Jap. J. Phycol. (Sôrui) 31 : 148-155. September 20, 1983

Distribution of *Ulva pertusa* and amount of nitrogen in Yamaguchi Bay

Shiroh UNO*, Yasuji SAKAI** and Koji YOSHIKAWA**

*Far Seas Fisheries Research Laboratoy, Orido, Shimizu, Shizuoka-ken, 424 Japan
** Nansei Regional Fisheries Research Laboratory, Ohno-cho, Saeki-gun, Hiroshima-ken, 739-04 Japan

UNO, S., SAKAI, Y. and YOSHIKAWA, K. 1983. Distribution of *Ulva pertusa* and amount of nitrogen in Yamaguchi Bay. Jap. J. Phycol. 31 : 148-155.

It is said that *Ulva pertusa* has increased in abundance with the progression of eutrophication in the Seto Inland Sea. The authors drew distribution maps of *U. pertusa*, and estimated the quantity of total nitrogen in *U. pertusa*, seawater (DIN, DON, and PON), and sediment (solid and liquid fractions) in Yamaguchi Bay in July and November 1976. *U. pertusa* existed thickly at the middle part of both east and west sides of the bay. The highest standing stock was 5.3 kg (wet weight)/m^2 in November. The total amount of nitrogen in *U. pertusa* in the bay was estimated to be about 3.8 and 12.1 tonnes in July and November, respectively. The analyses of the other materials showed that the sum of nitrogen in the sediment exceeded that in any other component. The total amount of nitrogen in *U. pertusa* in the bay greatly exceeded that in the seston including phytoplankton. It is thought that *U. partusa* holds the most important position among living materials in the nitrogen cycle in the bay.

Key Index Words: *nitrogen cycle*; *nitrogen distribution*; Ulva pertusa.

Recently, for understanding the eutrophication in estuarine or coastal regions, studies of nitrogen or phosphorus cycles in the sea have been carried out at many research bodies. Nitrogen and phosphorus seem to be the main factors involved in eutrophication. It is thought that plants in large seaweed beds play an important role in the nitrogen and phosphorus cycles. Recent works on nutrient cycles in the sea have concentrated on phytoplankton, the predominant life in the sea, and have not paid much attention to the seaweeds. However, some recent investigators (IIZUMI 1975, PENHALE *et al.* 1977, etc.) studied the ecocystem of the eelgrass (*Zostera marina*) beds.

The present authors have studied the nitrogen stock in *U. pertusa* beds in Yamaguchi Bay. *U. pertusa* is ordinaly seen on any shore of the Seto Inland Sea and is said to have increased in abundance with the progression of eutrophication in the sea.

Study area

Yamaguchi Bay is situated in the western part of the Seto Inland Sea. It is a secondary slender bay which is separated from Aio Bay by lwaya Peninsula. The mouth of the bay is about 4 km wide and its length is about 8 km. The area discussed in this paper is 15.18 km^2 and is indicated by stippling in Fig. 1. The deepest point at the mouth exceeds 10 m, and the 5 m depth line extends into the bay parallel to the peninsula. The average depth of the bay is 1.04 m at mean level.

As five small rivers are flow into the bay, chlorinity of the water is low: the chlorinity of the surface water at Stn. 2 varied from 8.3 to 17.1‰. The maximum current speed was 25 cm/sec at the mouth

* Present address : Seikai Regional Fisheries Research Laboratory, Kokubu-cho 49, Nagasaki, 850 Japan

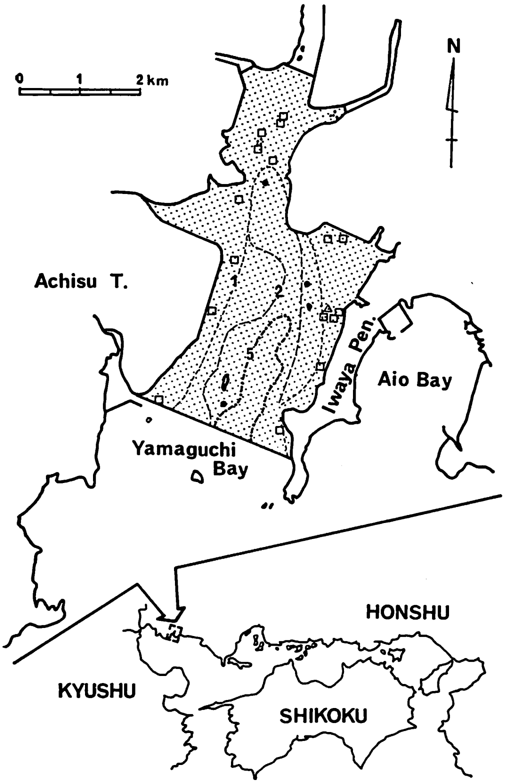

Fig. 1. Maps of Yamaguchi Bay and the Seto Inland Sea. Solid circles: stations for seawater and sediment analyses. Open triangle: a station for sediment analysis. Open square: stations for the determination of standing stock of *Ulva pertusa*. Numerals at isodepth contours are in meter.

of the bay in November. The grain size composition of the surface sediment in the bay widely varied with time and sampling stations. The main components of the sediment were silt and sand.

Methods

Field observations were carried out on July 13 and November 24, 1976. The distribution of *U. pertusa* in the bay was observed by naked eyes and minutely recorded on the map. *U. pertusa* in the quadrat of 50 cm × 50 cm was sampled for the estimation of total amount of the plant in the bay. Then standing stock of *U. pertusa* were determined at seventeen stations on the intertidal zone. While *U. pertusa* in the deep water were sampled by nets, or counted by diving observation.

Determinations of organic carbon and nitrogen in *U. pertusa* and sediment were carried out by a Yanagimoto CN Coder MT-500 with measurement error less than 2%. Sediment samples collected in July were weighed and then centrifuged to separate theoretically liquid (dissolved) from solid (particulate) fraction. The deposited solid materials were weighed again and then dried. Finally, they were tared to determine dry/wet weight ratio of the sediment.

Seawater was sampled from surface and bottom layers at high and low tides. They were also sorted into two parts: particulate matter collected on Whatman GF/C glass fiber filters and the rest dissolved matter passed through the filters. A Yanagimoto CHN Corder MT-2 was employed to determine particulate organic nitrogen (PON). Dissolved inorganic nitrogen (DIN) is the integrated value of nitrate, nitrite, and ammonium nitrogen, determined by the methods of SOLÓRZANO (1969), BENDSCHNEIDER and ROBINSON (1952) and WOOD *et al.* (1967), respectively. Dissolved organic nitrogen (DON) was analysed with Kjeldahl digestion method based on STRICKLAND and PARSONS (1968).

The large tidal range cause remarkable variation of the volume of seawater in Yamaguchi Bay. For convenience, the authors estimated the nitrogen stock in the water at the mean tidal level for assessing the role of *U. pertusa* in the nitrogen cycle in seaweed beds.

The nitrogen in *U. pertura* (N_u) in the whole bay, is expressed as equation (1):

$$N_u = U \cdot f_u \cdot F, \tag{1}$$

where U is the total amount (wet weight) of *U. pertusa* in the bay, f_u is the ratio of dry to wet weight of *U. pertusa*, determined as 0.15 in the present experiment, and F is the ntrogen content on a dry weight basis of *U. pertusa* determined as 0.037 here.

Each of the nitrogen as DIN, DON, and

PON, in seawater of the bay (N_w), is obtained by equation (2):

$$N_w = \Sigma_n \cdot d_w \cdot S/p\,, \tag{2}$$

where n is the nitrogen concentration of each sample in gN/m³, d_w is the mean water depth of the bay in meter, S is the area of the bay concerned in this paper in m², and p is the number of samples collected.

In July, nitrogen in the sediment was divided into two parts: the solid fraction (sediment completely excluding water), the liquid fraction (all the volume of interstitial water). Total nitrogen in the solid fraction (N_s) and in the liquid fraction (N_i) of the sediment in the bay are calculated by equations (3) and (4).

$$N_s = \Sigma_{ns} \cdot V_s \cdot d_c \cdot S/(V_s + V_{si}) \cdot p\,, \tag{3}$$

$$N_i = \Sigma_{ni} \cdot (V_i + V_{si}) \cdot d_c \cdot S/(V_s + V_i + V_{si}) \cdot p, \tag{4}$$

where ns is the nitrogen content of dried sediment in μgN/g and ni is the nitrogen concentration of liquid fraction in gN/m³ at each station sampled, d_c is the thickness of the sediment core concerned with nitrogen cycle in the bay (assumed to be 0.1 m), V_s, V_i and V_{si} are volumes of the dried sediment, interstial water taken by centrifuging, and the water contained in the sediment after centrifuging. These values are obtained by the solution of following equations:

$$V_s + V_i + V_{si} = V$$

$$\rho_m = (V_i + V_{si}) \cdot \rho_i + V_s \cdot \rho_s$$

$$r_1 = V_s \cdot \rho_s / \rho_m$$

$$r_2 = V_s \cdot \rho_s / (V_{si} \cdot \rho_i + V_s \cdot \rho_s)\,,$$

where V is unit volume of the whole sediment in 0.1 m³, ρ_s, ρ_i, and ρ_m are specific gravities of the solid fraction (determined as 2.6 as the average of all the three stations), liquid fraction (calculated as 1.02 at σ_{15}), and the whole sediment, respectively, r_1 and r_2 are weight ratios of solid fraction to the whole sediment determined as 0.61 as the average), and to the sediment after centrifuging (determined as 0.73).

Nitrogen of the whole sediment in November is expressed by the sum of N_s plus N_i in equations (3) and (4).

Results and Discussion

Figs. 2 and 3 show distributions of *U. pertusa* in the bay in July and November, respectively. In July *U. pertura* was found most densely at the middle part of the both east and west sides of the bay. The highest standing stock was about 2 kg/m² in wet weight. At the central part of the bay *U. pertusa* existed thinly with the value from 0.5 to 10 g (wet weight)/m². In November the areas of high density were also located at both sides of the middle part of the bay. The highest standing stock was 5.3 kg/m² in the month. The total amounts of *U. pertusa* in the bay were 684 tonnes in July and 2187 tonnes in November.

Fig. 2. Distribution of *Ulva pertusa* (wet weight) in Yamaguchi Bay in July 1976.

Fig. 3. Distribution of *Ulva pertusa* (wet weight) in Yamaguchi Bay in November 1976.

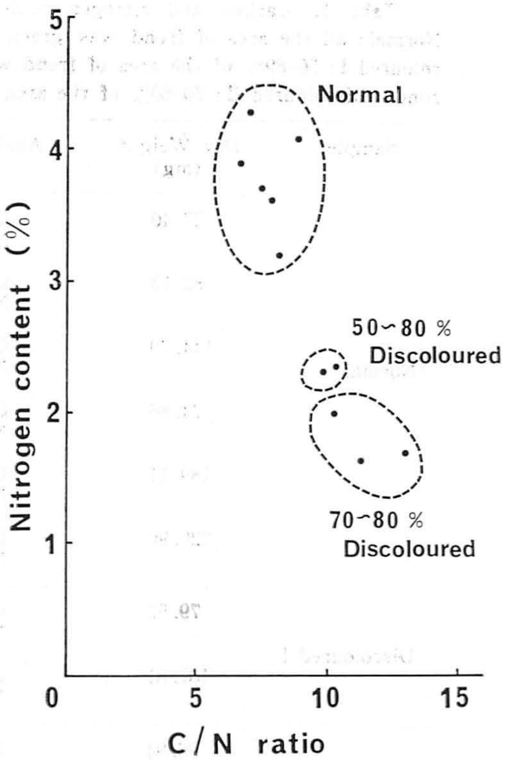

Fig. 4. Relationships between nitrogen content (% dry weight) and C/N ratio in *Ulva pertusa* of three different discolouration types.

Organic carbon and nitrogen of *U. pertusa* are shown in Table 1. The average carbon and nitrogen contents of healthy growing *U. pertusa* were 7.6 and 3.7% dry weight respectively. Nitrogen content of *U. pertusa* was about half that of *Porphyra yezoensis* in which it varied from 6.2 to 7.9% in a day (OOHUSA *et al.* 1978). The present figures of *U. pertusa* did not differ very much from that of *Zostera marina* (1.9-4.3 %, after HARRISON and MANN 1975).

The average carbon/nitrogen ratio of *U. pertusa* was 7.42 by weight. Both of the carbon and nitrogen contents gradually decreased with decline of the growth of *U. pertusa*. Nitrogen content decreased at quicker rate than did carbon, so the C/N ratio of *U. pertusa* tended to rise with decline of the growth as indicated in Fig. 4. Such values of the C/N ratio have been also recognized in phytoplankton. REDFIELD (1934) and FLEMING (1940) showed a C/N ratio of 7.0 based on the number of carbon and nitrogen atoms (the ratio by weight is about 6.0) for natural phytoplankton. UNO (1974) indicated that the average C/N ratio of the diatom *Skeletonema costatum* in continuous culture was 5.75 by weight. Furthermore, UNO (1978) also found that many organic materials in the sea showed a tendency to increase the C/N ratio as nitrogen content decreased.

Table 2 shows the total amount of nitrogen in six components in the bay. Almost all the nitrogen in the bay existed in the solid fraction of the sediment with the value of about three order of magnitude higher than that of any other component. Values of nitrogen existed in the other components did not much differ from each other. *U. pertusa* in the whole bay comprised 3.80 tonnes of nitrogen in July and 12.14 tonnes

Table 1. Carbon and nitrogen content in *Ulva pertusa* under three different types. Normal: all the area of frond was green, sampled in seawater or intertidal zone. Discoloured I: 50–80% of the area of frond was discoloured, sampled in seawater or intertidal zone. Discoloured II: 70–80% of the area of frond was discoloured, sampled in splash zone.

Sample	Dry Weight (mg)	Analyzed Value (%)	C/N Ratio (Weight)	Average
Normal	27.40	C : 31.90 N : 4.00	7.98	C : 27.55% N : 3.72% C/N : 7.42
	82.13	C : 29.45 N : 4.21	7.00	
	144.70	C : 26.73 N : 3.62	7.39	
	174.86	C : 27.74 N : 3.56	7.80	
	189.11	C : 25.13 N : 3.83	6.56	
	220.90	C : 25.14 N : 3.12	8.05	
Discoloured I	79.52	C : 23.18 N : 2.28	10.17	C : 22.66% N : 2.27% C/N : 9.99
	187.81	C : 22.14 N : 2.26	9.81	
Discoloured II	96.94	C : 20.18 N : 1.95	10.34	C : 19.99% N : 1.73% C/N : 11.6
	108.31	C : 17.98 N : 1.60	11.27	
	125.53	C : 21.80 N : 1.65	13.24	

Table 2. The estimated amounts (in tonnes) of nitrogen in *Ulva pertusa*, seawater, and sediment in Yamaguchi Bay, July and November 1976.

Components		July	November
Ulva		3.80	12.14
Seawater	DIN	2.06	1.63
	DON	6.88	5.37
	PON	0.89	1.27
Sediment	Solid	1,395.10	1,333.11
	Liquid	6.74	
Total		1,415.47	1,343.52

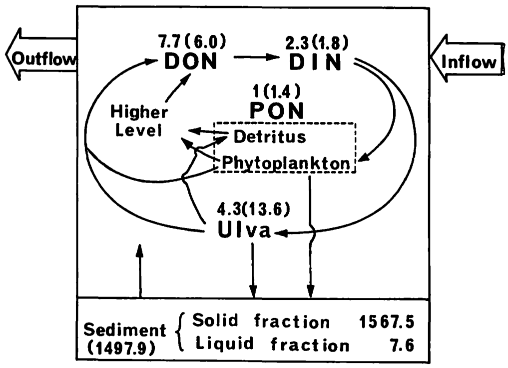

Fig. 5. Schematic diagram of the nitrogen cycle in Yamaguchi Bay. Each values in relative to PON in July. In parentheses are shown the November values.

in November. Fig. 5 express schematically the nitrogen cycle in the bay, taking the value of PON in July as the standard.

The column thickness of seawater in the present study was ten times greater than the core thickness of sediment samples. Nevertheless, nitrogen stock in the sediment exceeded that in all other components of the bay, due to the remarkable difference of nitrogen concentration of sediment (ca. 700 ppm) from that of the others (e.g., ca. 60 $\mu g/l \fallingdotseq 0.06$ ppm as PON). The nitrogen content in the sandy sediment of Yamaguchi Bay was lower than that of Harima-Nada, in the eastern part of the Seto Inland Sea, which was 1630 ppm in average at 46 stations (UNO 1978). In the sediment of the East China Sea, HAMADA and HAMADA (1963) found that the nitrogen content varied from 300 to 700 ppm.

For convenience the present authors selected a sediment core thickness of 10 cm, even though nitrogen should exist in the sediment below 10 cm depth. IIZUMI (1975) indicated that nitrate, nitrite, and phosphorus in the interstitial water from the sediment of an eelgrass bed decreased below 10 cm of core depth, but ammonia increased. According to him water content and ignition loss of the sediment did not changed vertically. Living organisms in the sediment usually exist in a thin layer at the surface. PERKINS (1974) and TEAL and WIESER (1966) pointed out that meiobenthos are commonly most abundant in the upper 1-2 cm layer of the sediment. Additionally, TANIDA and OKUDA (1958) indicated that more than 90% of macrobenthos have been found within the upper 10 cm core depth. Consequently, the layer of sediment appears the most important for the nitrogen cycle. The amount of nitrogen in interstitial water of the sediment represented only 0.48% that of solid fraction, but its nitrogen concentration was twenty time shigher than the dissolved nitrogen in seawater.

In Table 2, nitrogen contained in phytoplankton was included in the PON calculation because of the difficulties of separating it from the other particulate materials in the seawater. Usually phytoplankton is attributed to the most abundant living organism in the sea. However, in the shallow waters of Yamaguchi Bay *U. pertusa* was the most dominant living organism in the nitrogen cycle. The amount of nitrogen in a water column is directly dependent on the thickness of water column. If the mean depth of the bay were 10 m, the amounts of DIN, DON, and PON would be about ten times greater than the present results.

In 1981, meiobenthos of Yamaguchi Bay was observed and the biomass was varied from 20-2645 and 157-2333 mg/m^2 in July and December, respectively. In Oumi Bay, the next bay at east side of Aio Bay, macrobenthos existed with the value from 714 to 3450 g/m^2 in June and from 270 to 2340 g/m^2 in November 1982, while meiobenthos also existed from 223 to 1080 mg/m^2 in June and from 159 to 581 mg/m^2 in November.

TANIDA and OKUDA (1958) showed that the biomass of macrobenthos in Matsushima Bay was 2.28 kg/m^2 (average value of three stations). This value is fairly close by its weight to the higher values of standing stock of *U. pertusa* in the coastal zone of Yamaguchi Bay. Usually, the macrobenthos have 10-100 times more biomass than the meiobenthos (FENCHEL 1969). However, if the almost components of macrobenthos are bivalves, the biomass of macrobenthos in weight will be much higher than that of the meiobenthos just like as Oumi Bay. We have no numerical data on the macrobenthos in Yamaguchi Bay, but have recognized many bivalves there. Therefore the biomass of benthos in Yamaguchi Bay would be equivalent to the standing stock of *U. pertusa* in the bay.

In Yamaguchi Bay the total nitrogen decreased by 92 tonnes from July to November. This was mainly caused by a change in the sediment nitrogen. However, variation of the sediment nitrogen between July and November was smaller than that of other materials. The values of nitrogen in Table 2 were all determined based on many assumptions and definitions. The nitrogen in *U. pertusa* would be closest to the actual value. On the other hand, the estimate of nitrogen in seawater was based on the mean value of the surface and bottom samples at three stations during low and high tides. The nitrogen in the sediment of various stations changed from sample to sample, but was based on the mean value of four stations at low tide. It will be necessary to take more samples to improve the accuracy of the nitrogen estimation.

In estuaries, especially where algal beds are present, seaweeds could play a predominant role in the nitrogen cycle by virtue of its quantity. It is thought that *U. pertusa* occupies the most important position among the living materials in the nitrogen cycle in Yamaguchi Bay. As such, it must perform a role of buffer for nutrients in estuarine water.

Acknowledgements

The authors wish to express their sincere thanks to Drs. Yunosuke SAITO and Akio MURAKAMI, who gave them an opportunity to carry out this study. They are most grateful to Mr. Thomas B. MCCORMICK III and Dr. Sigeiti HAYASI for their interest and critical reading of the manuscript. Thanks are also extended to Miss Harumi MURAKAMI for her assistance in preparation of the manuscript.

They are indebted to Yamaguchi Naikai Fisheries Experimental Station of Yamaguchi Prefecture for the cooperation to this study.

References

BENDSCHNEIDER, K. and ROBINSON, R. J. 1952. A new spectrophotometric method for the determination of nitrite in sea water. J. Mar. Res., **11**: 87-96.

FENCHEL, T. 1969. The ecology of marine microbenthos IV. Structure and function of the benthic ecosystem, its chemical and physical factors and the microfauna communities with special reference to the ciliated protozoa. Ophelia, **6**: 1-182.

FLEMING. R.H. 1940. The composition of plankton and units for reporting populations and production. Sixth Pacific Congr., Calif., 1939, Proc. **3**: 535-540.

HAMADA, S. and HAMADA, R. 1963. A study of sea-mud in the East China and the Yellow seas, 2. On the granule size and the distribution of total nitrogen and ignition loss of the mud of the trawling ground. Bull. Seikai Reg. Fish. Res. Lab., No. **154**: 51-55. (in Japanese with English synopsis)

HARRISON, P. G. and MANN, K. H. 1975. Detritus formation from eelgrass (*Zostera marina* L.) : The relative effects of fragmentation, leaching, and decay. Limnol. Oceanogr., **20**: 924-934.

IIZUMI, H. 1975. Inorganic nitrogen metabolism of *Zostera marina* bed. Master thesis, Ocean Res. Inst., Univ. Tokyo. 73pp. (in Japanese)

OOHUSA, T., ARAKI, S., SAKURAI, T. and SAITOH, M. 1978. Diurnal variation of the photosynthetic pigments, total nitrogen and total nitrogen/total carbohydrate ratio of cultivated *Porphyra* thalli and their relationships to the quantity of dried Nori. Jap. J. Phycol., **26**: 185-187. (in Japanese with English abstract)

PENHALE, P. A., SMITH, O. S. Jr. 1977. Excretion of dissolved organic carbon by eelgrass (*Zostera marina*) and its epiphytes. Limnol. Oceanogr., **22**: 400-407.

PERKINS, E. J. 1974. The biology of estuaries and coastal waters. Academic Press, London and Now York. 678pp.

REDFIELD, A. C. 1934. On the proportions of organic derivatives in sea water and their relation to the composition of Plankton. p. 176-192, In James Johnstone Memorial Volume, Liverpool Univ. Press. 348pp.

STRICKLAND, J. D.H. and PARSONS, T. R. 1968. A practical handbook of seawater analysis. Bull. 167, Fish. Res. Bd. Canada, Ottawa, 311pp.

SOLÓRZANO, L. 1969. Determination of ammonia in natural waters by the phenolhypochlorite method. Limnol. Oceanogr., **14**: 799-801.

TEAL, J. M. and WIESER, W. 1966. The distribution and ecology of Nematodes in Georgia salt marsh. Limnol. Oceanogr., **11**: 217-222.

TANIDA, S. and OKUDA, T. 1958. Fundamental investigation on the marine resources of Matsushima Bay, VII. Vertical distribution of benthos and these seasonal succession. Bull. Tohoku Reg. Fish. Res. Lab., **11**: 112-126. (in Japanese with English abstract)

UNO, S. 1974. Phytoplankton production under some experimental conditions of environment. Doctor thesis, Res. Inst. Nor. Pac. Fish., Hokkaido Univ. 147pp. (in Japanese)

UNO, S. 1978. Carbon/nitrogen ratios of organic materials in the sea. Report of GSK Conf. 1972, Fisheries Agency. p. 7-12. (in Japanese)

WOOD, E. D., ARMSTRONG, F. A. and RICHARDS, F. A. 1967. Determination of nitrate in sea water by cadmium-copper reduction to nitrite. J. mar. biol. Ass. U. K., **47**: 23-31.

宇野史郎・酒井保次*・吉川浩二*：山口湾におけるアナアオサの分布と窒素の量

近年，瀬戸内海では富栄養化の進行と共にアナアオサの量は増大しつつあると言われる。1976年7月，及び11月に山口湾におけるアナアオサの分布を調べ，また湾内のアナアオサ，海水 (DIN, DON, 及び PON)，底質（泥粒及び間げき水）の窒素量を推定した。アナアオサは湾両岸の各々中央部に高密度で分布し，現存量最大値は11月の 5.3 kg（湿重量)/m² であった。この湾内のアナアオサ中の窒素の総量は7月に 3.8 ton 11月に 12.1 ton であった。窒素の総量は底質において著しく多かった。アナアオサ中の窒素量は，ここでの水深が浅い為に植物プランクトンを含む懸濁物などよりもはるかに卓越していた。この湾においては，アナアオサは窒素循環の中で最も重要な生物としての役割を果たしているであろうことが推察された。(424 清水市折戸 5-7-1 遠洋水産研究所 * 739-04 広島県佐伯郡大野町 7782 南西海区水産研究所)