): Soil sedimentation, not so clear water, not so vivid corals.
Yoshihara A(100m offing (△): Lagoon with sand and soil, clear water, lots of weed and grass.
Yoshihara B(500m offing (◎): Near reef flat, big communities of branch corals.
South end of Sukuji Beach (△): Not so clear water with soil, corals on rocks in zostella.
Kannonsaki (X): No coral, sever soil sedimentation by port construction.
Hirano (◎): North end of the Is., clear water, recovering from damage by the starfish.
Shiraho (X): In front of the village, reef mostly covered by sargassum.
Tonogusuku (X): West end of the Port, studded *Poc.* near shore bank, reef covered by weeds and soft corals.

1996.09.06-08 (Iriomote Is.)
Haemisaki (X): Reef covered completely by sargassum.
Paimisaki (○): Reef with no lagoon, lots of corals but small masses.
Sabamisaki (◎): Dense corals, look like vivid.
Hokabanare Is. (◎): Ditto.
South coast of Uranouchi Bay Mouth (△): Lots of sargassum.
West Beach of Hunaura Port (△): Sedimentation by port making, sparse corals in zostella.
Uehara (△) : Ditto.
Hoshizunakaigan (○): Many bathers in lagoon, not so clear water, *Poc.*, *Mon.* and *Por.*
Sonai (△): Traces of branch corals in zostella and sagassum, damage by port construction?

Table 2. Coral vegetation grade, bottom and water quality at observational stations.

Date ST.	Grade	Bottom	NH4	NO3	NO2	PN	PO4	PP	Chla
				(μM)					(μg/ℓ)
1992.10.15 (Sesoko Is.)									
Sesoko Beach	(◎)	rock	3.15	0.27	0.05	0.23	ND	0.00	0.20
Ditto	(○)	sand	2.43	0.90	0.03	0.30	ND	0.01	0.20
Front of Center	(◎)	rock	3.00	1.54	0.06	0.71	ND	0.00	0.70
1993.09.04-05 (Okinawa Is.)									
Ike Is.	(○)	rock	1.10	2.22	1.91	1.10	0.08	0.10	0.26
Naha Marina	(○)	sand	1.46	4.35	1.56	1.28	0.25	0.14	0.49
Kitatan	(○)	sand	2.90	2.53	0.22	1.74	0.19	0.29	0.48
Tancha	(○)	fine sand	0.37	1.69	0.22	3.24	0.08	0.39	0.75
Nago	(△)	bank	1.23	0.74	0.21	0.94	0.16	0.11	0.29
Ige	(△)	fine sand	0.48	9.20	0.31	5.11	0.08	0.43	3.05
Chinen	(X)	sand	0.22	5.20	0.23	2.47	0.10	0.25	1.57
Taira	(X)	red sand	0.87	1.20	0.10	0.65	0.07	0.10	0.50
Yagaji	(X)	soil	1.34	5.27	0.21	16.81	0.22	1.91	14.14
Nakagusuku	(X)	soil	2.86	12.37	0.63	2.55	1.73	0.41	0.43
Yone	(X)	soil	10.00	72.73	2.13	4.94	0.36	0.72	3.86
1994.06.21-22, 23, 28-29 (Sesoko Is., Okinawa Is., Tokashiki Is. and Miyako Is.)									
Aragusuku	(◎)	rock	0.23	0.43		0.44	0.04	0.05	0.16
W.E Aharen	(◎)	rock	3.03	0.42		1.09	0.61	0.07	0.11
Sesoko Beach	(◎)	rock	0.38	0.85		0.39	0.78	0.08	0.28
Ditto	(○)	sand	0.73	1.28		0.61	0.83	0.07	0.35
Sunayama B.	(○)	rock	0.17	0.52		0.54	0.02	0.08	0.33
Tokashiku	(○)	rock	0.83	1.20		0.65	0.73	0.06	0.27
Kinmisaki	(○)	rock	1.39	0.83		1.13	0.83	0.10	0.22
Ige	(△)	silt	0.39	0.19		0.59	0.77	0.10	0.32
Yonabaru	(X)	fine sand	18.27	19.23		5.14	1.58	1.12	7.78
1995.08.30-09.1 (Ishigaki Is.)									
Urasoko St.1-5	(◎)	rock	0.05	0.46	0.05	0.50	0.05	0.03	0.41
Yoshihara B	(◎)	rock	0.27	0.31	0.07	0.42	0.07	0.01	0.07
Hirano	(◎)	sand	0.24	0.40	0.07	0.46	0.07	0.03	0.14
Urasoko St.6-9	(○)	rock	ND	0.33	0.04	0.61	0.04	0.04	0.55
St.10	(△)	silt	0.32	0.36	0.05	0.64	0.04	0.05	0.46
Yoshihara A	(△)	sandy soil	0.09	0.76	0.11	0.40	0.04	0.01	0.12
S.E. Sukuji	(△)	silt	ND	0.32	0.04	0.47	0.05	0.03	0.24
Shiraho	(X)	rock	0.75	0.66	0.06	0.54	0.07	0.02	0.28
Tonogusuku	(X)	stones	1.59	1.73	0.09	0.88	0.26	0.08	0.83
Kannonsaki	(X)	silt	1.84	1.19	0.13	1.82	0.11	0.24	2.30
1996.09.06-08 (Iriomote Is.)									
Sabamisaki	(◎)	rock	0.61	0.63	0.03		0.02		0.36
Hokabanare Is.	(◎)	rock	0.65	1.40	0.04		0.08		0.06
Paimisaki	(○)	rock	1.13	0.54	0.06		0.08		0.10
Hosizuna B.	(○)	rock	1.59	0.93	0.12		0.04		0.41
S. Uranouti B.	(△)	rock	0.40	0.18	0.04		0.03		0.16
W. Hunaura P.	(△)	silt	0.85	0.38	0.04		0.00		0.49
Uehara	(△)	silt	0.93	0.25	0.03		0.01		0.25
Sonai	(△)	stones	0.73	0.17	0.08		0.02		0.36
Haemisaki	(X)	rock	0.99	1.03	0.06		0.07		0.33

Table 3. Overlook of coral coral reefs(higher medium lines), RNA/DNA of corals (lower midium lines), nutrients (μ M), Chl-a (μ g/l), SS (mg/l) (bottom lines) at stations of Ishigaki Is. on Aug.30 to Sep.1, 1995.

Stations	St.1	Hirano	Yoshihara B	St.5	Sokochi	St.10	Yoshihara A	Kannonsaki	Shiraho	Tonoshiro
Grade of corals	◎	◎	◎	○	△	△	△	X	X	X
Macro-phyts					grass		grass		weed	weed
bottom	reef	reef	reef	reef	silt	silt	sandy soil	silt	reef	stones
Acropora nob.	1.55	1.48	1.45	1.37	1.21	1.13	1.07	1.03	---	---
	1.48	1.47	1.43	1.34	1.17	1.07	1.07	1.01	---	---
Poccillopora dam.	---	1.01	---	---	1.27	1.98	---	1.91	---	1.99
	---	0.99	---	---	1.27	1.98	---	2.15	---	1.94
DIN	0.63	0.71	0.65	0.43	0.36	1.06	0.96	3.16	1.47	3.41
NH_4	0.09	0.29	0.27	ND	ND	0.63	0.09	1.84	0.92	1.59
PN	0.50	0.46	0.42	0.55	0.47	0.61	0.40	1.82	0.54	0.88
DIP	0.04	0.07	0.07	0.04	0.05	0.06	0.04	0.11	0.08	0.26
PP	0.01	0.03	0.01	0.04	0.03	0.05	0.01	0.24	0.02	0.08
Chl.a	0.30	0.11	0.07	0.60	0.24	0.37	0.12	2.30	0.19	0.83
SS	0.27	1.04	1.52	1.04	1.37	0.40	0.47	5.13	0.91	1.51

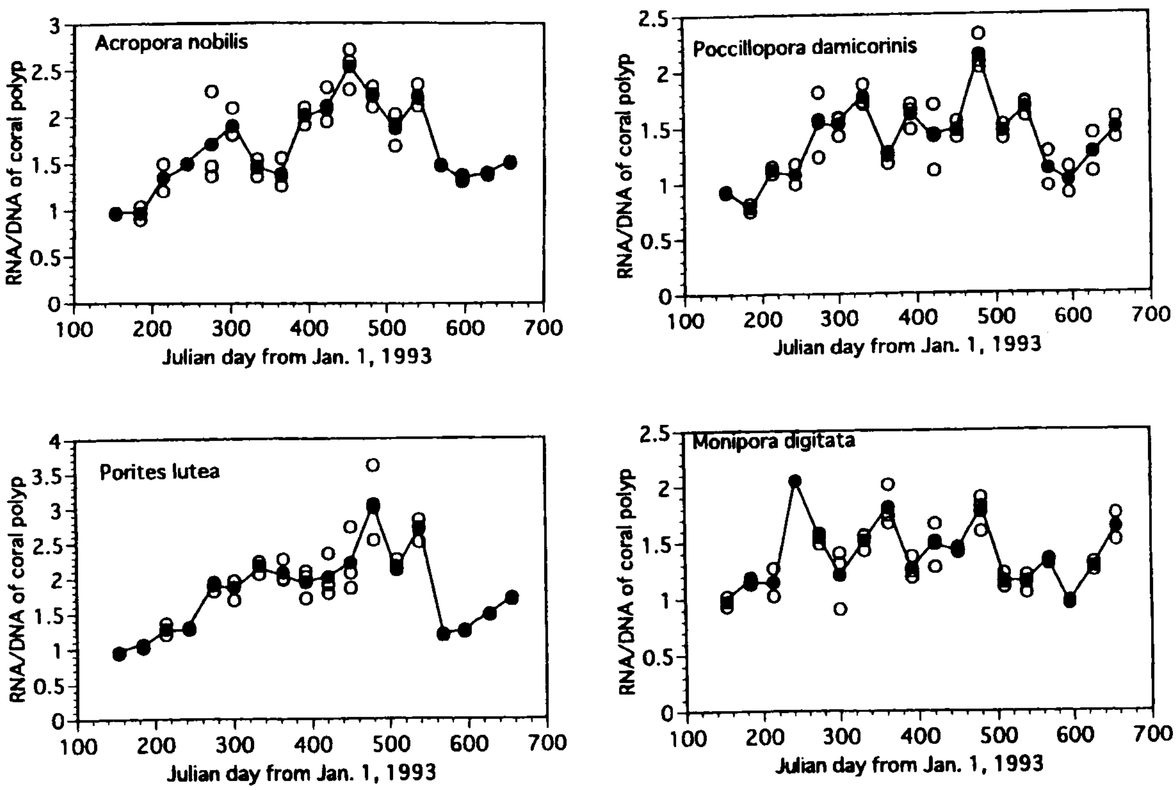

Fig. 1 . Seasonal variation of RNA/DNA in coral tissue of 4 species, *Acropora nobilis*, *Porites lutea*, *Poccillopora damicornis*, *Montipora digitata* in a reef of Sesoko Is..

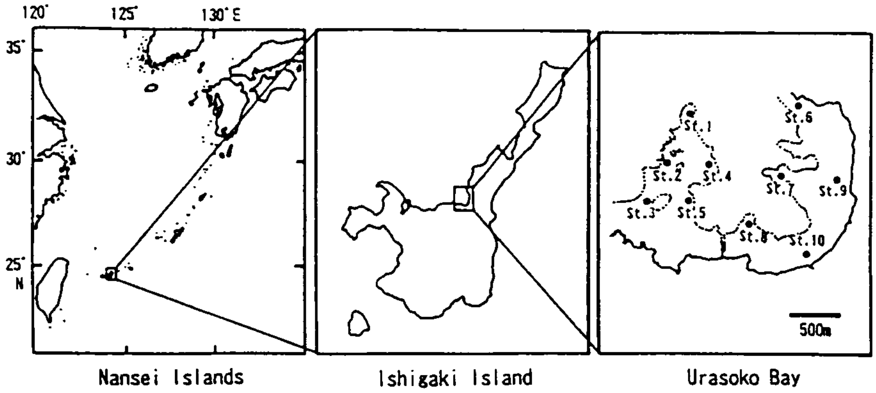

Fig. 1 Map of the south-western Japan showing the Nansei Islands, the Ishigaki Island, and the location of the study sites in the Urasoko Bay.

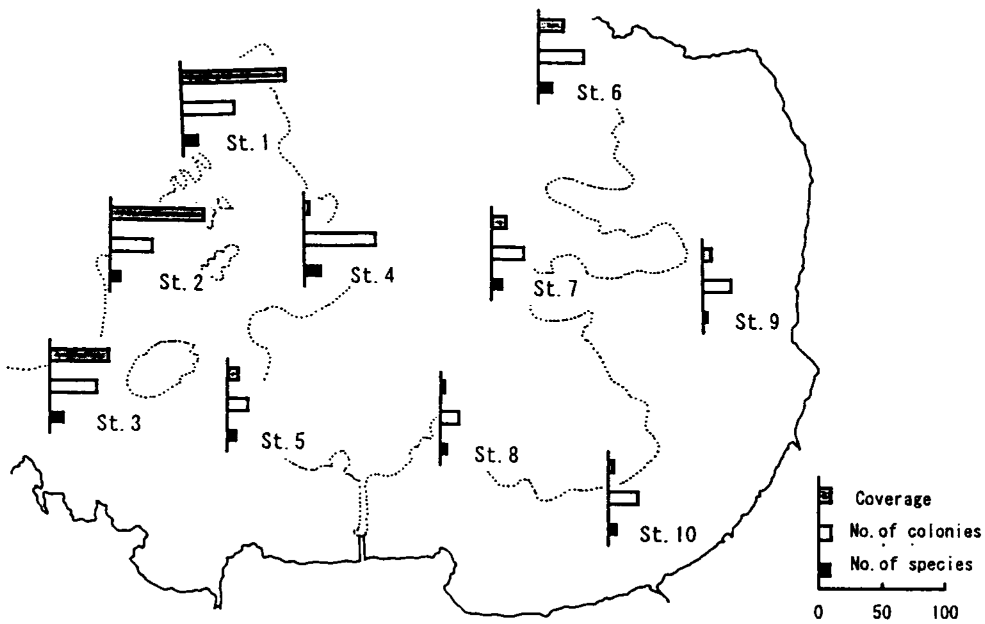

Fig. 2 Average coral coverage, no of coral colonies, and the number of coral species at ten study sites of the Urasoko Bay. Surveyed on Aug. 28-Sep. 15, 1995

Table 1 Average coral coverage for dominant hermatypic corals of the study sites. Surveyed on Aug. 28-Sep. 15, 1995

Coverage (cm²/m²)

	St. 1	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8	St. 9	St. 10
Acropora hyacinthus	3484	3447	572	660	0	0	0	0	0	0
Acropora digitifera	2802	3079	1320	1806	0	89	0	0	0	0
Acropora millepora	3	0	1191	0	181	454	0	0	0	37
Acropora formosa	0	0	763	386	0	413	0	0	0	0
Acropora nobilis	0	0	406	222	851	0	418	0	0	0
Acropora pulchra	368	19	1390	305	0	37	0	0	0	0
Acropora elseyi	0	0	0	0	270	1503	0	0	0	0
Acropora spp.	1580	951	3043	0	1259	412	273	97	0	259
Montipora digitata	0	0	0	4	9	78	1301	389	41	0
Montipora aequituberculata	73	0	0	0	0	193	547	0	0	0
Montipora spp.	22	0	153	48	0	275	1321	227	158	15
Porites lutea	0	20	0	0	71	0	18	370	959	777
Porites evermanni	0	0	0	0	0	0	0	0	1048	1156
Porites cylindrica	23	0	0	0	0	0	0	0	33	228
Millepora exaesa	8	0	0	0	16	0	11	26	27	40
Millepora tenella	0	327	0	0	0	0	10	0	0	0
Pavona venosa	0	0	0	0	0	0	0	0	0	228
Faviids	64	64	386	207	0	0	11	121	55	116
Others	126	40	64	71	121	106	25	0	21	90
Total	8552	7947	9288	3707	2778	3561	3933	1230	2342	2935

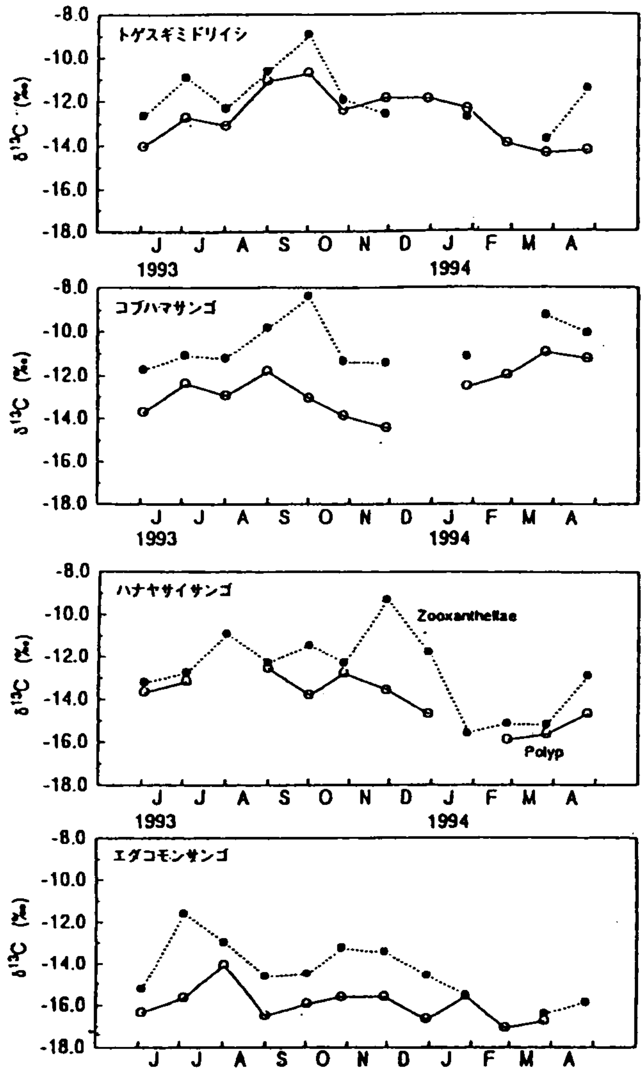

Fig.2. Seasonal variation of $\delta^{13}C$ in symbiotic algae and coral tissue of the 4 species, *Acropora nobilis*, *Porites lutea*, *Poccillopora damicornis*, *Montipora digitata* (from top to bottom) in a reef of Sesoko Is.

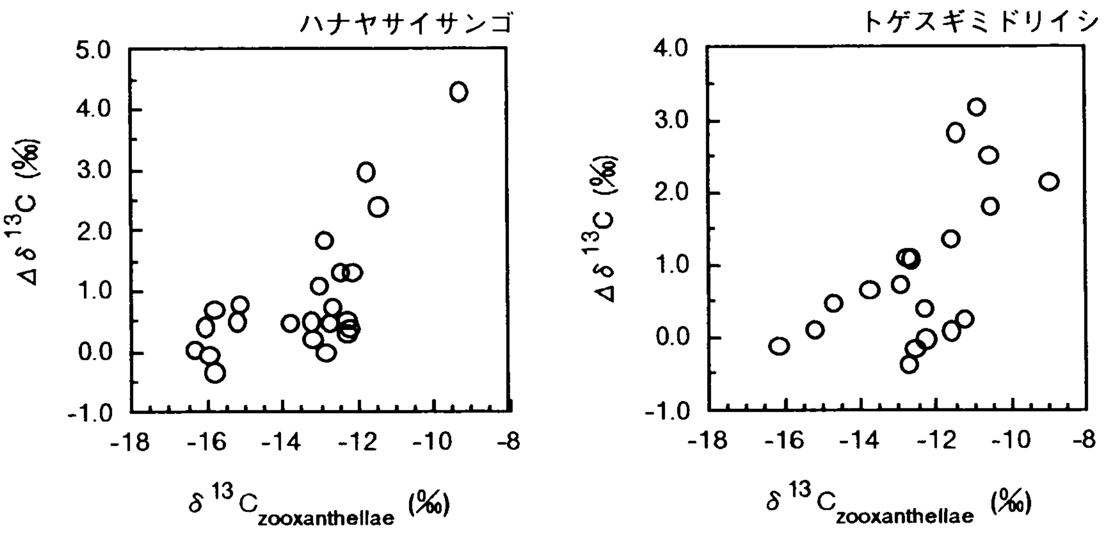

Fig. 3. Correlation between $\delta^{13}C$ and $\Delta\delta^{13}C$, the difference of $\delta^{13}C$ between symbiotic algae and coral tissue of *Poccillopora damicorinis* (left) and *Acropora nobilis* (right) in Ryukyu Is.