

A study of the coastal seawater in Yap Island and Ulithi Atoll, Federated States of Micronesia, 2001

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Abstract

In the coastal reefs of Yap Island and Ulithi Atoll, water analysis to determine the environmental conditions of marine plant flora was carried out during October 2001. Seawater was collected and analyzed at 37 stations; 12 in Yap and 25 in Ulithi Atoll. Water temperature, salinity, dissolved oxygen (DO), pH, nitrate-nitrogen, nitrite-nitrogen, ammonium-nitrogen, inorganic phosphate and silicate were analyzed. The average water temperature, salinity and DO for Yap were 29.5 °C, 33.2 psu and 6.20 mg l⁻¹, respectively. Whereas, those of Ulithi Atoll were 29.5 °C, 33.5 psu and 6.90 mg l⁻¹, respectively. The average dissolved inorganic nitrogen (DIN), dissolved inorganic phosphate (DIP) and N to P ratios were: 4.40 μM, 0.27 μM, 2.65 μM and 26, respectively. Whereas, those of Ulithi Atoll were 5.26 μM, 0.24 μM, 2.70 μM and 32, respectively. There were no significant differences in any factors between the two locations and the amount of dissolved nutrients of each locality showed characteristic low concentrations of tropic and subtropic southwestern Pacific waters.

Keywords: coastal seawater, coral reef, Micronesia, seagrass bed, water quality

Introduction

Yap State is the western most state of the Federated States of Micronesia and comprises of four large islands, 7 smaller islands and 134 atolls. Yap Island is the largest island in the state, and is surrounded by marginal coral reefs. Ulithi Atoll is approximately 150 km east of Yap proper and is one of the largest atolls in Micronesia. The marine benthic algae of Yap Island have been reported by several investigators (REINBOLD 1901; OKAMURA 1904, 1916; SCHMIDT 1928; SUGIYAMA 1942; HOLLENBERG 1968a, 1968b; TSUDA and BELK 1972; DE WREEDE 1973; AMESBURY et al. 1976). Those of Ulithi Atoll also have been reported by TRONO (1968, 1969), DE WREEDE (1973) and TSUDA (1976). However, a sufficient report on the marine plant flora of each district was needed. Furthermore, the environmental characteristics of the coastal waters with regards to marine plants in these districts have never been reported except for by NORO et al. (2001).

During the Yap and Ulithi research expedition conducted by the Kagoshima University Research Center for the Pacific Islands in October 2001, we had an opportunity to investigate marine algal flora and to analyze the surface seawater in these districts. In this paper, we report the results of the water analysis, and discuss their characteristics in these districts.

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Materials and Methods

The survey was carried out in Yap Island on October 17 to 18, 29 to 30, 2001, and in Ulithi Atoll on October 20 to 25, 2001. A total 37 samples were collected from the surface water as shown in figures 1 and 2. Temperature, salinity and dissolved oxygen (DO) were taken with a YSI DO meter (Yellow Spring Instruments, Ohio, USA), and pH was measured with a Yokogawa Model PH/82 pH meter (Yokogawa Electric Co., Tokyo, Japan) in the field. Dissolved nutrient analysis was performed using a DR/2000 Spectrophotometer (HACH Co., Colorado, USA). Dissolved inorganic nitrogen (DIN) was calculated as follows:

$$\text{DIN} = (\text{NO}_2\text{-N}) + (\text{NO}_3\text{-N}) + (\text{NH}_4\text{-N})$$

Results

Yap Island

Twelve stations were sampled in Yap Proper. Within the main harbor, 4 stations were sampled (stations 1, 3, 36 and 37 in Fig. 1 and Table 1).

In Stations 1, 3, 5, 31, 32, 33, 36 and 37 the bottom consisted mainly of fine sand and some silt. Especially, expansive seagrass beds were confirmed at Sts. 1, 3, 5, 31, 32 and 36 (Fig. 1). Stations 2, 4, 34 and 35 consisted mainly of corals (Fig. 1).

Environmental conditions varied little among the stations (Tables 1 and 3). The average water temperature was 29.5 °C with a maximum of 30.5 °C occurring at St. 1 and a minimum of 28.3 °C at St. 34. Salinity averaged 33.2 psu with a high of 34.4 psu at St. 5 and a low of 31.0 psu at St. 2. No salinity data was taken at St. 3. The average dissolved oxygen concentration (DO) was 6.17 mg l⁻¹. The highest DO occurred at St. 31 (7.5 mg l⁻¹) and the lowest at St. 34 (2.83 mg l⁻¹). DO was not measured at Sts. 2, 3 and 4. Average pH was 7.93 with a high of 8.13 at St. 2 and a low of 7.36 at St. 34.

Water quality in the coastal area was also analyzed. Nitrate-nitrogen, nitrite-nitrogen, ammonium-nitrogen, inorganic phosphate and silicate concentrations were determined. Table 2 shows the molar concentrations of each compound as well as the total dissolved inorganic nitrogen (DIN), inorganic phosphate (DIP) and the nitrogen to phosphorous ratio (N:P).

The concentrations of nitrite-nitrogen, nitrate-nitrogen and ammonium-nitrogen varied

Table 1. Station location and environmental data for Yap Proper durin the survey in October 2001

Station	Location	Latitude	Longitude	Temperature (°C)	Salinity (PSU)	DO (mg/l)	pH
1	Okeef	9°31'39.7"N	138°07'49.0"E	30.5	31.4	4.82	7.90
2	Tomil	9°29'39.7"N	138°07'44.1"E	29.5	31.0	7.00	8.13
3	Tomil	9°30'50.5"N	138°07'43.6"E	29.7	-	6.75	8.03
4	Milil	9°36'03.2"N	138°07'51.6"E	30.3	33.9	6.81	7.97
5	Milil	9°35'32.7"N	138°08'16.8"E	29.1	34.4	6.06	7.90
31	Wanyan Bay	9°33'32.8"N	138°12'00.5"E	29.4	33.2	7.50	7.97
32	Munguuy Bay	9°33'29.8"N	138°10'40.6"E	30.2	34.0	5.69	7.85
33	Tomil	9°30'30.3"N	138°09'49.4"E	29.6	33.3	7.25	8.10
34	Balabat	9°29'54.8"N	138°06'49.6"E	28.3	33.2	2.83	7.36
35	Balabat	9°29'28.6"N	138°07'00.5"E	27.8	33.1	6.13	7.89
36	Tomil	9°30'51.6"N	138°08'09.0"E	29.4	34.2	6.13	8.09
37	Okeef	9°31'36.4"N	138°07'58.8"E	30.1	33.0	7.12	8.00

- : no data

Table 2. Nutrient analysis data for Yap Proper during the survey in October 2001

Station	NO ₂ -N	NO ₃ -N	NH ₄ -N	PO ₄ -P (μ M)	SiO ₂ -Si	DIN	DIP	N:P
1	0.14	4.14	1.43	0.21	2.26	5.71	0.21	27
2	0.14	4.86	1.43	0.11	0.97	6.43	0.11	61
3	0.79	5.64	0.71	0.53	4.38	7.14	0.53	14
4	0.21	1.21	0.71	0.63	1.80	2.14	0.63	3
5	1.07	5.36	ND	0.11	5.97	6.43	0.11	61
31	0.14	1.29	0.71	0.32	1.73	2.14	0.32	7
32	0.07	0.64	ND	0.11	1.93	0.71	0.11	7
33	0.71	3.57	0.71	0.11	1.45	5.00	0.11	47
34	0.86	4.86	1.43	0.63	3.69	7.14	0.63	11
35	0.14	1.29	ND	0.11	4.71	1.43	0.11	14
36	0.21	4.07	ND	0.11	0.93	4.29	0.11	41
37	0.64	3.64	ND	0.32	2.00	4.29	0.32	14

ND: below detection limits

Table 3. Station location and environmental data for Ulithi Atoll during the survey in October 2001

Station	Location	Latitude	Longitude	Temperature ($^{\circ}$ C)	Salinity (PSU)	DO (mg/l)	pH
6	Potangeras*	10 $^{\circ}$ 04'26.9"N	139 $^{\circ}$ 40'22.2"E	29.5	32.80	8.49	8.16
7	Potangeras	10 $^{\circ}$ 04'29.4"N	139 $^{\circ}$ 40'04.4"E	29.2	33.20	6.00	8.17
8	Mogmog*	10 $^{\circ}$ 05'09.8"N	139 $^{\circ}$ 42'43.3"E	29.4	34.30	8.00	7.55
9	Mogmog	10 $^{\circ}$ 05'10.7"N	139 $^{\circ}$ 42'42.3"E	29.3	34.50	7.41	7.52
10	Mogmog*	10 $^{\circ}$ 05'10.7"N	139 $^{\circ}$ 42'42.3"E	30.3	34.30	10.40	7.84
11	Falalop*	10 $^{\circ}$ 01'00.9"N	139 $^{\circ}$ 47'07.4"E	28.3	32.90	5.67	7.78
12	Falalop*	10 $^{\circ}$ 00'49.1"N	139 $^{\circ}$ 47'24.2"E	29.0	33.80	5.92	7.98
13	Falalop	10 $^{\circ}$ 00'41.4"N	139 $^{\circ}$ 47'31.0"E	29.7	34.40	5.84	8.12
14	Falalop	10 $^{\circ}$ 01'16.2"N	139 $^{\circ}$ 47'06.2"E	29.0	34.00	6.25	8.00
15	Asor*	10 $^{\circ}$ 01'39.5"N	139 $^{\circ}$ 45'39.2"E	28.5	33.20	6.56	7.60
16	Asor*	10 $^{\circ}$ 01'32.5"N	139 $^{\circ}$ 46'10.3"E	30.1	34.10	6.40	8.12
17	Asor	10 $^{\circ}$ 02'02.5"N	139 $^{\circ}$ 45'47.0"E	29.4	33.70	6.28	8.08
18	Asor*	10 $^{\circ}$ 01'59.8"N	139 $^{\circ}$ 45'25.8"E	28.7	33.20	5.85	7.73
19	Sorleng*	10 $^{\circ}$ 04'46.4"N	139 $^{\circ}$ 44'08.0"E	28.1	32.60	6.10	7.44
20	Yag / Sorleng*	10 $^{\circ}$ 04'36.1"N	139 $^{\circ}$ 44'32.0"E	28.5	33.10	6.33	7.81
21	Yag / Sorleng	10 $^{\circ}$ 04'36.1"N	139 $^{\circ}$ 44'30.0"E	30.1	32.60	6.68	7.61
22	Mogmog*	10 $^{\circ}$ 05'11.7"N	139 $^{\circ}$ 42'22.2"E	30.9	30.60	7.61	7.83
23	Mogmog	10 $^{\circ}$ 05'15.1"N	139 $^{\circ}$ 42'14.3"E	30.2	33.70	6.73	7.65
24	Potangeras*	10 $^{\circ}$ 04'27.2"N	139 $^{\circ}$ 40'24.7"E	31.4	33.90	7.30	7.68
25	Fassari	9 $^{\circ}$ 54'00.3"N	139 $^{\circ}$ 39'23.8"E	28.4	33.20	5.67	7.75
26	Fassari*	9 $^{\circ}$ 54'33.5"N	139 $^{\circ}$ 39'27.2"E	28.6	33.90	8.96	7.38
27	Fassari*	9 $^{\circ}$ 54'00.3"N	139 $^{\circ}$ 39'23.8"E	30.0	33.90	6.64	7.59
28	Fassari	9 $^{\circ}$ 54'41.0"N	139 $^{\circ}$ 39'36.1"E	33.0	34.30	7.91	8.12
29	Fassari	9 $^{\circ}$ 54'11.5"N	139 $^{\circ}$ 39'21.4"E	30.4	34.10	8.07	7.79
30	Asor*	10 $^{\circ}$ 01'39.5"N	139 $^{\circ}$ 45'39.2"E	28.5	33.20	6.03	7.95

*: indicates areas inside of the atoll, otherwise areas are outside of the atoll

among stations. Concentrations of nitrite-nitrogen ranged from 0.07 μ M to 1.07 μ M (Sts. 32 and 5 respectively) with an average of 0.43 μ M. Nitrate-nitrogen concentrations had an average of 3.38 μ M, a high of 5.64 μ M (St. 3) and a low of 0.64 μ M (St. 32). For ammonium-nitrogen, the average was 1.02 μ M, the high was at Sts. 1, 2 and 34 (1.43 μ M) and the low was at Sts. 3, 4

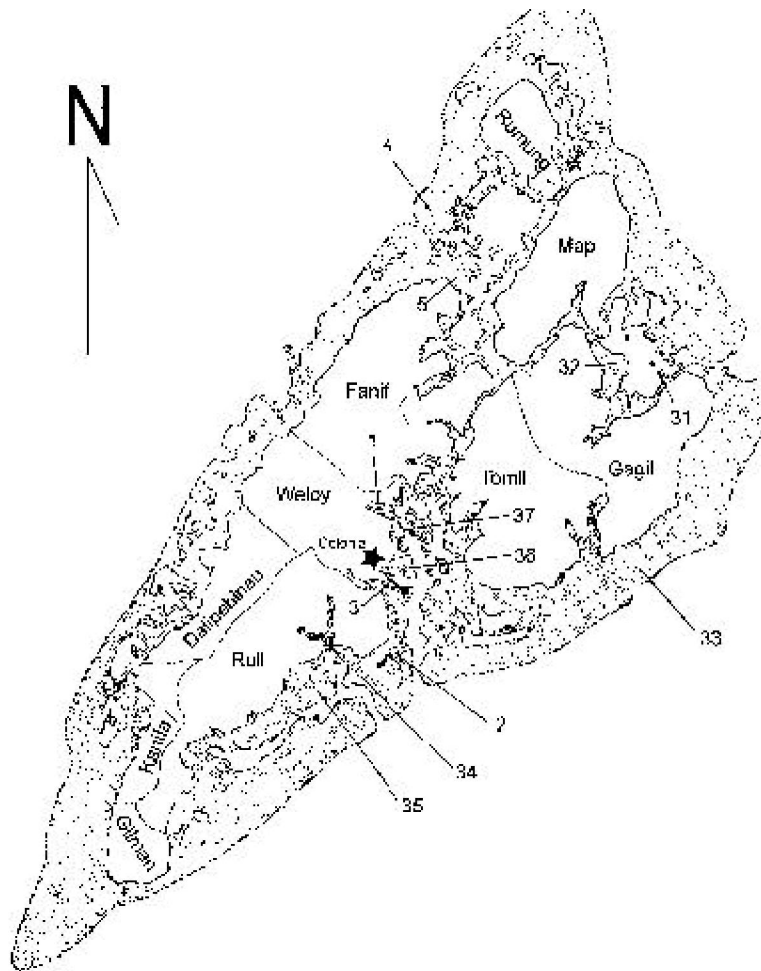


Fig. 1. Map of Yap Island (Yap State) showing the 12 stations during the survey in October 2001

and 33 ($0.71 \mu\text{M}$). At Sts. 5, 32, 35, 36 and 37, ammonium-nitrogen was not detected.

The highest concentration of DIN was at Sts. 3 and 34 and the lowest was sampled at St. 32. At Sts. 3 and 34, the DIN concentration was $7.14 \mu\text{M}$ with a nitrogen breakdown at St. 3 of $0.79 \mu\text{M}$ nitrite-nitrogen, $5.64 \mu\text{M}$ nitrate-nitrogen and $0.71 \mu\text{M}$ ammonium-nitrogen. St. 34 had concentrations of $0.86 \mu\text{M}$ nitrite-nitrogen, $4.86 \mu\text{M}$ nitrate-nitrogen and $1.43 \mu\text{M}$ ammonium-nitrogen. St. 32 had the lowest sampled DIN ($0.71 \mu\text{M}$: $0.07 \mu\text{M}$ nitrite-nitrogen and $0.64 \mu\text{M}$ nitrate-nitrogen) with ammonium-nitrogen not being detected.

Concentrations of dissolved inorganic phosphate ($\text{PO}_4\text{-P}$) ranged from 0.11 to $0.63 \mu\text{M}$, the low at Sts. 2, 5, 32, 33, 35 and 36, and the high at Sts. 4 and 34. The average DIP concentration was $0.27 \mu\text{M}$.

The N:P ratio was a low 3 at St. 4 and was 61 at St. 2 with an average of 26.

Silicate concentrations were also analyzed. Silicate was found to average $2.65 \mu\text{M}$ with a high of $5.97 \mu\text{M}$ at St. 5 and a low of $0.93 \mu\text{M}$ at St. 36.

Ulithi Atoll

Twenty-five stations were analyzed at Ulithi Atoll with 10 stations within the atoll and 15 outside of the atoll. A total of 6 islands were visited. Substrate of Sts. 6, 7, 9, 11, 13-17, 20, 21, 23-27, 29 and 30 consisted of mainly corals (Fig. 2) whereas, Sts. 8, 10, 12, 18, 19, 22 and 27 comprised of fine sand, silt and dead corals (Fig. 2).

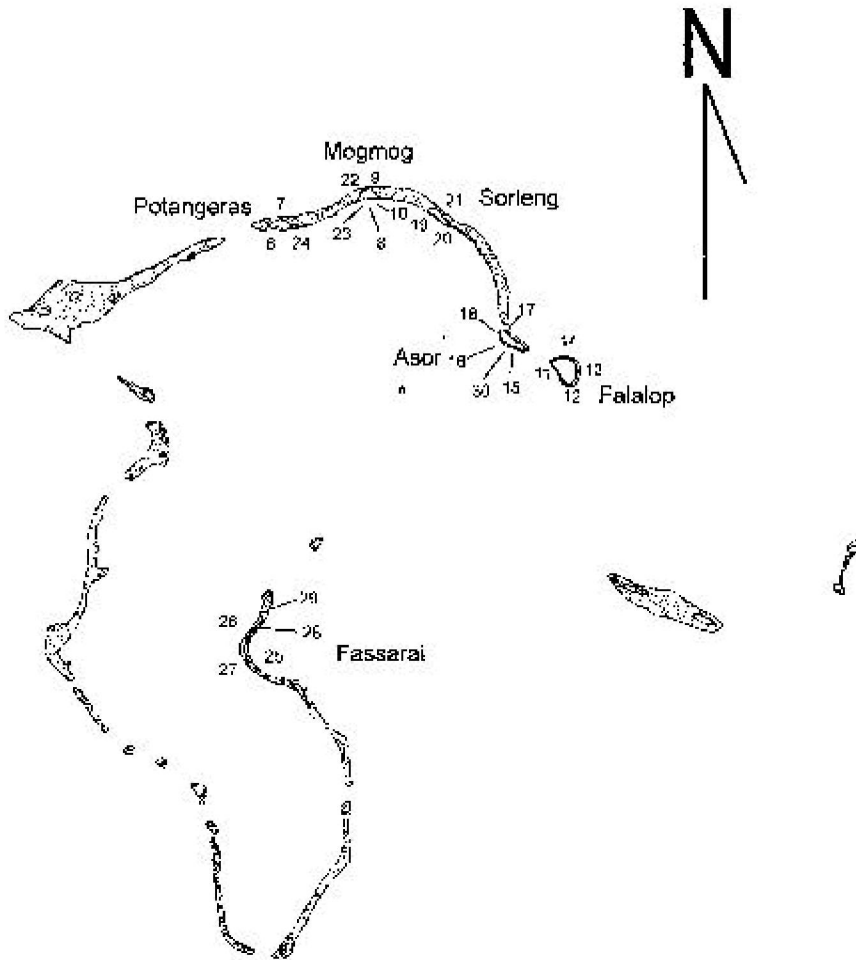


Fig. 2. Map of Ulithi Atoll (Yap State) showing the 25 stations during the survey in October 2001

The average values for the physical variables are listed in Table 3. Temperature varied from 28.1 °C (St. 19) to 33.0 °C (St. 28) with an average of 29.5 °C. Salinity ranged from 30.6 psu (St. 22) to 34.5 psu (St. 9) with an average of 33.5 psu. Dissolved oxygen had an average of 7.81 mg l⁻¹ a high of 10.40 mg l⁻¹ (St. 10) and a low of 5.67 mg l⁻¹ (St. 11).

Chemical characteristics of the stations were also determined (Table 4). DIN was found to average 5.26 µM. The highest value occurred at St. 27 (8.57 µM) and the lowest value occurred at St. 8 (0.71 µM). Broken down, the average nitrite-nitrogen was 0.69 µM, the high was 1.43 µM at St. 30 and the low was 0.07 µM at St. 10. The average nitrate-nitrogen was 4.02 µM, the high was 5.71 µM at St. 29 and the low was 0.14 µM at St. 8. The average ammonium-nitrogen

Table 4. Nutrient analysis data for Ulithi Atoll during the survey in October 2001

Station	NO ₂ -N	NO ₃ -N	NH ₄ -N	PO ₄ -P (μ M)	SiO ₂ -Si	DIN	DIP	N:P
6	0.79	4.21	ND	0.11	1.85	5.00	0.11	47
7	0.64	4.36	ND	0.32	1.91	5.00	0.32	16
8	0.57	0.14	ND	0.63	0.55	0.71	0.63	1
9	0.86	5.57	ND	ND	3.28	6.43	-	-
10	0.07	3.50	ND	0.11	1.86	3.57	0.11	34
11	0.93	5.50	ND	0.42	2.13	6.43	0.42	15
12	0.71	4.29	ND	0.21	2.15	5.00	0.21	24
13	0.71	4.29	ND	0.84	2.50	5.00	0.84	6
14	0.71	4.29	1.43	0.11	2.91	6.43	0.11	61
15	0.64	2.93	0.71	0.11	2.76	4.29	0.11	41
16	0.79	4.93	ND	0.11	3.08	5.71	0.11	54
17	0.93	4.07	0.71	0.11	3.76	5.71	0.11	54
18	0.93	5.50	ND	0.21	6.29	6.43	0.21	31
19	0.21	4.07	0.71	0.11	0.98	5.00	0.11	47
20	1.00	4.00	ND	0.21	3.63	5.00	0.21	24
21	0.64	4.36	0.71	0.32	2.20	5.71	0.32	18
22	0.57	0.86	ND	0.11	3.23	1.43	0.11	14
23	0.14	4.14	2.14	0.11	1.17	6.43	0.11	61
24	0.14	1.29	2.14	0.21	1.76	3.57	0.21	17
25	0.86	3.43	ND	0.11	1.75	4.29	0.11	41
26	0.79	4.93	1.43	0.11	2.58	7.14	0.11	68
27	0.71	6.43	1.43	0.21	7.41	8.57	0.21	41
28	0.79	4.93	1.43	0.21	2.38	7.14	0.21	34
29	0.71	5.71	ND	0.53	1.91	6.43	0.53	12
30	1.43	2.86	0.71	0.32	3.50	5.00	0.32	16

ND: below detection limits, -: no data

was 1.23 μ M, the high was 2.14 μ M at Sts. 23 and 24 and the low was 0.71 μ M at Sts. 15, 17, 19, 21 and 30. ammonium-nitrogen was not detected at Sts. 6 to 13, 16, 18, 20, 22, 25 and 29.

Dissolved inorganic phosphate was an average of 0.24 μ M with a high of 0.84 μ M and a low of 0.11 μ M. The high occurred at St. 13 and the low occurred at Sts. 1, 10, 14–17, 19, 22, 23, 25 and 26. Inorganic phosphate was not detected at St. 9.

The N to P ratio was the lowest at St. 8 with a ratio of 1 and the highest occurred at St. 26 with a value of 68. The average ratio was 18.

Silicate concentrations averaged 2.70 μ M with a high at Sts. 27 of 7.41 μ M and a low at St. 8 of 0.55 μ M.

Discussion

The physical parameters for Yap Proper, outer reef of Ulithi Atoll, inner reef of Ulithi Atoll and the composite of Ulithi Atoll showed that there was no significant difference between all areas and all parameters (Tables 1 and 3). Temperatures varied widely at Yap and the outer reef of Ulithi, however this can be attributed to the different times the surface temperature was recorded. The highest temperature occurred along the outer reef of Ulithi and was 33.0 °C. The lowest value of 27.8 °C was recorded in Yap. Temperatures averaged 33.2 °C in Yap and 29.5 °C in Ulithi. Salinity, also showed a large variation at Yap. However, variation was the greatest



Fig. 3. Seagrass beds at St. 31 (Yap, 1.5 m depth)



Fig. 4. *Caulerpa* population growing on the sandy bottom at St. 33 (Yap, 2 m depth)



Fig. 5. Coral reef at St. 35 (Yap, 20 m depth)



Fig. 6. Coral reef at St. 15 (Ulithi, 2 m depth)

Figs 3-6. Substrata of the study sites in Yap Island and Ulithi Atoll during the survey in October 2001

along the Inner Reef of Ulithi with a range of 30.6 to 34.5 psu. A salinity of 34.5 psu was the highest value, located along the inner reef of Ulithi and the low was found to be 30.6 psu recorded outside of the atoll. Salinity averaged 33.2 psu in Yap and 33.5 psu in Ulithi. Dissolved oxygen concentrations were high at all areas, with the highest value occurring at the inner reef (10.4 mg l^{-1}) and the lowest value occurring at Yap (2.4 mg l^{-1}). Average DO in Yap was 6.2 mg l^{-1} and in Ulithi it was 6.9 mg l^{-1} . Values for pH varied from a low of 7.36 to a high of 8.17, Yap and the outer reef, respectively. Average pH was 7.93 in Yap and 7.81 in Ulithi.

Dissolved inorganic nitrogen varied widely. The highest value was detected at the inner reef with a value of $8.57 \text{ }\mu\text{M}$ and the lowest value was from Yap with a value of $0.71 \text{ }\mu\text{M}$. DIN averaged $4.40 \text{ }\mu\text{M}$ at Yap and $5.26 \text{ }\mu\text{M}$ in Ulithi. Inorganic phosphate (DIP) averaged $0.28 \text{ }\mu\text{M}$ in Yap and $0.24 \text{ }\mu\text{M}$ in Ulithi. The highest valued occurred at the outer reef of Ulithi ($0.84 \text{ }\mu\text{M}$) and the lowest value of $0.11 \text{ }\mu\text{M}$ occurred in all general locations.

The average N to P ratio for Yap was 26 and the average for Ulithi was 32. Both the high and low occurred at the inner reef with values of 68 and 1, respectively.

In 1999, NORO et al., conducted a survey of coastal seawater in Yap during October 21 to 26, 1999. The temperature, salinity and pH are lower than that of the 1999 survey whereas, dissolved oxygen was found to be higher. Nutrient concentrations were also different between these two surveys. Silicate and DIP decreased and DIN increased. Nitrogen to phosphorous ratios also increased. Differences in values of the environmental parameters may be partially explained by

the location of stations during this study. Stations in this survey concentrated primarily within the harbor, whereas the 1999 survey was well distributed around the entire island. Salinity may have also been affected by the periodic squalls that were encountered during data collection.

Differences in DIN and DIP may have been due to the different sampling and storage regimes of this study and the 1999 survey. Samples in this study were not treated with acid to lower the pH. Sampled sea water was only placed in the onboard deep freezer. Therefore any significant discrepancies would be likely due to the preservation procedure. The large difference in silicate concentrations may also be due to differences in the way the samples were preserved.

Compared to the near shore, water nutrient profile of a higher latitude subtropical reef, such as Sesoko Island, Okinawa Prefecture, Japan, values from Yap and Ulithi fell within the same ranges as those of Okinawa (CROSSLAND 1982). Nitrite-nitrogen and nitrate-nitrogen of Sesoko Is. were 0.30 μM and 29.05 μM in June 1981, respectively. Also, the silicate and DIP concentrations were 10.90 μM and 0.70 μM in the same sampling period.

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