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SEASONAL VARIATION IN CHEMICAL CONSTITUENTS OF CERTAIN BROWN SEAWEEDS AND SEAWATER FROM SAURASHTRA COAST: I. CARBON, NITROGEN AND PHOSPHORUS

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ABSTRACT

The annual mean concentration of C, N and P in seawaters of Porbandar and Okha coasts varied from 2100-2500, 6.15-13.75 and 0.10-1.62 μg-atℓ^{-1} respectively. Depletion of P takes place during maximum biomass period, while no such marked depletion of N was noticed. The N:P values of whole seaweed probably indicate integrated concentrations of the ambient medium during the previous months. High C:N ratios were observed in senescent and slow growth stages followed by reproductive phase and early and rapid growth phases. Hence, C:N ratio variation in a seaweed population is attributable to their different phenological stages. The N:P atomic ratio trend is opposite to C:N trend in *Cystoseira indica* and *Sargassum johnstonii* with two reproductive stages in their life cycles (one year); whereas in *Sargassum tenerrimum* with single reproductive stage in its one year life cycle does not show this trend. The critical internal values for N and P for the aforementioned seaweeds in the field conditions were 1.84-2.05% and 0.10-0.16% dry wt. respectively.

Key-words: Seasonal variation, seawater, seaweeds, carbon, nitrogen, phosphorus, Saurashtra coast.

INTRODUCTION

The concentration of macronutrients (C, N, P etc.) and micronutrients (Mn, Zn, Cu, Co, etc.) in seawater is non-conservative. Various nutrients absorbed by the seaweeds are replenished incessantly into the ambient medium through trophic levels of various orders and/or directly by their death and decay. Consequently there is no dearth of these constituents for the perpetuation of plant life in the marine environment. Therefore, a comprehensive evaluation of nutrient levels in seawater and seaweeds is indispensable in the chemical oceanographic studies. In our earlier study (Rao and Indusekhar, 1987) the deviation of Redfield ratio of seaweed groups from phytoplanktonic composition was discussed. In the present investigation an attempt has been made to study the above deviated C:N and N:P ratios in different phenological stages in 3 brown seaweeds *viz*., *Cystoseira indica* (Thivy *et* Doshi) Mairh, *Sargassum johnstonii* Setchell and Gardner and *Sargassum tenerrimum* J. Ag. collected from Porbandar and Okha reefs of Saurashtra coast during October 1982 to September 1983.

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MATERIAL AND METHODS

The location, topographical features of the sampling sites, the method of collection and the analysis of seawater is dealt in Rao and Indusekhar (1987).

Seaweed samples were collected from middle part of the intertidal region (middle mid-littoral) at Porbandar and from lower part of the intertidal zone (lower mid-littoral) at Okha in a marked region of 3×21 meters transact which is selected at 0.8 m level (tentatively) with reference to zero datum line. During October 1982 the selected individual seaweed species of more or less the same height has been identified and tagged. Ten to twenty plants more or less of the same age were taken randomly for growth and dry weight measurements.

Precision of the analysis determined from nine samples (each in duplicate) collected from Okha during October/November 1982, as percentage of coefficient of variations was 7, 5, 4, 5 respectively for PO_4, NO_2, NO_3 and NH_4 in seawater and 3, 1 and 1 respectively for C, N and P in *S. tenerrimum*.

RESULTS AND DISCUSSION

Seawater

No seasonal variation was observed in total dissolved inorganic carbon (ΣCO_2-C), total inorganic N(NO_3+NO_2+NH_4) and dissolved inorganic phosphorus (PO_4-P) contents of seawater at both the places. Their concentrations remained more or less same at both the places (Fig.1 a-f).

Total dissolved inorganic carbon: High biomass production (Fig.2 a-c) during November-January (coincides with low winter temperature) was due to exceedingly high photosynthetic rates over respiration. This should result in high pH and low ΣCO_2-C. But the observed ΣCO_2-C values during this period were high (Fig.1 a). Low seaweed production was observed during July-September (coincides with moderately higher temperature than winter temperature), probably due to fall in photosynthetic rate. Oxidation of the dead vegetative matter also takes place. As a result the ΣCO_2-C content of the ambient medium should increase. But the observed ΣCO_2-C during this period was lower (Fig.1 a). It is rather difficult to explain the reason and trend of observed ΣCO_2-C concentration in ambient medium in terms of biological activity alone because ΣCO_2-C is also sensitive to temperature, local variations of reef and water movements etc.

Dissolved inorganic nitrogen species: Several workers (Sreedharan and Mohammed Salih, 1974; Raghavendra and Reddy, 1981) observed high concentration of NO_3, NO_2, NH_4 during monsoon months and minimum during the period when the biological activity was more. The high content of nitrogen species is due to land drainage. The high total inorganic N content during September in the absence of land drainage may be due to water with high nitrogen species content, via current and tides. During

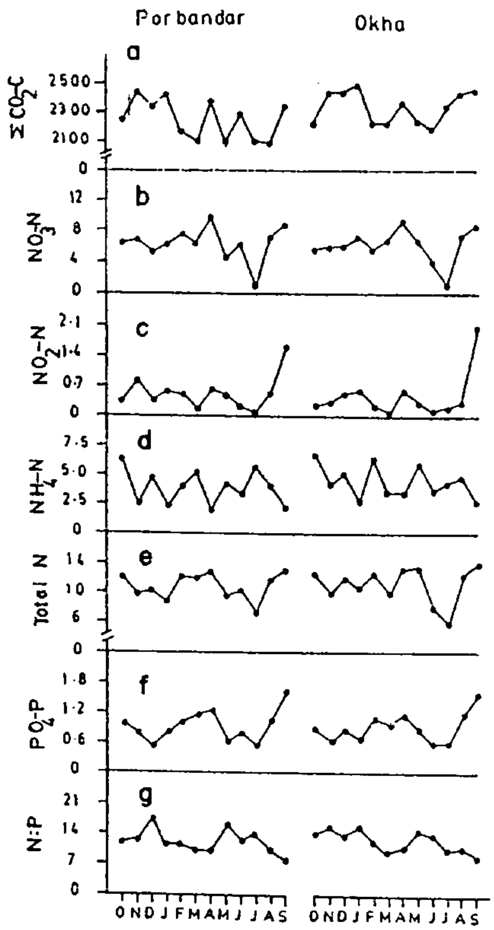

Fig.1 a-g. Monthly variations of nutrients concentration (µg-at.l^{-1}) in seawater (average of 3 values)

the period of maximum biological activity, nitrogen species yield intermediate values (Fig.1 b-c). It seems that high proportions of phytoplankton (phytoplankton blooms have been observed by Gopalakrishnan (1972) in these waters during September) is consumed by zooplankton and fish and the particulate organic N is released to the water in the form of soluble inorganic N through their excreta.

Dissolved inorganic phosphorus: The high P content recorded during monsoon with maximum in September is probably due to the nutrient rich water. During the high biological active movement period lower values of P were observed in the ambient medium (Fig.1 f). Similar trend was also reported in temperate (Armstrong and Butler, 1960) and tropical waters (Menzel and Ryther, 1960).

Johannes and Betzer (1975) reported P as 150 times higher in bottom sediments than in over lying waters. Laboratory experiments of Reddy and Sankaranarayanan (1972) revealed that the sediments from the relatively high saline areas in the estuary released P continuously to the over lying waters, whereas the sediments from the less saline reaches showed a reverse trend by adsorbing P. Therefore, it seems in the present case where turbidity is predominant due to tidal fluctuations and the absence of fresh water inflow, that P is regenerated into the ambient medium from the sediments. However, the low P values in the ambient medium indicate that the biological requirement of P may slightly be higher than what is released from sediments.

N:P ratios: Although NO_3 and PO_4 are removed from seawater in constant proportions of 15:1 (Redfield, Ketchum and Richards, 1963), variations occur in some waters. The N:P ratios of 5:1 and 8:1 are common in inshore waters (Stefansson and Richards, 1963; Pratt, 1965) and in surface waters, there may be acute fall in this ratio due to depletion in N, probably caused by phytoplankton growth. However, in reef waters where algal beds are dominant, marked variation in N:P may be expected. In the present study (Fig.1 g) during high algal biomass period, higher ratios of N:P and in low biomass period lower N:P ratios were noticed. It seems that during the active biomass period greater part of P is being removed by seaweeds. Armstrong and Butler (1960) have also observed low (10.51) ratios of N:P during winter (low biological activity) and high (19:1) ratios during summer.

Table I — Phenological stages of seaweeds

Early and active growth period	Reproductive period	Slow and senescent period
	C. indica (Porbandar)	
November-December and April-May	December-January and May-June	February-March and July-September
	C. indica (Okha)	
October-December and April-May	December-January and May-June	February-March and July-September
	S. tenerrimum (Porbandar and Okha)	
October-December	December-February	March-August
	*S. Johnstonii** (Okha)	
October-December and April-May	December-January and May-June	February-March and July-August

* *S. johnstonii* Setchell and Gardner was reported by Thivy and Chauhan (1964) from Okha coast and observed full fruiting condition during February. Only one fruiting stage was observed by them and seasonal succession was not studied. In the present study it is significant to note the second reproductive stage during May-June.

Seaweeds

Carbon, nitrogen and phosphorus contents: The phenological stages and duration of seaweeds are shown in Table I. During early growth, C is found to be less while N and P were more. In slow growth period (shedding of branches) C was observed in moderate quantities while N and P concentrations were lower than the early period of growth. In senescent period (characterised by stumpy shoots and rhizomatous branches), higher C contents were observed while N and P contents were low (Fig.2 d-g).

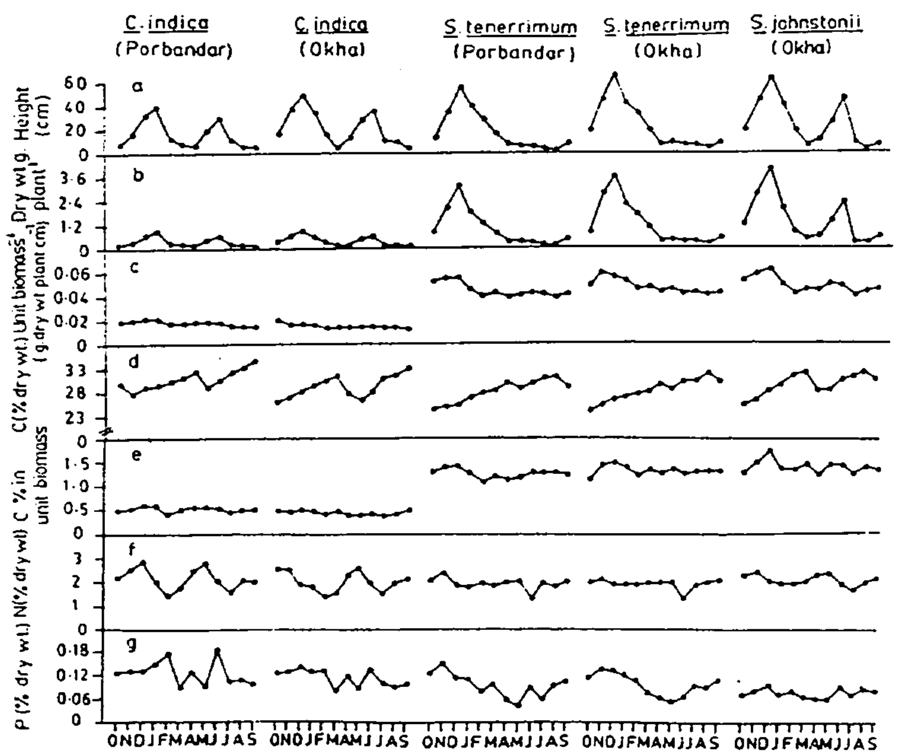

Fig.2 a-g. Carbon, nitrogen and phosphorus contents and growth in seaweeds (average of 3 values)

Carbon was more in unit biomass during high production period (Fig.2 e). However, maximum production period is not characterised by maximum percentage of C (Fig.2 d). This may be due to the fact that the younger tissues (possessing less structural C in their cell walls) are predominant over the older tissues (possessing more structural C in their cell walls).

Tissue analysis can be used as a standard measure of determining the nutritional status of algae (Gerloff and Skoog, 1954; Hanisak, 1979; Gordon, Birch and McComb, 1981). Accordingly regardless of the composition of the external medium and factors affecting the uptake of N or P, a fairly definite concentrations (critical levels) of N or P must be maintained in the tissues to permit optimum growth. The tissue content of N or P may continue to increase far above this critical level when it is in abundant supply, but the excess has little effect on growth. Thus the critical, internal value for N is taken as the value of seaweed tissue concentration of N at the optimal growth of seaweed. Hanisak (1983) recorded this value to be about 2%, on dry wt. basis and was established in laboratory under controlled supply of nutrients and light regimes. But, in field conditions seaweed growth rate may be controlled by the possible limiting nutrient elements, and by environmental factors. In such conditions the laboratory results may not hold good for the *in situ* seaweed population. Therefore, in the present study concentration of N in seaweeds at their maximum productivity was considered as critical value of N. For Porbandar seaweeds the critical values for N (% dry wt.) are 2.05 (*C. indica*), 1.87 (*S. tenerrimum*) and for Okha plants these are 1.89 (*C. indica*), 1.87 (*S. tenerrimum*) and 2.01 (*S. johnstonii*). These values are in agreement with those reported (1.8-2.0%) by DeBoer (1981).

During early and rapid growth phase, new tissues are generated and N content is also found to be more in biomass increment period. During slow growth and senescence period in most of the cases N content is less than the critical value indicating that storage of N is very limited. Moreover these phases possess less pigmented parts and hence contain less N (Bird, Habig and DeBusk, 1982). However, in temperate seaweeds, substantial to moderate storage of N is reported (Hanisak, 1983) and these reserves are used up for growth during periods of low external supplies. The difference in N storage may be due to the adaptation of algae for different environments and also their high tissue differentiation.

Similar to N critical levels, P critical values are taken. The observed P critical values (% dry wt.) for Porbandar seaweeds are 0.16 (*C. indica*) and 0.12 (*S. tenerrimum*) and for Okha seaweeds these are 0.15 (*C. indica*), 0.13 (*S. tenerrimum*) and 0.10 (*S. johnstonii*). The present range of P critical values for brown seaweeds is 0.10-0.16% which falls within the reported range (0.06-0.33%) for a green alga, *Cladophora* sp. by Gordon, Birch and McComb (1981) and Gerloff and Fitzgerald (1975). Though the critical values are not reported, the seaweeds, *Acetaubularia* sp., *Enteromorpha* sp., *Ceramium* sp. and *Ulothrix* sp. accumulate large amounts of polyphosphates and it is believed that these reserves are utilised in growth when there is depletion of external supply of P (DeBoer, 1981). However, in the present study no P surplus (relative to critical value) was observed and hence there may not be P reserves in these seaweeds except in *C. indica* (Porbandar) where higher P content was observed in the second stage of its maximum biomass period.

Tissue concentrations of P in culture of *Cladophora* sp. show linear relation to the substrate concentration, even at more than the ecologically relevant concentration (Gordon, Birch and McComb, 1981). Similar observations are made in field conditions in *Cladophora glomerata*, *Ceramium tenuicorne* and apical parts of *Fucus vesiculosus* in Baltic waters (Wallentinus, 1981). In the present study high P content in seaweeds was observed when its concentration in ambient medium was moderate. Probably in the above studies, the sampling material is small annuals or apical parts of perennial plant with high surface to volume ratio. Seaweeds of our study are larger plants and younger to older part ratio varied considerably; hence their tissue concentration of N and P may not sharply be indicated by the ambient medium concentration. Therefore, larger plant tissue analysis may probably indicate prehistory of the integrated concentration of the ambient medium, whereas phytoplankton and small seaweeds or small apical part of the large seaweeds indicate the current status of the ambient medium.

C:N ratios: C:N ratios exhibit distinct seasonality. High C:N ratios are found in senescent and slow growth periods followed by reproductive and early and rapid growth phases.

The physiological significance of C:N ratios in seaweeds has been accounted by several workers (Neill, 1976; Hanisak, 1979). Higher C:N values indicate nitrogen limitation while lower values indicate nitrogen surplus. The reported range of critical values for C:N ratio for a few species are 10-15 (Hanisak, 1983). The annual mean of C:N ratio (14-19) in the present study are in agreement with those of the earlier reported by Atkinson and Smith (1983), Rao and Indusekhar (1987).

Niell (1976) observed low C:N ratios during rapid increase in biomass and high during the low productivity period for the Spanish coast seaweeds. In the present study also similar trend is observed in Saurashtra seaweeds. Thus C:N ratio can be represented as shown below in the ascending order with respect to their phenological stages. Seaweeds in their early growth *and rapid biomass period < reproductive period < slow growth and senescent* period.

Myers (1951) observed low C:N ratio during carbohydrates depletion and high C:N ratio during low N assimilation in algae. In the present context it can be explained that in early growth or during rapid production period there would not be much reserved food materials (carbohydrates) and most of the assimilated C goes to structural C. N is high during this period and therefore may give low C:N ratio. During senescent period newer tissues are much less and therefore less N content. Moreover older tissues are enriched with structural C. Therefore high C:N would be possible during this period. Thus the shifts in the growth rate of seaweeds bring the changes in C:N ratios.

N:P ratios: The trend of N:P atomic ratio is opposite to the C:N trend in *C. indica* and *S. johnstonii* with two reproductive phases in their life cycles (one year); *S. tenerrimum* with single reproductive stage in its one year life cycle does not show the above trend of N:P (Table II).

N:P ratios vary widely from species to species, and in the same species during different months/phenological stages (Table II). Optimal N:P ratios are often considered to be around 15 (by atoms) for phytoplankton (Goldman, McCarthy and Peavey, 1970). The normal values of N:P atomic ratios for seaweeds are reported to be around at 10-35 (Atkinson and Smith, 1983; Rao and Indusekhar, 1987). However, higher or lower optimal ratios may be species specific (Gordon, Birch and McComb, 1981). The reported

Table II — Variations in C:N (dry wt. basis) and N:P (atomic ratio basis) with phenological stages of seaweed growth

Early and active growth period		Reproductive period		Slow and senescent growth period	
C:N	N:P	C:N	N:P	C:N	N:P
		C. indica (Porbandar)			
11.02±1.34	48±11	12.52±2.67	40±19	18.64±2.08	35±11
		C. indica (Okha)			
16.64±1.97	39±16	14.39±2.89	37±16	19.51±2.78	36± 8
		S. tenerrimum (Porbandar)			
12.32±1.35	34± 2	14.90±1.04	40±10	17.2±2.89	55±22
		S. tenerrimum (Okha)			
12.21±1.40	33± 3	13.99±0.37	34± 3	16.36±3.13	53±14
		S. johnstonii (Okha)			
11.92±1.23	62±12	14.02±1.57	54±14	16.73±1.52	51± 6

* Duration of each period as given in Table I.

range of N:P value is well within the range reported by Atkinson and Smith (1983) but lower than those reported by Wallentinus (1981).

C:N:P ratios: In phytoplankton C:N:P ratios (106:15:1) closely relate to the seawater composition (Redfield, Ketchum and Richards, 1963) but in seaweeds these values deviate. This may be due to the presence of highly organised tissues in their body system. It may also be a physiological adaptation to meet the constraints caused by their amphibiotic intertidal habitat (Niell, 1976; Atkinson and Smith, 1983; Rao and Indusekhar, 1987). Different groups of algae exhibit different C:N ratios. In nature, green, brown and red seaweeds occupy different positions (belts) in intertidal regions. Therefore C:N ratios may differ accordingly (Niell, 1976; Rao and Indusekhar, 1987). Though the intertidal position affects C:N ratios in each group of algae, same species growing in different heights in intertidal position may have little effect in their C:N ratios. But as noted in the present study the metabolic changes caused in the life cycles of seaweeds bring drastic changes in their C:N and N:P ratios. As C:N and N:P ratios vary with phenology of the seaweed, integrated values of the C:N:P of their life period would give better picture of the seaweed biomass.

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