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Carbon, Nitrogen & Phosphorus Ratios in Seawater & Seaweeds of Saurashtra, North West Coast of India

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The concentrations of C, N and P in seaweeds vary from 19.72-41.01%, 1.19-3.60% and 0.0857-0.2482% (dry wt) respectively. The atomic ratio of N:P in seawater is 12.6:1. C:N:P ratio for seaweeds is 550:35:1. Lower ratios of C:N are observed in the green seaweeds (10.28 ± 1.29) especially of upper part of the intertidal zone than in brown (16.05 ± 1.07) and red seaweeds (13.42 ± 2.56) growing at lower part of the intertidal zone. Slightly higher N:P atomic ratios are observed in green (38.50 ± 5.20) and brown (35.84 ± 6.87) seaweeds than in red seaweeds (32.19 ± 9.82). Thus the nutrient turn over in benthic systems has C:P and N:P relationships different from Redfield ratio.

Chemical oceanographic studies with special reference to the nutrients and their interrelationships in the north eastern Arabian Sea off the Saurashtra coast have been made by Sen Gupta *et al.*[1]. But there is little information on nutrient relationships in the shoreline waters of this coast. Seaweeds from the Saurashtra coast are over exploited for their protein content[2] but quantitative information on their C and P contents is scanty[3]. In the present study an attempt has been made to estimate the C,N and P concentration in seawater and seaweeds so as to suggest an empirical formula for the organic matter of seaweed biomass.

Materials and Methods

Seawater and seaweed samples were collected from the shores of Diu (lat.20°43'N; long. 71°02'E), Porbandar (lat. 21°38'N; long. 69°37'E) and Okha (lat. 22°28'N; long. 69°05'E) situated along the Saurashtra coast. There is no freshwater inflow at these places and the tide pattern is semidiurnal. The shores at Okha, Porbandar and Diu sites are rocky with a projecting ledge of limestone reef starting from the upper to lower intertidal level. In the latter 2 sites at the lower intertidal level noncalcareous rocks are also common. The reef's have a number of tide pools harbouring a good deal of algal population in intertidal region. The reef's seaward gradient is more gradual at Okha site than at Porbandar and Diu sites. Okha reef is situated on the Gulf mouth of Kutch and is completely open. Diu is also a completely open reef. Porbandar reef is partially protected by the artificial construction and is completely separated from the harbour, seawage and other effluents.

ΣCO_2-C was calculated in seawater using total alkalinity. *p*H and *in situ* temperature measurements were as per the method given by Strickland and Parsons[4]. Filtered (GF/C) samples were used for NO_3-N, NO_2-N, NH_4-N and PO_4-P estimations photometrically[5].

Seaweed samples were collected from different parts of the intertidal regions during the lowest low neap tide periods. Most of them were collected from a coral reef (dead) and a few red seaweed species were collected from noncalcareous rocky areas. After handpicking, seaweeds were cleaned with seawater, followed by tap water and finally distilled water. They were air dried and then exposed to 80°C for 4 h. Homogenised material (60 mesh) was used for analysis[6] of C, N and P.

Results and Discussion

The present range (2250-2300 μg- at. l^{-1}) of ΣCO_2 in seawater (Table 1) is more than the reported values for open ocean surface waters[7] (1950-2200 μg- at. l^{-1}). The value of total combined inorganic N (NO_2, NO_3 and NH_4) is also higher than that reported for tropical open ocean surface water[8]. The ratio between NO_3 and PO_4 in the upper 125 m of the Arabian Sea and Bay of Bengal[9] is 6:1. In the present study N:P ratio is 12.6:1. Nutrient content of inshore water usually differs from that of open ocean water due to the terrigenous runoff and interaction with sediments[8].

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Phytoplankton with a near Redfield ratio (N/P=10 to 20) possesses maximum productivity[10]. Thus in phytoplankton, higher N:P ratios indicate P limitation. Similarly higher C:N ratios indicate N limitation. In seaweeds also higher C:N ratios (>22) are observed in N limited cultures[11,12]. The present range of C:N ratios (8.2-18.8) in seaweeds is in agreement with the earlier reports[3,13,14]. Lower values are reported in the seaweeds of Minicoy Atoll[15] (0.98-7.33) in which the C:N ratios are well below the Redfield ratio. Niell[16] observed higher C:N ratio in species growing below the intertidal zone than in those growing at lower less exposed levels. The present study shows that the C:N ratios in green seaweeds growing at upper part of the intertidal zone (*Enteromorpha intestinalis*, *Enteromorpha* sp., *Ulva fasciata* and *Chaetomorpha antennina*) and at mid intertidal zone (*Cladophora fascicularis*), are lower (10.28 ± 1.29) than those of brown seaweeds (16.05 ± 1.07) and many of the red seaweeds (13.42 ± 2.56) of lower intertidal zone (Table 2). Green seaweeds are richer in proteins than brown[2] and many of the red seaweeds. Consequently C:N ratios would be less

Table 1 — Total Carbon (ΣCO_2), Reactive Phosphorus and Nitrogen Species Contents of Seawater

[Mean of 3 analyses expressed as μg- at. l^{-1}]

	ΣCO_2-C	PO_4-P	NO_3-N	NO_2-N	NH_4-N	Total N ($NO_3+NO_2+NH_4$)
Diu	2250	1.00	7.53	0.39	4.25	12.17
Porbandar	2300	1.32	8.89	0.35	5.89	15.13
Okha	2250	0.98	9.01	0.47	4.73	14.21

Table 2 — Carbon, Nitrogen and Phosphorus Contents of Seaweeds and Their Ratios

[Serial nos. 1-4, 5 and 6-24 species have been collected respectively from upper, middle and lower parts of the intertidal zone. Site codes: D,P,O respectively for Diu, Porbandar and Okha]

Sl.No.		Place of collection	C (% dry wt)	N (% dry wt)	P (μg. 100 mg^{-1} dry wt)	C:N (% basis)	C:N:P (atomic ratio basis)
Green seaweeds							
1.	*Enteromorpha intestinalis*	D	27.84	3.36	211.64	8.3	340:35:1
	(Linn.) Link	P	28.48	3.48	197.38	8.2	373:39:1
		O	26.08	2.91	186.58	8.9	361:36:1
2.	*Enteromorpha* sp.	D	25.74	2.81	181.25	9.2	367:34:1
		P	27.85	2.94	200.52	9.5	359:32:1
3.	*Ulva fasciata* Delile	D	29.17	2.75	171.96	10.6	438:36:1
		P	28.30	2.74	166.82	10.3	438:36:1
		O	27.75	2.62	157.20	10.6	456:37:1
4.	*Chaetomorpha antennina*	D	27.34	2.51	159.56	10.6	443:35:1
	(Bory) Kuetz	P	28.90	2.64	175.51	10.9	425:33:1
		O	26.10	2.35	150.37	11.1	448:35:1
5.	*Cladophora fascicularis*	D	26.82	2.29	134.39	11.7	515:38:1
	(Mertens) Kuetz	P	28.70	2.50	143.60	11.5	518:38:1
		O	25.43	2.04	128.75	12.5	510:35:1
6.	*Bryopsis plumosa* (Huds.)	D	37.49	2.50	111.98	15.0	865:49:1
	Ag.	P	38.01	2.67	115.83	14.2	848:51:1
		O	38.50	2.57	126.04	15.0	789:45:1
7.	*Caulerpa racemosa*	D	40.50	2.29	140.55	17.7	744:36:1
	(Forssk.) Weber V. Bosse	P	41.01	2.24	132.18	18.3	801:37:1
		O	38.84	2.06	113.69	18.8	882:40:1
8.	*Valoniopsis pachynema*	D	30.24	2.09	101.93	14.4	766:45:1
	(Mertens) Boergs	P	28.58	1.87	95.82	15.3	770:45:1
	Mean of green seaweeds		30.80 ± 5.35	2.55 ± 0.40	150.16 ± 33.35	12.39 ± 3.22	38.50 ± 5.20 (N/P atomic ratio)
			27.46 ± 1.24 (upper and mid intertidal)			10.25 ± 1.29 (upper and mid intertidal)	
			36.65 ± 4.64 (lower intertidal)			16.09 ± 1.86 (lower intertidal)	

Contd

Table 2—Carbon, Nitrogen and Phosphorus Contents of Seaweeds and Their Ratios—*Contd*

Sl No.		Place of collection	C (% dry wt)	N (% dry wt)	P (μg. 100 mg^{-1} dry wt)	C:N (% basis)	C:N:P (atomic ratio basis)
Brown seaweeds							
9.	*Dictyota dichotoma* (Huds) Lamour	D	35.75	2.13	145.07	16.8	637:32:1
		P	36.61	2.19	140.59	16.7	673:34:1
		O	35.63	2.05	128.78	17.4	714:35:1
10.	*Padina tetrastromatica* Hauck	D	28.68	1.87	138.59	15.3	535:30:1
		P	29.36	1.79	145.81	16.4	520:27:1
		O	27.02	1.73	112.08	15.6	622:34:1
11.	*Padina* sp.	P	29.71	1.82	112.61	16.3	682:36:1
12.	*Spatoglossum asperum* J. Ag.	D	37.36	2.49	161.18	15.0	599:34:1
		P	36.91	2.29	147.72	16.1	645:34:1
		O	35.78	2.15	136.87	16.6	675:35:1
13.	*Cystoseira indica* (Thivy *et* Doshi) Mairh	D	32.00	2.03	135.39	15.7	610:33:1
		P	31.20	1.86	123.47	16.8	652:33:1
		O	32.37	1.91	140.16	16.8	597:30:1
14.	*Sargassum johnstonii* Setchell and Gardner	O	32.17	1.79	108.05	18.0	769:37:1
15.	*S. swartzii* (Turn) C. Ag.	P	29.73	1.80	118.39	16.5	648:33:1
		O	32.71	2.04	127.83	16.0	661:35:1
16.	*S. tenerrimum* J. Ag.	D	30.01	1.99	102.03	15.1	760:43:1
		P	30.30	2.20	94.65	13.8	823:51:1
		O	29.70	2.12	85.78	14.0	894:55:1
	Mean of brown seaweeds		32.26 ± 3.17	2.01 ± 0.20	126.58 ± 19.20	16.05 ± 1.07	35.84 ± 6.87 (N/P atomic ratio)
Red seaweeds							
17.	*Gelidiella acerosa* (Forsk.) Feldman *et* Hamel	D	30.50	2.38	195.40	12.8	403:27:1
		P	29.81	2.31	186.36	12.9	413:27:1
		O	31.30	2.62	248.17	12.0	326:23:1
18.	*Amphiroa anceps* (Lamk.) Decsne	D	21.45	1.24	149.01	17.3	372:18:1
		P	19.72	1.19	114.96	16.5	443:23:1
		O	20.83	1.25	125.40	16.6	429:22:1
19.	*Sarconema filiforma* (Sond.) Kylin	P	30.93	2.48	109.81	12.5	728:50:1
		O	29.63	2.17	101.85	13.6	751:47:1
20.	**Hypnea musciformis* (Wulf.) Lamour.	D	35.13	2.75	185.93	12.8	488:33:1
		P	33.60	2.60	177.06	12.9	490:33:1
		O	33.38	2.48	162.10	13.4	532:34:1
21.	**Gracilaria corticata* (Agadh.) J. Ag.	D	32.00	3.38	177.90	9.5	465:42:1
		P	31.10	3.60	169.80	8.6	473:47:1
		O	29.00	3.06	132.27	9.5	566:51:1
22.	*Acanthophora spicifera* (Vehl.)Boergs	D	30.00	1.72	174.62	17.4	444:22:1
		P	28.51	1.68	156.44	16.9	470:24:1
23.	*Chondria armata* (Kuetz.) Okamura var. *plumaris* Boergs	D	31.23	2.08	154.52	15.0	522:30:1
		O	33.50	2.20	170.38	15.2	507:29:1
24.	*Laurencia* sp.	D	29.93	2.40	170.35	12.4	454:31:1
		P	28.05	2.29	157.46	12.2	460:32:1
		O	31.00	2.59	181.81	11.9	440:31:1
	Mean of red seaweeds		29.55 ± 4.11	2.31 ± 0.64	161.97 ± 33.16	13.42 ± 2.56	32.19 ± 9.82 (N/P atomic ratio)

*Species collected from noncalcareous rock areas.

in green seaweeds.

Slightly higher atomic ratios of N:P (Table 2) are observed in green seaweeds (38.50 ± 5.20) and brown seaweeds (35.84 ± 6.87) than in red seaweeds (32.19 ± 9.82). Because P content is more variable than C and N, the N:P ratio varies widely. The present data on N:P atomic ratios (18-55) are well within the range reported by Wallentinus[17] (8-66) and Atkinson and Smith[14] (9-74), except for *Spaerococcus* spp.

Nutritional status of the medium would influence the C:P and N:P ratios of the seaweeds[14,17]. The 3 study sites do not differ markedly in their nutrient status of the seawater (Table 1). The observed difference in C:P, N:P values of seaweeds may be attributed mainly to their intertidal position and differences in their interspecific metabolic levels and also to the different phenological stages of the sampling materials[3,16,17].

Sen Gupta *et al.*[1] have reported that planktonic organisms of the Arabian Sea have a C:N:P composition approximating to the Redfield ratio[18] (C:N:P = 106:16:1). In this study it is observed that the mean atomic C:N:P ratio in seaweeds is 550:35:1, which is markedly higher than Redfield ratio for phytoplankton.

The atomic ratio 106:16:1 for C,N and P in oceanic plankton[18] is similar to that of deeper seawater layers. Redfield *et al.*[18] have concluded that any change in the concentration of C,N,P in water would be reflected concomittantly in the ratios of C,N,P concentration in plankton. In free floating and short lived planktonic organisms the surface to volume ratio is high and the uptake and release of nutrients probably tend towards the Redfield ratio. Seaweeds are attached forms and long lived, possessing lower surface to volume ratio and are subjected to repeated wave action and desiccation. In order to withstand this environmental stress, they might have been adopted with elaborate structural C and N content leading to higher C:N:P ratio and hence the possibility of markedly positive deviation from the Redfield ratio.

C:N and C:P ratios of the seaweeds in the present study are respectively 2.4 and 5.2 times (Table 2) greater than those of Redfield ratios of these waters[1]. Thus the N:P ratio of seaweeds is 2.2 times higher than the N:P ratio of phytoplankton[18]. Further, the results show that as per the mean seaweed to seawater concentration, P is less than N (Table 3). This may indicate that these seaweeds are limited for P availability, although it has been reported that N availability limits seaweed growth in temperate seaweeds during a part of the growing season[19].

The investigations of Wallentinus[20] on Baltic macroalgae in the nutrient medium with ecologically relevant concentrations of N and P, manifest that their N uptake rates are always higher than those of P at more or less the same concentrations. The ratios of maximum uptake rates (V max.) to half saturation constants (km) are also, in general, higher for N than those of P, which in turn also reveals that seaweeds are limited for P availability.

While establishing an empirical formula for phytoplankton composition stoichiometric constants have been derived from Δ AOU to ΔP and ΔAOU to ΔN ratios[1,21]. In the present study the organic matter of seaweed biomass could be tentatively figured out as $(CH_2O)_{550}$ $(NH_3)_{35}$ H_3PO_4, using the mean C:N:P atomic ratios as stoichiometric constants.

The mass balance of oxidative decomposition of phytoplanktonic organic matter, in the Arabian Sea water expressed by Sen Gupta *et al.*[1] is

$$105\,CO_2 + 15\,HNO_3 + H_3PO_4 + 120\,H_2O$$
$$= (CH_2O)_{105}\,(NH_3)_{15}H_3PO_4 + 135\,O_2$$

The equation would need slight modification, if a somewhat different phytoplankton C:N:P ratios are used, or if ammonia rather than nitrate is the primary source of nitrogen[14], and Redfield ratio doesn't hold good in reef water, where the proximity of land and turbulence lead to saturation

Table 3— Range and Mean Contents of C, N, P in Seawater and Seaweeds

	C	N	P	C:N:P
		Seawater (μg- at. l^{-1})		
Range	2250-2300	12.17-15.73	0.98-1.32	—
Mean	2270	13.84	1.10	—
		Seaweeds ($\times 10^5$ μg- at. kg^{-1} dry wt)		
Range	160.0-341.75	8.50-25.71	0.2764-0.8006	—
Mean	257.0 ± 36.8	16.47 ± 3.57	0.47 ± 0.10	550:35:1
		Seaweed tissue to seawater conc.		
Mean	11.45×10^3	1.18×10^5	0.43×10^5	—

with atmospheric CO_2 and O_2. The mass balance equation for the metabolism of organic matter of seaweed biomass from Saurashtra coast can be presented as

$$550\,CO_2 + 585\,H_2O + 35\,HNO_3 + H_3PO_4 = (CH_2O)_{550}\,(NH_3)_{35}\,H_3PO_4 + 620\,O_2$$

Despite the minor differences, the present empirical formula for the organic matter of seaweed biomass is comparable with that of Atkinson and Smith[14] who have first applied this concept to the benthic marine plants. Owing to their specialised composition emerging from their intertidal habitat and diversification of their carbohydrates, generalisation of the above equation for the seaweeds may not be feasible. As cited by Atkinson and Smith[14] the estimates of the net production, based on depletion of P, matched the net community production, as independently measured by CO_2 and O_2 fluxes of the medium. But their[14] values for production in benthic algal communities, based on the nutrient turnover in the medium for its C:P of the Redfield ratio for conversion of P to C equivalents, underestimate by about 80%. The present study also indicates that the nutrient turnover in benthic systems has C:P and N:P relationships different from Redfield ratio.

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